Results from the Initial Field Trials of a Borehole Gravity Meter for Mining and Geotechnical Applications

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ABSTRACT

Scintrex is in the final stages of the development of a borehole gravity meter, for mining and geotechnical applications. It is designed to log inside NQ (57 mm I.D.) drill rods to a depth of 3,000 m, using standard four (4) and seven (7) conductor wireline cable. The achieved sensitivity is better than 5 µgal, and is operable in boreholes inclined from 30^0 to vertical. École Polytechnique of Montreal has developed forward modelling software, as part of this project. Partial financial support was provided by the Ontario government (IRAP) and through a CAMIRO project sponsored by BHP Billiton, Vale Inco, AREVA Resources Canada and Schlumberger. The first field test of the prototype probe was successfully conducted in December 2008 for Vale Inco in a borehole located in Norman Township near Sudbury, Ontario. The results of this test show a large amplitude bipolar residual gravity anomaly, with the crossover at 1,400 m down the hole where the borehole intersected sulphides. A repeat log of the hole indicates that the Gravilog system achieved operational specifications close to its targets.

The second field test was conducted in March 2009 for AREVA in a newly drilled, vertical borehole at Shea Creek in northern Saskatchewan. The results clearly show the unconformity, and the bulk density calculations show an indication of a low density zone at the base of the Athabasca sandstone.

The third and fourth field tests are planned in the first half of 2010 for Schlumberger and BHPB respectively. The first commercial Gravilog survey was successfully conducted in October 2009 in a deep mining hole in the USA. Additional Gravilog systems are being built at Scintrex and commercial surveys are being planned in several countries for 2010.

Gravity measurements inside boreholes provide evidence of density variations both in the immediate vicinity and at a distance from the hole. Scintrex's development of a new borehole gravimeter will, for the first time, allow the application of gravity logging in typical mining and geotechnical boreholes.

Primary applications of the Gravilog system in mining include the sensing and mass-estimates of massive sulphide bodies, either intersected by or in close proximity to the borehole; or accurate bulk density measurements of formations intersected by the hole. In some cases (e.g. iron deposits) there is a semi-quantitative relationship between bulk density and grade of the deposit.

Key words: borehole gravity, gravity meter, bulk density, remote detection

INTRODUCTION

The development of a Borehole Gravity Meter suitable for mining applications commenced at Scintrex in September 2005. Initial field testing of the prototype "Gravilog" tool, in a borehole near Lindsay, Ontario, was completed in October 2008, followed by a second successful field trial in December in a borehole chosen by Vale Inco in Norman township near Sudbury, Ontario (Seigel et al, 2009). A third field trial was conducted in March 2009 with AREVA Resources Canada Inc. at Shea Creek in northern Saskatchewan. Field tests for the other two sponsors of the project have been postponed upon the request of the sponsors until the first half of 2010. The first commercial Gravilog survey was successfully conducted in October 2009 in a deep borehole in the USA. Additional Gravilog systems are being built by Scintrex, and commercial Gravilog surveys are being planned in several countries in 2010.

Borehole gravity has two main applications (Seigel et al, 2007). It is a valuable exploration tool, for mapping of density variations remote from the borehole. A second application, unique to borehole gravity, is bulk density determination of formations intersected by the borehole, which is significant in grade control and other mining applications.

The new Scintrex Gravilog BHG system can be deployed down to 3,000 metres depth inside small diameter boreholes (NQ drill rods) inclined from 30^0 to vertical. It is designed to provide the precision needed for detailed bulk density determinations of narrow formations and the high data acquisition rates required for efficient operations. A summary of the target design specifications is shown in Table 1. For a more complete description of the application of the Gravilog system in mining, see Seigel et al, 2007.

	Target specification
Sensitivity	better than 5 µGal with a one minute reading time
Operating range	7000 mGal
Max sonde diameter	48 mm
Max sonde length	Approx 3 m
Max. operating depth	3000 m (water filled hole)
Minimum hole diameter	NQ drill rods (57.2 mm)
Max. hole deviation from the vertical	60 degrees
Operating temperature range	0^0C - +70^0C (downhole section) -40^0C - +50^0C (uphole section excluding PC)
Vertical position determination in borehole	+/- 5 cm between successive stations (depth will be determined with a combination of pressure sensor, winch encoder and inclinometer)

Table 1: Scintrex's Gravilog BHG system, Target Specifications (from Seigel et al, 2007).

BACKGROUND

Today's relative land gravity meters measure accelerations at the earth's surface with microgal sensitivity. Despite this ability to acquire field measurements in parts per billion at or above the earth's surface, the inverse square falloff of gravity with distance from the source is a serious limitation for deeper mining and petroleum exploration. LaCoste & Romberg developed a borehole gravity meter over 30 years ago, but the size and operational limitations of the probe made it impractical for mining applications. Scintrex, with partial financial support from a group of industry sponsors and the Canadian government, reduced the size of its quartz sensor and developed automatic levelling, temperature control and electronics systems to fit into a small diameter probe suitable for mining boreholes. After completing a series of in-house tests, the Gravilog prototype was deemed to be ready for its first full-scale field test for an industry sponsor in December 2008.

VALE INCO TEST, SUDBURY, ONTARIO

The location of the first field trial of the Gravilog tool was a close to vertical borehole selected by Vale Inco in Norman Township, near Sudbury, Ontario. The drill site is shown in Figure 1.

Figure 1: Norman Township Test Site

The Gravilog system was mobilized by strapping it onto the bed of a tractor supplied by Vale Inco. On arrival at the borehole, the Scintrex crew deployed the probe inside the NQ drill rods, lowered it to 1000 m and left it overnight to stabilize. Logging commenced immediately the next morning. The borehole was logged in both directions over the next two days (Figure 2).

Figure 2: Norman Township Test – Data Acquisition

The Norman test borehole intersects the "Lower Zone" of a mineralized zone (Figure 3). Between 1000 m to 1400 m, the geologic log (courtesy of Vale Inco) describes norite, pegmatite and gabbro. From 1400 to 1800 m, granite, granite breccia and diabase are logged.

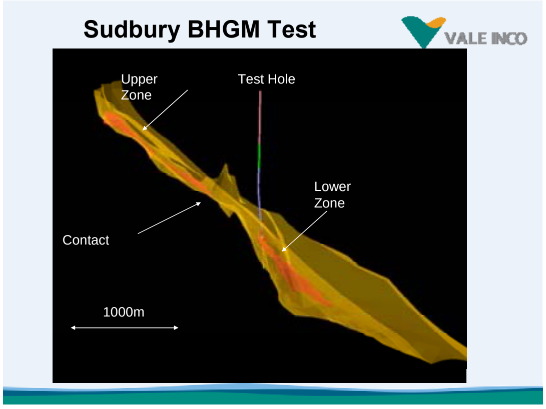

Figure 3: Norman Township Test Site, Looking East

The hole "intersects sulphides from 1400m to 1480m. The upper half of this interval is very weak, disseminated mineralization averaging 10-20% Sulphide (SG= 2.8-3). The lower half of the intersection is much better, consisting mostly of massive to semi-massive sulphides grading above 50% Sulphide (SG=3.5-4)." (courtesy of Vale Inco) . This intersection represents the updip fringe of a massive "Lower Zone" sulphide, which is part of a large mineralized zone, dipping about 35^0. A second massive "Upper Zone" lies some hundreds of metres updip of the intersection in this mineralized zone. Weak disseminated sulphides are also intersected in the borehole below 1750 m.

The Gravilog probe was deployed inside NQ drill rods to collect gravity measurements in the Norman borehole. The hole was logged from 1200 m to a depth of 1800m, both upwards and downwards, between December 12 to 14, 2008. The reading intervals varied from 50 m in the host rock to 10 m through the mineralized zone. Depths were measured both using the winch counter at the surface and the pressure sensor in the probe. Water was added to the hole as necessary to keep the water level constant during logging, for operation of the pressure sensor. At each station, the clamp was deployed to secure the probe, the pressure was recorded, the gravity sensor was leveled, two 60 second gravity measurements were taken, the clamp was then disengaged and the probe was moved to the next station location using the winch counter for a depth reference. This procedure required about 5 minutes at each station plus the time required for moving between stations.

The residual gravity from the two logs were processed separately and presented together (Figure 4). The mean repeatability of the gravity readings across the intersection is 6.0 μGals. After applying the normal suite of corrections to the observed gravity data, (including Bouguer gravity corrections using 2.77 g/cm^3 slab density), a bipolar residual gravity anomaly of about 1.4 mGal peak to peak magnitude was observed, clearly indicating the presence of a large mass of high density sulphides, related to the intersection.

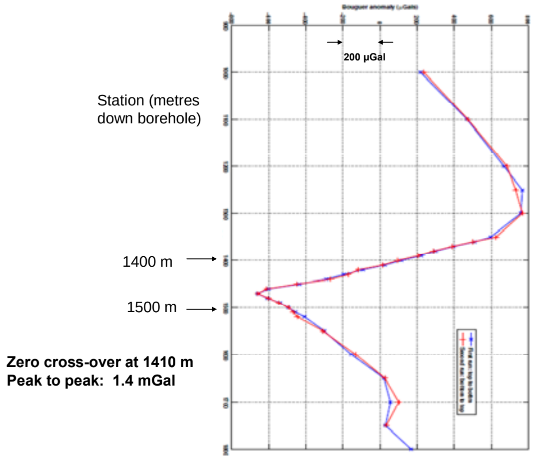

Figure 4: Norman Township Test, Residual Gravity

Bulk densities in the Norman borehole were calculated from the residual gravity data using a proprietary algorithm developed by Dr. Jeff MacQueen at Micro-g LaCoste that makes use of the complete set of measured gravity differences (Figure 5). Error bars are included in the figure.

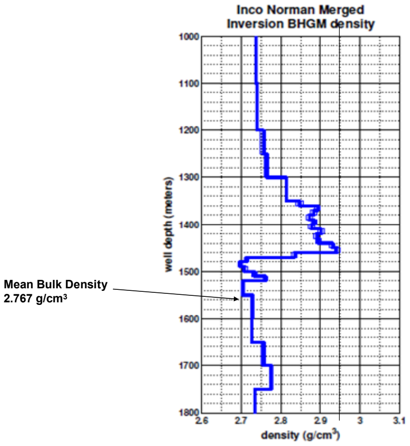

Figure 5: Norman Township Test, Bulk Densities

The bulk densities calculated from the gravity data are representative of the host rock density above the intersection. They increase through the intersection, from 2.77 g/cm^3 at 1300 m to 2.95 g/cm^3 at 1460 m, then fall off rapidly beneath the intersection. These results are consistent with the comments provided by Vale Inco (see above).

AREVA RESOURCES CANADA INC. TEST, SHEA CREEK, SASKATCHEWAN

The location of the second field trial of the Gravilog tool was a vertical borehole selected by AREVA Resources at Shea Creek, near the decommissioned Cluff Lake uranium mine in northern Saskatchewan**.** The drill site is shown in Figure 6.

Figure 6: Shea Creek Test Site

The generalized geology at Shea Creek is shown in Figure 7. The unconformity at 730 m depth separates the overlying Athabasca sandstone (2.5 g/cm^3) from the Archean basement (2.67 g/cm^3). Alteration at the unconformity, if present, causes zones of lower density above and below the unconformity. Alteration was evident in the geologic log of the hole (courtesy of AREVA Resources). High density uranium ore was not present in the hole.

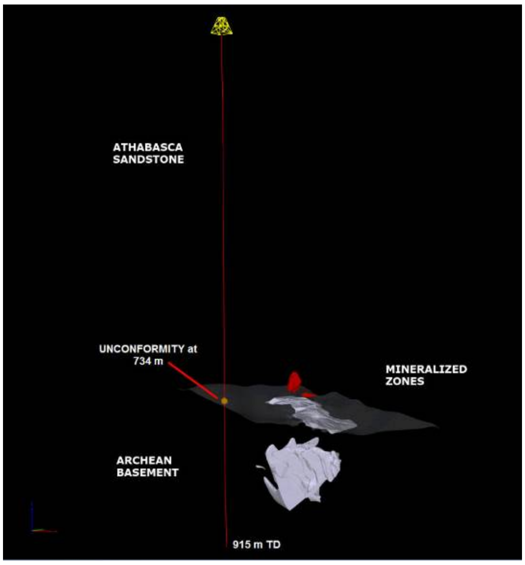

Figure 7: Shea Creek Test Site Mineralization

The Shea Creek borehole was logged with Gravilog from the surface to a depth of 870 m. The probe was initially deployed inside the NQ drill rods to a depth of 500 m on March 25 and left overnight. Measurements were collected on March 26 from 500 m to 870 m, returning to 500 m, and then ascending to the surface. Station spacing varied from 100 m in the Athabasca sandstone above 500 m to 5 m through the section from 710 m to 800 m depth. The data acquisition procedures were similar to the Norman test described above.

The Gravilog probe contains a total count gamma sensor, and a large spike was observed when the probe passed the unconformity (Figure 8).

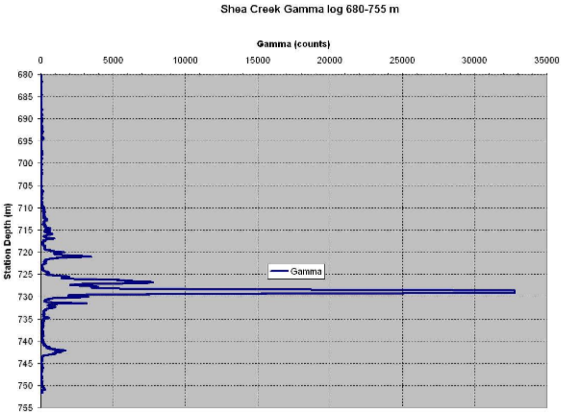

Figure 8: Shea Creek Test Gamma Log, 680 – 755 m

The Shea Creek borehole was vertical, and rotation of the Gravilog probe occurred during moves between stations. Offsets in the measurements of gravity, ambient temperature and inclinometer data were observed that appear to be correlated to rotation..Reasons for this were still under investigation at the time of writing this paper, These effects were removed using least squares processing. The mean repeatability of the least squares processed gravity data is 5.8 μGal.

Unlike the Norman test hole, the Shea Creek borehole did not intersect a high density body. The free air corrected gravity profile shows a linear trend as the Gravilog probe moves progressively deeper through the Athabasca sandstone into the Archean basement (Fig 9).

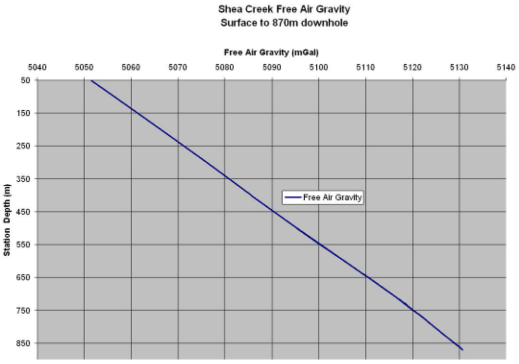

Figure 9: Shea Creek Gravity, Free Air Corrected

The bulk density log is more revealing. The density change from Athabasca sandstone to Archean basement at 730 m down hole is evident. There is a zone of lower density in the Athabasca sandstone immediately above the unconformity that may be the result of alteration (Figure 10).

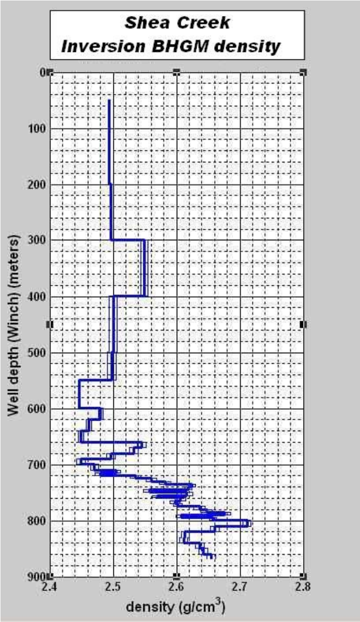

Figure 10: Shea Creek Test Bulk Density Log

GRAVILOG SYSTEM TEST PROGRAM – NEXT STEPS

The cause of the measurement offsets recorded during the Shea Creek test is being investigated at Scintrex at the time of writing this paper. Offsets appear to correlate to rotation of the sonde. Scintrex has attached small stabilizers to the Gravilog probe that prevent the sonde rotating in inclined holes. Sonde rotation was not encountered in the almost vertical Norman hole. It is expected that the cause of these offsets will be uncovered by careful forensic examination of the probe and appropriately resolved.

The remaining two field tests are scheduled in the third quarter of 2009.

Scintrex is testing a second Gravilog probe at the time of writing this paper, and additional Gravilog systems are being built. It is expected that Gravilog services will be commercially available for mining and geotechnical applications about the time of the SAGA conference in September 2009.

CONCLUSIONS

Scintrex has successfully completed two field trials of the prototype Gravilog borehole gravity meter for industry sponsors. The logging efficiency and the data quality are close to the expected targets. Additional Gravilog probes are now being manufactured at Scintrex, and the last two field trials for the industry sponsors are planned for the third quarter of 2009.

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