Update on Development of a Borehole Gravity Meter for Mining Applications

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ABSTRACT
This short paper summarizes the purpose and provides an update of the progress made to date on the development of the “Gravilog” borehole gravimeter at Scintrex. Scintrex’s Gravilog borehole gravity system will be a new tool, with a wide range of mining and geotechnical applications. It will be capable of logging inside NQ drill rods to 2,000 m depth, using standard 4 conductor cable. The Gravilog will have a sensitivity of better than 5 µgal, and can be operated in boreholes that deviate up to 60° from vertical. École Polytechnique de Montréal is developing forward modeling software as part of this project.

The first Gravilog surveys, in sponsors’ boreholes, are planned for mid 2008.

INTRODUCTION
The development of a Borehole Gravity Meter suitable for mining applications commenced at Scintrex in September 2005. Plans are now being made for in-house testing of the prototype “Gravilog” tool in a borehole near Lindsay, Ontario, starting in October 2007. The industry sponsors of the project will then conduct tests in boreholes of their choice, in the summer of 2008. It is expected that the first two production Scintrex Gravilog BHG meters will be available for logging suitable boreholes in late 2008 or early 2009.

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, allowing useful gravity measurements to be made relative to targets at great depth. A second application, unique to borehole gravity, is bulk density determination of formations intersected by the borehole.

The new Scintrex Gravilog BHG system is designed to overcome many of the limitations encountered with the L&R tool. It can be deployed down to 2,000 metres depth inside smaller boreholes (NQ drill rods), with deviations from vertical of up to 60°. It will provide the precision needed for detailed bulk density determinations of narrow formations, and the high production rates required for efficient operations. A summary of the target design specifications is shown in Table 1. For a description of the application of the Gravilog system in mining, see Seigel et al, 2007.

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<th>Target specification</th>
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<tr>
<td>Sensitivity</td>
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<td>Max sonde diameter</td>
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<td>Max. hole deviation from the vertical</td>
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<td>Operating temperature range</td>
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<td>Vertical position determination in borehole</td>
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Table 1: Scintrex’s Gravilog BHG system, Target Specifications (from Seigel et al, 2007).

BACKGROUND
The utility of gravity measurements in boreholes was described by Neal Smith over 50 years ago (Smith, 1951). LaCoste & Romberg’s borehole gravity meter is now over 30 years old and there are several examples of successful applications of BHG by the petroleum industry available on Edcon’s website, www.edcon.com. The L&R BHG system can only be used in large diameter, vertical boreholes, making it impractical for most mining applications.

Modeling of the expected BHG response of CVRD Inco’s Kelly Lake Cu/Ni orebody in the Sudbury Basin (Figure 1) shows its prospective value for mining exploration. The modeling shows that a large gravity response from the Kelly Lake deposit could be detected from a borehole. Its gravity response on the surface will be difficult to detect, due to its considerable depth below surface. (for more detail and additional modeling, see Seigel et al, 2007).
Figure 1: Gravilog for mining exploration. Model of a near miss of the Kelly Lake orebody (from Seigel et al., 2007)

Figure 2, downloaded from Edcon’s website, shows how borehole gravity data provides bulk formation density. This is a unique feature of borehole gravity data, and requires precise relative positioning of successive measurements and careful survey procedures to ensure the best quality data is recorded. A case study showing the successful application of this technique to detect bypassed gas zones using the L&R BHG meter is available on www.edcon.com.

Figure 2: Bulk Density Determination using Borehole Gravity measurements.

Despite its age, the data quality obtained when the L&R BHG meter is used by knowledgeable operators is excellent, and bulk densities of formations as thin as 3 metres can be measured to better than 0.02 g/cm³. Figure 3 shows the bulk density log obtained in one of the holes logged by a Micro-g LaCoste survey crew in late 2006 using the L&R BHG system at the Pacific Northwest National Laboratories’ Hanford Waste Treatment Plant in Washington State, USA. Gravity measurements were collected every 10 feet (3 metres) in the borehole. The L&R BHG measurement accuracies were better than 5 µGal and great care was taken to precisely position the gravity sensor at each reading location. The BHG data collected at 10 foot intervals provided bulk density measurements of the rocks within about 50 feet (15 metres) of the hole to an accuracy of +/- 0.02 g/cm³.

Figure 3: PNNL Waste Treatment Plant, Hanford, Well C4993: Comparison of bulk densities computed from Borehole Gravity data and blocked γ-γ densities, 10 ft intervals

The bulk densities calculated by the BHG measurements accurately map the series of high density massive basalt flows in the sedimentary package at the Hanford waste disposal site. The gamma-gamma densities are distorted by wash-outs at the top of the basalts.

This unique feature of BHG measurements can provide quantitative grade control data in iron ore mines (Seigel et al, 2007)

SCINTREX GRAVILOG SYSTEM

Figure 4 shows the layout of Scintrex’s Gravilog BHG system. The gravity module (gravity sensor and the sensor electronics) is located below a slip ring, allowing this portion of the system to rotate around the vertical axis of the tool. The rest of the electronics and the auxiliary devices are located above the slip ring.

Figure 4: Layout of the Scintrex Gravilog System
The outside diameter of the Gravilog system is 48 mm, and
the mechanical design of the components must work with
severe size restrictions. Figure 5 shows the Gravity Sensor
housing (the Gravity Ball), which encloses the quartz sensor.
It is considerably smaller than a golf ball.

Figure 5: Scintrex Gravilog Sensor Housing

The Gravity Ball is suspended on a yoke with tilt motors,
which, coupled with the slip ring, provide the leveling
mechanism that is controlled from the surface by the
operator. Tilts, measured by specially designed level
bubbles mounted on the ball, must be known to within two
arcseconds. Temperature control at the sensor must be at
micro degree C levels, and is provided by heaters installed
on and around the ball.

A further challenge that needed to be overcome is the
repackaging of the electronics onto suitably small size
boards.

Communication from the Gravilog to the surface will be
continuously supplied via modem. The operator at the
surface will control the system using a rugged PC and
Scintrex’s Gravilog software. The GUI screen, with
simulated data, is shown in Figure 6.

Figure 6: Scintrex Gravilog GUI

The forward modeling software developed by Giroux and
Chouteau at École Polytechnique allows structures to be
entered as either polyhedral objects (GOCAD) or rectilinear
grids (UBC-GIF). There are several options for displaying
results. Figure 7 shows a simple display for the calculated
gravity and gravity gradient responses in a borehole.

Figure 7: BHG Modeling Software

The software can also be used to model surface responses.
For the example shown in Figure 7, the operator would
simply select the surface profiles available in the bottom left
hand box.

Several auxiliary systems must be integrated with the
Gravilog system for a complete borehole logging tool. The
downhole system requires a pressure sensor, inclinometer,
CCL/gamma and sidewall clamp. Uphole, the system will
include a barometer and logging system (rugged PC). The
winch, winch counter, cable and power supply can either be
supplied with the Gravilog system or, if available, by the
customer.

GAVILOG SYSTEM TEST PROGRAM

Individual components of the Gravilog system are bench
tested prior to assembly. Upon completion of the prototype
Gravilog system, bench tests of the complete measurement
sequence under operator control will be conducted. All the
Gravilog sensors and modules will be tested at various sonde
inclinations to confirm that the integrated system is working
properly.

The final in-house shake down test of the Gravilog system
will be conducted in an accessible borehole near Lindsay,
Ontario, kindly supplied by Sir Sandford Fleming College.
The shake down field test program will include

- Confirmation of proper functioning of all Gravilog
  sensors and modules as a logging system, (except
  for the CCL and inclinometer) in a waterfilled
  borehole
- Confirmation of standard deviation of one minute
  gravity measurements
- Demonstration of repeatability of logging runs in
  the hole
- Develop solutions to problems that arise.
- Develop efficient Gravilog logging procedures
- Determination of effective logging rate per station

Upon completion of the field shake down tests, the Gravilog
system will be available during Q2 and Q3, 2008 for
operation tests in boreholes selected by the industry
sponsors.
CONCLUSIONS

The development of a Borehole Gravity Meter for mining applications at Scintrex has progressed to the assembly of a complete Gravilog prototype system ready for shake-down tests in a borehole near Lindsay, Ontario. Operational tests in boreholes selected by the industry sponsors are planned for the middle of 2008.

ACKNOWLEDGEMENTS

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REFERENCES