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Logging during diamond drilling – Autonomous logging integrated into the Bottom Hole Assembly

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SUMMARY

Logging total count gamma data while diamond drilling an HQ borehole has been achieved using an autonomous shuttle. The shuttle is integrated into the Bottom Hole Assembly (BHA) prior to drilling. Logging is initiated at the beginning of each core run and the shuttle unit continuously logs at 1 second intervals. Continuous logging combined with the relatively slow rate of penetration of diamond drilling results in high fidelity logs at 1-5 cm intervals. The data is collected by the drilling crew, who download and email the data at the end of each core run for near real time analysis. Little to no interruption to the normal drilling process is experienced once the Shuttle has been integrated into the BHA. Autonomous logging while diamond drilling enables the collection of in-situ rock property measurements, without the risks and costs associated with later wireline logging. This value is added to the drilling process at little expense.

INTRODUCTION

Mineral exploration heavily depends on borehole drilling to map and discover deposits (Bieniawski, 1989; Hyne, 2012). In-depth knowledge of the chemical and physical rock properties is paramount and assays of core and chip samples is standard practice, yet surprisingly, there is a lack of in situ down-hole rock property measurements collected. The reluctance to collect down-hole rock property measurements is driven by cost and risk. Mineralisation is in general associated with complex geometries, fluid movement, fractures, faults and intrusive structures which make borehole environments unstable. Thus for borehole wireline surveys to be conducted safely in mineral exploration settings, it is common practice to have a drill rig standing over the borehole, adding to the wireline survey costs. Logging while drilling (LWD) can eliminate much of the risk and costs of wireline operations and add value to the drilling process. LWD is common practice in the petroleum industry (Collett et al., 2012; Goldberg et al., 2003; McMonnies et al., 2007), however the small inner diameter (<100 mm) of drill strings and much smaller budgets in mineral exploration drilling has restricted such developments of LWD technologies in diamond drilling (Reynolds, 2011; Witherly, 2012).

A Shuttle for logging total count gamma during diamond drilling has been developed by Deep Exploration Technologies CRC, Project 2-2. The Shuttle has been designed to be deployed above the core barrel and below the back-end assembly. Each cycle begins with initiation at the surface with each deployment of the empty core tube. Then once drilling fills the core-barrel the data is downloaded at the end of the core run to the surface and the cycle repeats. The Shuttle was field tested at the DET CRC research facility in Brukunga, South Australia and is shown in Figure 1.

Figure 1. The Shuttle after field testing at DET CRC research facility in Brukunga, South Australia. This tool is inserted between the back-end assembly and inner core-tube. Outer tube sub units of equivalent length are inserted in the drill-string BHA prior to drilling to keep the core latching mechanisms in their proper place.

The Shuttle uses a data acquisition electronics and user input device developed by Globaltech (a DET CRC affiliate and research/engineering partner). This system continuously logs water pressure, acceleration, and total count gamma at 1 second intervals. The water head pressure (P) is used to register the shuttle's depth during the drilling progress, and also used to monitor what type of activity is being done by the drill rig. Other sensors may also be deployed. At the end of the drill run (usually up to 3 m) the shuttle is retrieved along with the rock core and the data is downloaded from the Shuttle to the hand unit via an infra-red data link. This shuttle-core-tube assembly is left intact during data collection as the battery will last for many tens of core run cycles before needing replacement. The data is collected without disruption to the drilling process and the Shuttle is operated easily by the drilling crew.

FIELD TESTS

The Shuttle was tested in Brukunga research drill hole RD05 during the period of 28th March through to 10th of April 2014. These tests were the first tests of the Shuttle and were conducted unsupervised and under normal drilling conditions by the drillers. The entire Shuttle system was shipped in a single instrument case as an "extra" bag by the testing scientists. Training the drillers on site in how to use the shuttle took less than 10 minutes. This is in part due to the logging and interrogation system being nearly identical to many commercial core/borehole orientation tools, which are in wide use today.

Twenty five shuttle/drilling runs were completed over a 60 m drilling interval. Figure 2 shows an example of the raw data. Total count gamma (black) and fluid pressure (red) are plotted in the left hand panel. The first derivative of pressure has been plotted in the right hand panel as this is used to gauge the drilling activity. Through visual analysis of the gamma, pressure and dP/dt plots it is easy to determine the periods of continuous drilling, when the shuttle is tripping in and out of the borehole with the core tube and other drilling related events. These have been annotated within Figure 2.

As the shuttle is located at the top of the BHA the data is collected over the 3 m section of the previous core run. i.e. the shuttle sensors are always approximately 3 m from the drill bit. Due to the low rate of penetration of diamond drilling (approximately 10 to 15 cm / minute), 10 readings can be stacked together to give a high quality reading every 25 mm. This is 4 times greater spatially and 10 times more accurate than typical wire-line readings taken at 10 cm intervals and 4 m / minute logging speed. Thus an advantage of the shuttle is that it enables sensors to be used at logging speeds that could not be economically viable otherwise. In addition, the sensor used in the Shuttle is a NaI crystal only 25mm in diameter x 50mm long (so that it may be used in future even on BQ drill rigs). This size normally too small to produce high quality data at fast wireline logging speeds.

A composite log of the 25 Shuttle core runs is displayed in Figure 3. The shuttle data (blue) is displayed against TC gamma data (black) collected on a wireline. There are two gaps in the shuttle data due to data accidentally being overwritten and there is a discrepancy between the two logs at 77 and 80 m. This 3 m discrepancy is believed to be due to incorrect file/depth documentation. These issues are being addressed within firmware and software revisions. As research drill hole RD05 is not completed, a suite of geophysical wireline logs has not yet been collected. For this reason the AutoSonde™ was deployed on the drill rig wireline. The AutoSonde™ is analogous to the Shuttle and logs gamma and pressure continuously with time however it is normally deployed at the end of drilling and is pulled out of the hole with the drill rods. The rig wireline is not as controllable as a logging winch and the depth estimation is produced from a simple linear interpolation from top to bottom of the hole. Despite these issues there is very good correlation between the two logs. It should also be noted that the AutoSonde™ sensor has a significantly larger crystal detector, which produces gamma counts at 3x the Shuttle sensor rate. However, the longer residence time gives the Shuttle a significant signal-to-noise advantage overall.

Multiple physical parameters are changed during the drilling process to manage bit degradation and rate of penetration, and using solely pressure to determine depth is not reliable by itself to gauge depth of progress. Monitoring of such physical mechanisms as pressure, water flow and acceleration plus mast height can be integrated into the hand-held to resolve the shuttle depth registration issues. Implementation of accelerometers in the shuttle and monitoring of common drilling parameters on the drill head are in progress and partially tested, but at the time of writing some of these extra sensors are not integrated into the Shuttle system.

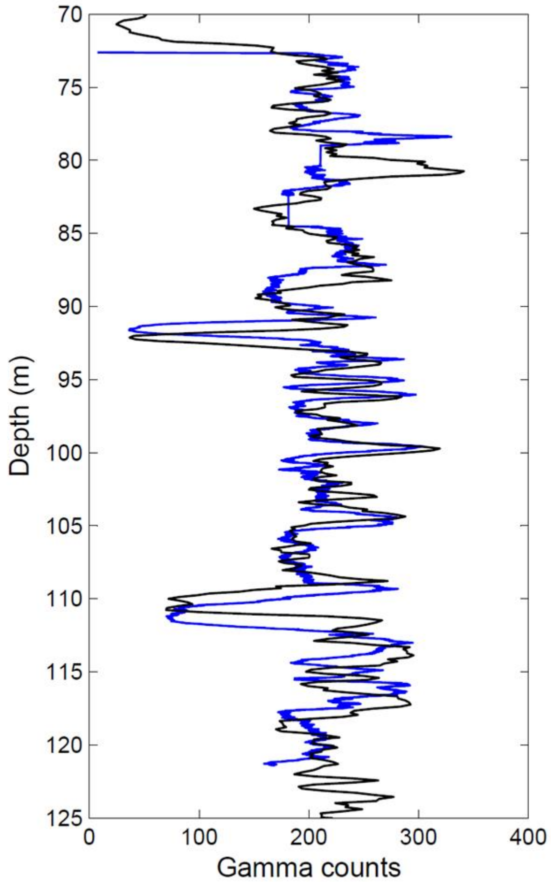

Figure 3. Comparison of the Shuttle (blue) with a gamma log collected on the drill rig wireline and AutoSonde™. Depth registration of the rig log was estimated using a linear time depth relationship i.e. a slip ring or wireline counter was not used.

CONCLUSIONS

An autonomous logging shuttle incorporated into the bottom hole assembly of a diamond drill string has been proven to collect high fidelity TC gamma data during diamond drilling. The Shuttle has survived under normal drilling conditions with no mechanical failures or faults. Continuous recording at 1 second intervals and the slow rate of penetration, results in spatially dense data with resolution to 2.5 cm.

Down-hole pressure analysis can be used to identify the start and stop of the drilling interval to convert the gamma log to depth. Further work is required to automate the depth registration; however the current depth estimations are accurate within 0.5 m. Many of the benefits of LWD are now possible to achieve in small diameter boreholes with the Shuttle.

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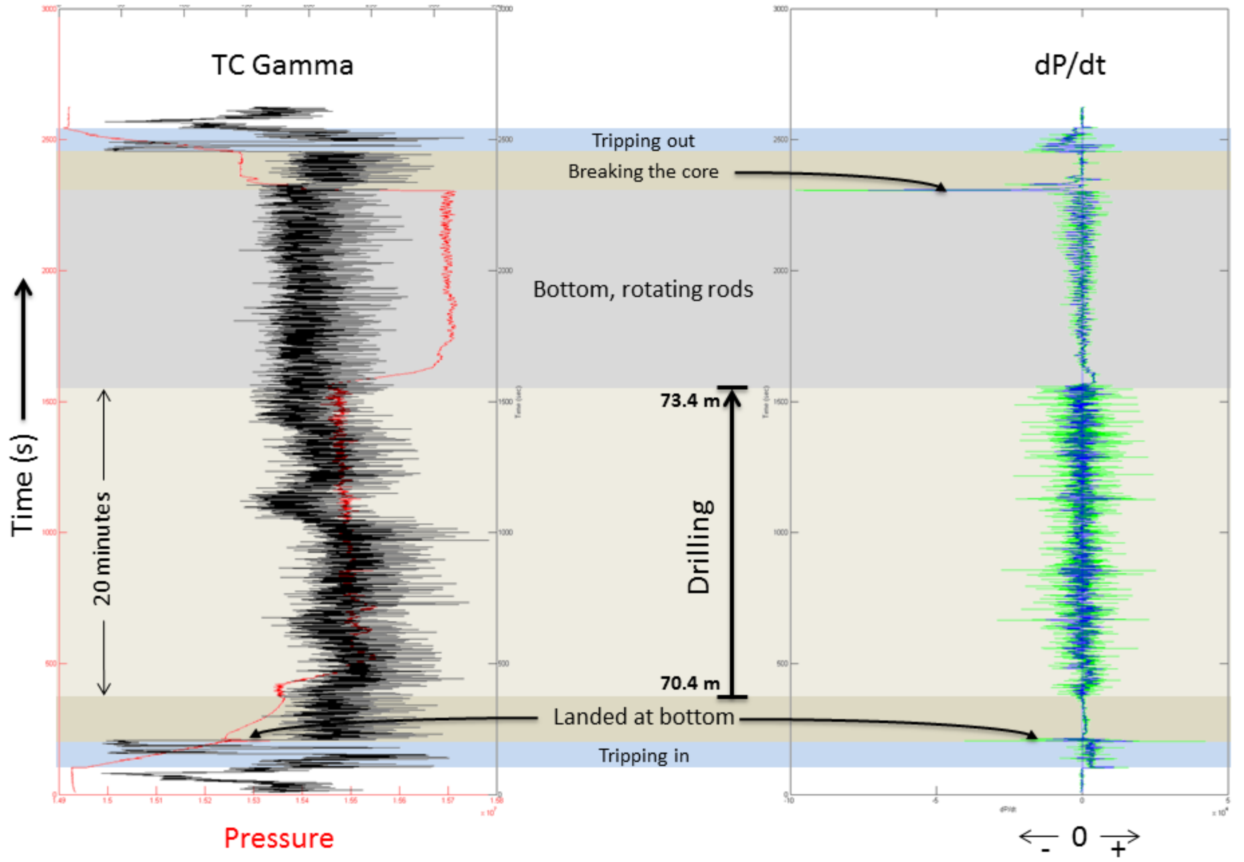

Figure 2. Example of Shuttle data collected during a drilling run. The logging interval, tripping the core tube in and out and other diamond drilling related events can clearly be interpreted from the pressure and dP/dt data.