Amsterdam '14

Tu D201 14

Logging While Drilling Via Autonomous Sonde

A. Kepic* (DET CRC/Curtin University), C.J. Dupuis (DET CRC/Laval University), G. Stewart (DET CRC/Globaltech), B. Wilkinson (DET CRC/Globaltech), A. Greenwood (DET CRC/Curtin University) & A. Podolska (DET CRC/Curtin University)

SUMMARY

We present a method of geophysical logging while tripping drill rods to produce logs similar to wireline logs. The process is autinmous in that it does not require any significant changes by the driller and does not requie any modifications to the drill rig. Using starting depth, rod length, and sensors on the sonde a geophysical log can be created when the drill rods are retreived upon hole completion. Thus, thi smethodology is very suitable for slimhole and diamond drilling methods that do not case teh completed hole. Such holes often collapse and are too expensive to log via wireline logging.

Introduction

Logging while drilling (LWD) is a technique that implements geophysical and petrophysical sensors as part of the bottom-hole assembly (BHA). Such tools have largely replaced wireline technologies in the petroleum industry (Collett et al., 2012; Goldberg et al., 2003). In addition to providing important logistical advantages in terms of minimising rig time, the ability to acquire real-time petrophysical data enables the identification of geological units (McMonnies et al., 2007) and serves as input to geophysical/geological modelling (Smith et al., 2012). In mineral exploration LWD is largely unknown despite the likely benefits to future mineral exploration, especially as new discoveries tend to be deeper and buried under significant weathering or recent sediments (Witherley, 2012). Small diameter holes (less than 80 mm typically) and the incompatibility of the core-retrieval technologies with current wireline sensors have proven to be major stumbling blocks to the development of LWD tools in this industry. An additional problem to any technology development in mineral exploration is that the level of investment and return that can be made is significantly less than in petroleum; thus, the technology must be low cost to develop and implement. The Deep Exploration Technologies Cooperative Research Centre (DET CRC) in Australia is developing LWD tools with these future challenges in mind, but with a pragmatic approach that enables backward compatibility with the existing slim-hole diamond drilling technologies adopted worldwide. These tools require no modifications to existing drill-rigs or the drilling process.

A huge technical challenge is the limited space for sensors in current diamond drilling technology. The drill bit that produces the rock core is at the end of a hollow column of steel tubes called drill rods. These are hollow to enable flushing of the drill cuttings ground by the bit and for the retrieval of the core via a device called a core barrel (Hyne, 2012). Thus, the effective space available for sensors and electronics in the drill-string is an annulus of only 2-4 mm thickness, which limits what can be done without weakening the drill-string. DET CRC research has pursued two pragmatic approaches to this problem (1) put the sensor package on the back of the inner core tube, measure through the drill-string rods, and "shuttle" the sensor package with core retrieval; or (2) to replace the inner core assembly prior to withdrawal of the drill string and log the open hole through the bit. The latter is the "autonomous sonde" method (Illustrated in Figure 1) and is similar to that used by Freudenthal et al., 2013. The shuttle approach requires sensors that can measure through steel or composite drill strings, such as natural gamma, but can deliver information to the surface every 3m when the core is retrieved. The autonomous sonde approach allows a greater variety of measurements to be made as it is exposed to the uncased hole upon drill-string withdrawal; however, information is gathered only during bit changes or at the end of drilling.

In both approaches removing the wire, and consequently the depth registration it affords introduces unique requirements for an integrated depth control mechanism within the LWD tool. The LWD tool presented in this work addresses this particular issue and the miniaturisation of sensors required by the geometry constraints. In particular, we show how a pressure sensor integrated into a sonde and knowledge of the drill-string withdrawal process, allows autonomous LWD in small diameter boreholes with correct depth registration.

Sonde Deployment Methodology

While the autonomous sonde for LWD data acquisition reported here will eventually contain multiple geophysical sensors and control electronics designed to fit within small diameter boreholes the initial sensor package developed by the DET CRC is a Total Count Gamma (TC Gamma) sensor. The sensor assemblies are restricted to less than 40 mm in diameter for operation within NQ drill-rods (47mm core, 75 mm hole), which is the most common size used in mineral exploration. Other sensors being integrated to the autonomous sonde are magnetic susceptibility and induction resistivity sensors plus a pressure sensor and accelerometer system for depth registration.

In the normal mode of operation, the sonde is deployed at the completion of the drilling phase or during a bit change. It is deployed such that it latches into place within the BHA and protrudes through the bit into the open hole (Figure 1). Once the sonde is deployed it is then retrieved with the drill string which is pulled in 3 or 6 m rod increments. This methodology provides safe passage for the sonde whilst allowing access to open-hole conditions. As the inner core tube for core retrieval is normally put in place during rod retrieval (for safety purposes in case the drill-string is accidentally released) placing the sonde assembly with this inner tube does not change significantly standard drilling practice nor waste time. The reported borehole depth and the pull increments are used for depth control and calibration of the pressure sensor. As rods are pulled in 3 to 6 m sections there is a natural pause in the sequence as rods are unscrewed from the string. This means that there is a succession of times where the rod string is moving towards the surface and where it is stationary. The pressure sensor used in the autonomous sonde is able to resolve changes of 5 cm or less in fluid head at depths of up to 3 km. Plateaus in the pressure signal (e.g. Figure 1(B)) are evident and correspond to the period where the drill string is still. These pressure readings are used to interpolate the data between the rod intervals giving us a rate of ascent of the drill string. Thus, with a reported starting depth the data may be reconstructed from two time series: the pressure sensor and the petrophysical measurement vs time (Figure 1). This depth mapping methodology is robust against fluid density changes. Errors from changes in length to the drill-string due to elongation and temperature are minimal because such drill strings are rarely more than 2 km long in mineral exploration and temperature changes within mineral exploration environments are generally small compared to those encountered in petroleum. Mud densities are also unlikely to be altered during the withdrawal of the drill string.

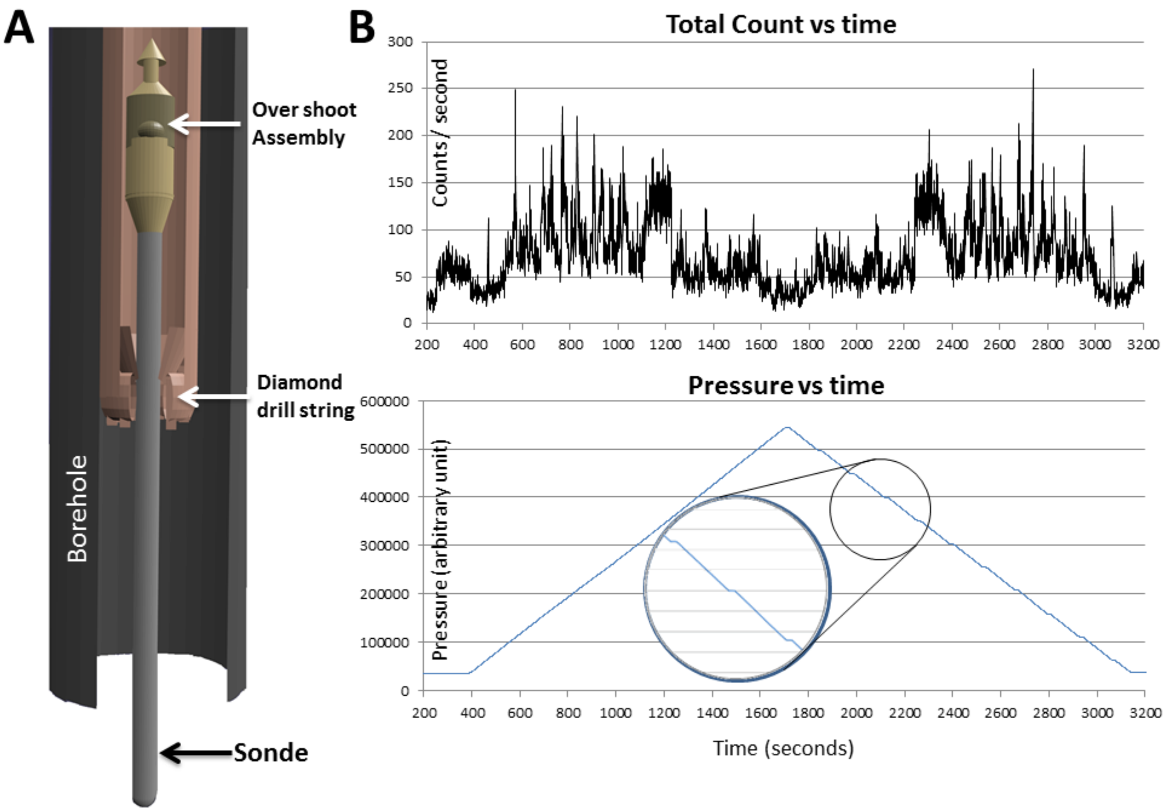

Figure 1: *A) A cut-away illustration of the autonomous sonde deployed in front of the bit. B) An example of TC Gamma and Pressure vs time series showing downward/upward symmetry. The sonde was lowered on a wireline in a cased hole at a constant rate downwards and then pulled upwards at the same rate while stopping briefly every 20m for 10 seconds to demonstrate the ability to see the stop–start nature (magnified insert on pressure vs time plot) of logging during rod removal.*

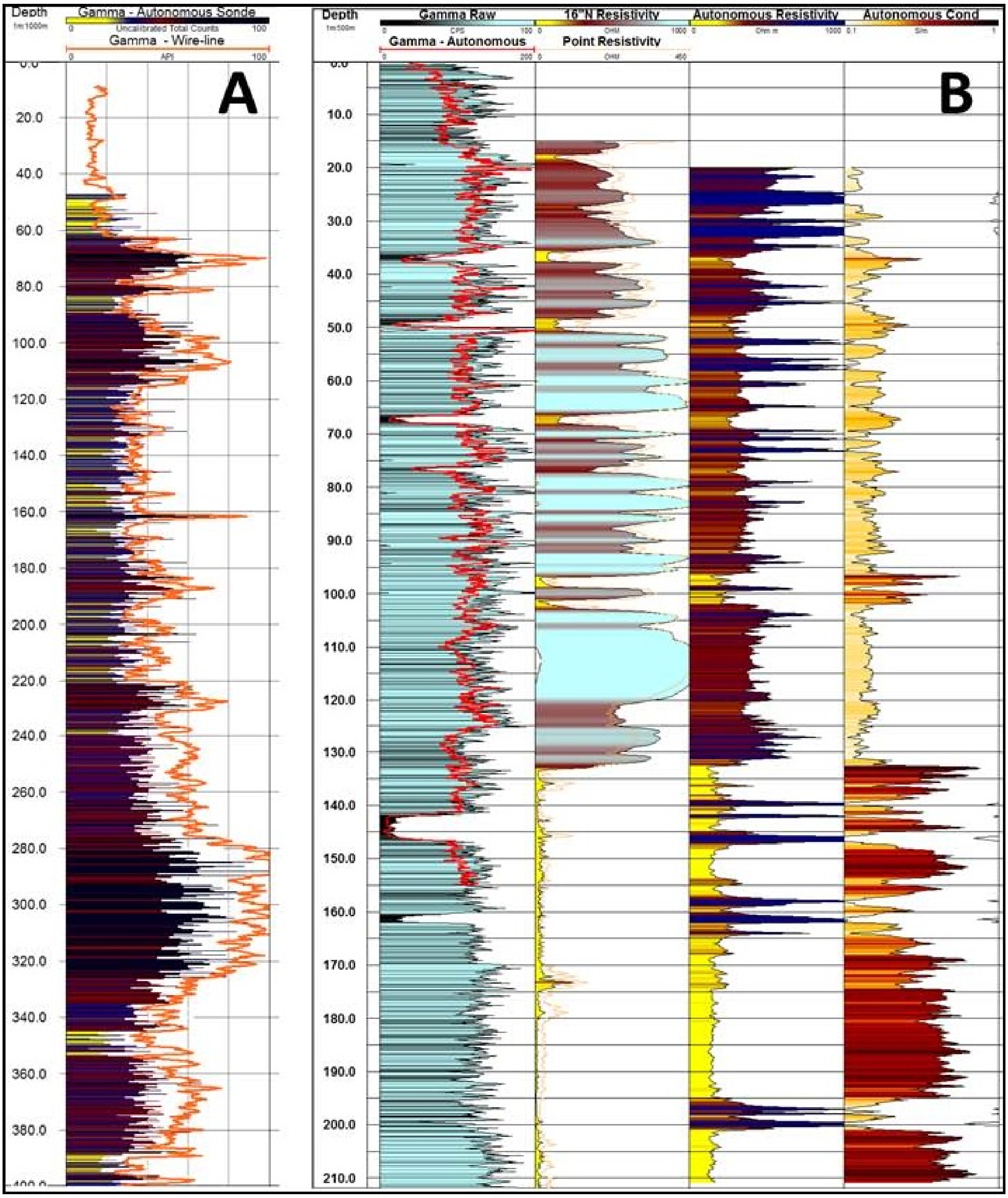

Figure 2: *Total Count Gamma data (FRP cased hole) using water column pressure for depth registration compared to standard wireline logging results in a sandstone/shale environment (A), and a comparison of the Autonomous Sonde TC gamma and Induction resistivity with wireline logs in meta-sediments with pyrite bands (B). In panel A the wireline data is the orange line and the sonde data is coloured bars. Despite lower signal due to a smaller sensor the two compare very well, with excellent depth correlation. In panel B the sonde gamma log (red line) is overlaid on the wireline log (leftmost bar plot in B). The other strip charts (left-to-right) in panel B compares 16"normal galvanic resistivity to an experimental induction resistivity/conductivity sensor on the sonde.*

Results

To validate our approach, initial testing of pressure-to-depth calibration was conducted in a nearby aquifer recharge borehole at the Beenyup Waste Water Treatment Plant (Perth, WA). This particular borehole was cased with fibreglass reinforced plastic (FRP) and penetrates two main aquifers consisting of sandstones and shales (Leederville and Yaragadee). The sonde was deployed on a wireline from surface to 400 m at a constant rate of 10 m/minute. The wireline was used as an external depth control for validation of the results of the experiment. On the upward ascent the sonde was stopped every 10 m and paused for 20 seconds to simulate a rod-change. In Figure 2, Panel A compares the TC gamma data retrieved by the sonde by our methodology (the purple-yellow coloured bars in panel A) vs a standard wireline log completed a few years ago (the orange line in panel A). The registration between the two data sets is very good, with distinctive geological features matched to approximately 0.5 m or better. A similar experiment was conducted at the Brukunga drilling test site (at a rehabilitated pyrite mine, www.detcrc.com.au) in South Australia to test the sonde against standard wireline logging for depth registration and data quality. Again the sonde data (TC gamma and an experimental induction resistivity sensor) match the changes seen in conventional wireline data very well despite the rapid rate of ascent (10-20 m/min) and a lower sensitivity gamma sensor.

Conclusions

A novel arrangement of geophysical sensors that can be placed at the end of a diamond drill-string has been developed and compared to conventional wireline tools. These tests show that despite fairly quick withdrawal rates of 10-20 m/min (as compared to standard wireline logging rates of 2-5m/min), and a small sensor, the data quality is suitable for geological interpretation. By using the water column pressure changes during drill-rod withdrawal we have created an "autonomous sonde" that operates without cable or wireline during measurement and only needs to know the drill-rod length and starting depth of withdrawal to produce logs with very good depth registration. With further refinements this tool may be used by drillers as part of the drilling process, without the requirement for a specialist technician to be present; thus, making geophysical logs a routine measurement in mineral exploration instead of a rarity.

Acknowledgements

The work has been supported by the Deep Exploration Technologies Cooperative Research Centre whose activities are funded by the Australian Government's Cooperative Research Centre Programme.

References

Collett, T.S., Lee, M.W., Zyrianova, M.V., Mrozewski, S.A., Guerin, G., Cook, A.E., and Goldberg, D.S. [2012] Gulf of Mexico Gas Hydrate Joint Industry Project Leg II logging-while-drilling data acquisition and analysis. *Mar. Pet. Geol*. **34**, 41–61.

Freudenthal, T., Steinke, S., Mohtadi, M., Hebbeln, D. and Wefer, G. [2013] Spectrum Gamma Ray bore hole logging while tripping with the sea floor drill rig MARUM-MeBo. In: *EGU General Assembly Conference Abstracts*, p.8203.

Goldberg, D., Myers, G., Grigar, K., Pettigrew, T., Mrozewski, S., Arceneaux, C. *et al*. [2003] Logging-While-Coring: New Technology Advances Scientific Drilling. In: *Transactions of the SPWLA 44th Annual Logging Symposium*. Houston: The Society of Petrophysicists and Well Log Analystg.

Hyne, N.J. [2012] Nontechnical Guide to Petroleum Geology, Exploration, Drilling, & Production. PennWell Books.

McMonnies, B., Gerrie, V. and Milkereit, B. [2007] Ground geophysics and borehole logging - A decade of improvements, in: Exploration in the New Millennium: Proceedings of the Fifth Decennial International Conference on Mineral Exploration, pp. 39-49.

Smith, R., Shore, M. and Rainsford, D. [2012]. How to make better use of physical properties in mineral exploration: the exploration site measurement. *Leading Edge* **31**, 330-337.

Witherly, K. [2012] The evolution of minerals exploration over 60 years and the imperative to explore undercover. *Leading Edge* **31**, 292–295.