*Paper 111*

# Development of a Borehole Gravity Meter for Mining Applications

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**ABSTRACT**

*Scintrex Limited of Concord, Ontario, Canada is continuing to develop the Gravilog mining system, a borehole gravimeter specifically designed for mining applications. The mining applications of such a tool are: detection of an off-hole orebody, determination of excess mass, 3D modelling, follow-up of surface and airborne gravity anomalies as well as bulk density information of the intersected formations.*

*The gravity sensor is a constructed of fused quartz, quite similar to our CG-5 sensor. The sensor will be lodged in a copper ball mounted on a yoke inside the sonde. The sonde is designed to fit in BQ drill holes or NQ drill rods, e.g. a maximum sonde diameter of 48 mm. The maximum sonde length is 2 m. The targeted specifications for the Gravilog are as follows: better than 5µGal and 7000 mGals for the sensitivity and operating range respectively; 2000 m and 60° for the maximum operating depth and hole deviation from vertical; 0° C to +70° C and -40° C to +50° C for the operating temperature of the sonde and surface components. The vertical positional accuracy is ± 5 cm using a combination of pressure sensor, winch encoder and fluxgate magnetometer. The data will be acquired through the means of a data acquisition program currently written by Scintrex. This program will be running on a ruggedised PC connected to the winch at surface. The program will continuously record the data along the drill hole and plotand it in real time.*

*Several corrections, such as depth, latitude, atmospheric pressure, instrumental drift, earth tides, surface topography and regional gradient have to be applied to borehole gravity data in order to achieve meaningful results. Field tests of the Gravilog are planned for October-November of 2007.*

## INTRODUCTION

The concept of using borehole gravity was first proposed by Smith (1950). LaCoste & Romberg later developed and successfully commercialised a large diameter borehole gravity meter for the petroleum industry.

Scintrex Limited has recently introduced the Gravilog, a slim borehole version based on the well-proven fused quartz technology sensor and designed to fit in boreholes of up to 48 mm in diameter. The functional depth of this sonde will be 2000 m. The target accuracy of the sensor will be better than 5 µGal.

## APPLICATIONS

With such a small diameter sonde, there are now many applications and orebodies that had been investigated with other methods either geophysical or non-geophysical which are now within reach.

Applications of borehole gravity include remote detection of orebodies, as previously mentioned, determination of excess mass, 3D modeling, follow-up of surface and airborne gravity anomalies as well as bulk density information on the intersected geological formations.

## DESIGN OF THE GRAVILOG

The sonde has a maximum length of 2 m and a diameter of 48 mm. The sensor is constructed of fused quartz and is based on our CG-5 relative gravity meter. The Gravilog sensor is much smaller than a CG-5 sensor. The Gravilog sensor is designed to fit into a 44 mm copper ball installed in a yoke in the sonde. Figure 2 illustrates this receptacle.

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**Figure 1:** Copper Ball housing the gravity sensor

## TARGETED SPECIFICATIONS

The targeted specifications of the Gravilog are summarized in Table 1.

## DATA ACQUISITION

Data acquired with the Gravilog will be logged with Scintrex's proprietary BGES (Borehole Gravity Evaluation Software) program. The BGES is installed on a PC outfitted to deal with rugged terrain on surface and continuously monitors and records the gravity signal. Figure 2 illustrates the BGES interface.

As previously mentioned, the position of the sonde will be accurately measured using a combination of pressure sensor, winch encoder and fluxgate magnetometer, as illustrated in Figure 3.

**Table 1: Gravilog Target Specifications**

| | Target specification |
|---|---|
| Sensitivity | better than 5 µGal with a one minute reading time (1 µGal is 10-9 of the earth's gravity field) |
| Operating range | 7000 milliGal |
| Max sonde diameter | 48 mm |
| Max sonde length | 2 m |
| Max. operating depth | 2000 m (water filled hole) |
| Minimum hole diameter | BQ (60 mm) and NQ drill rods (57.2 mm) |
| Max. hole deviation from the vertical | 60 degrees |
| Operating temperature range | 0C - +70C (downhole section) -40C- +50C (uphole section excluding PC) |
| Vertical position determination in borehole | +/- 5 cm (depth and trajectory will be determine with a combination of pressure sensor, winch encoder and fluxgate magnetometer |

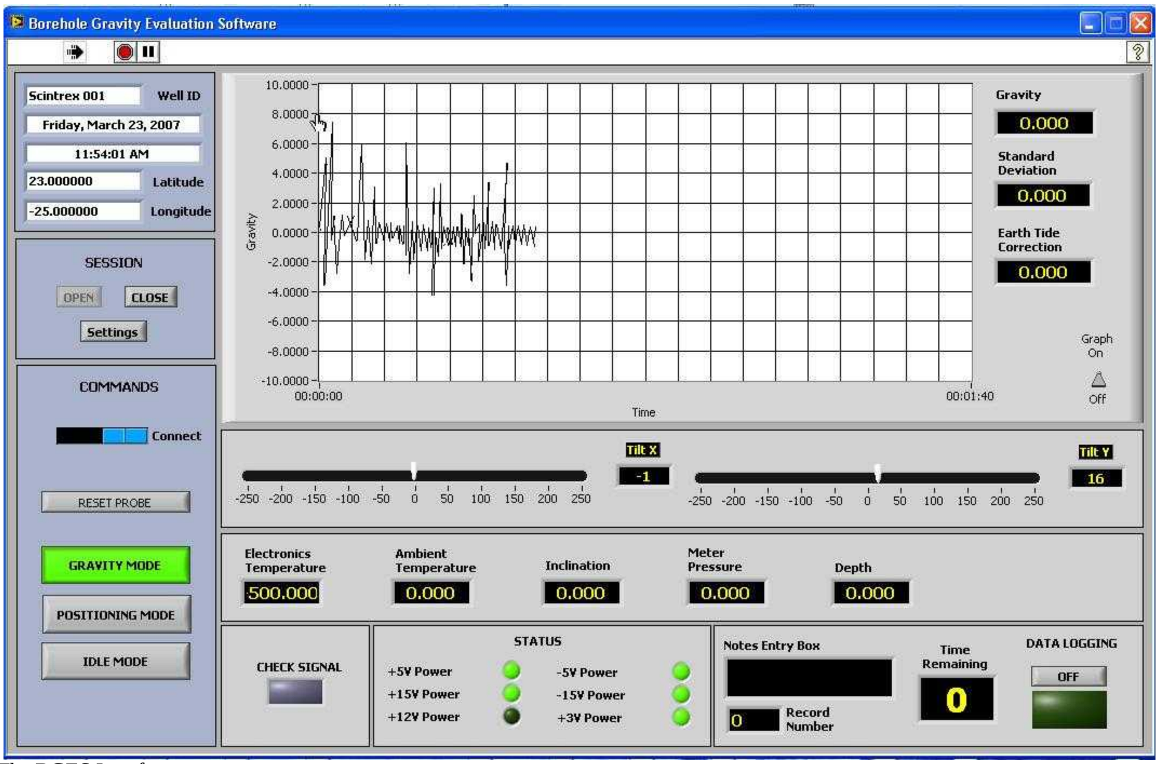


**Figure 2:** The BGES Interface

## DATA CORRECTIONS

To achieve a signal sensitivity of better than 5 µGal, the difference between two gravity values measured at adjacent locations must have a precision better than 7 µGal. This sets the cumulative target for errors in the corrections.

### Depth

This is the most critical factor. The accuracy of bulk density calculations requires accurate relative depths. The increment of gravity $\Delta g$, between two stations $\Delta z$ apart vertically, is given by:

$\Delta g/\Delta z = (0.3086 - 0.0838d)$ in milliGal/m…....................….(2)

where d = mean density of the formation between the two stations, in g/cm3.

If the inclination of the mining boreholes is $\phi$ degrees, then

$\Delta z = \Delta L \sin\phi$ ……………………………………...………….(3)

where $\Delta L$ is the slant distance (along the hole) between the two stations. Different means may be employed, solely or in combination, to achieve this relative vertical depth precision: a pressure gauge (on the sonde); a sheave wheel counter (for cable length $\Delta L$) plus a clinometer (0.5 deg resolution, on the sonde); and a CCL and/or fluxgate sensor (on the sonde), to detect the joints in the casing of the hole, for slant distance updates.

The first figure in the bracket in (2) is the normal "free-air" vertical gravity gradient, and must be removed accordingly. Once removed, the residual gradient is directly proportional to the bulk density between the two stations (1). The vertical depth precision required is, therefore, ~5 cm (relative, between stations > 5 m apart).

### Latitude

As in surface gravity measurements, borehole gravity measurements will be subject to variations with the Earth's latitude $\theta$. These variations are given by:

$\Delta g/\Delta x = 0.813 \sin 2\theta - 1.78 \times 10^{-3} \sin 4\theta$ in µGal/m…………...(4)

The correction for latitude may be as great as 0.8 µGals per metre N/S in mid latitudes, but decreases progressively towards the poles and the equator. The means employed to determine the latitude for each station may include: an orientation log of the hole (if available); and an axial fluxgate sensor, in uncased holes, plus the sheave wheel counter for slant distance.

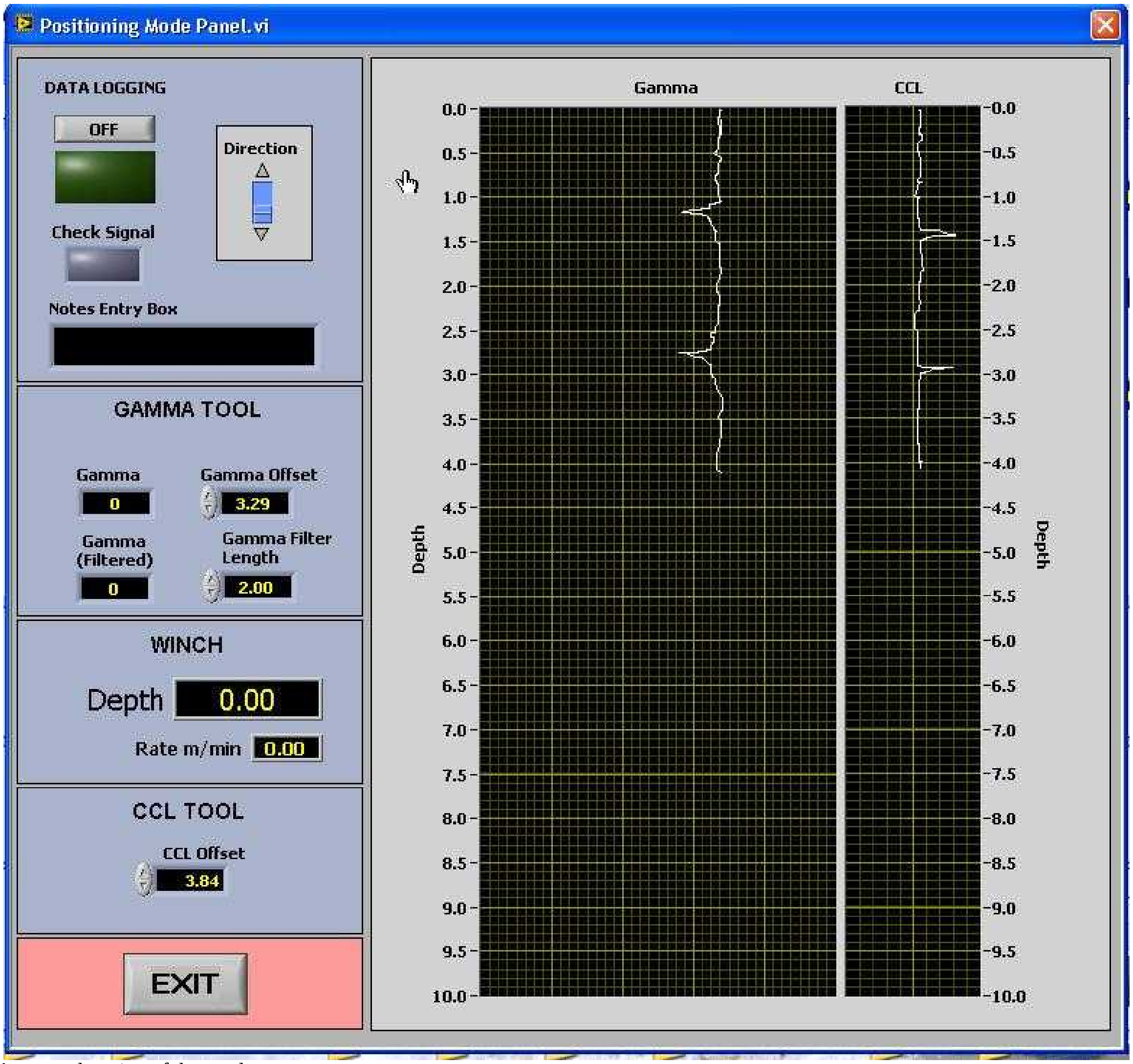


**Figure 3:** Accurate location of the sonde

### Atmospheric Pressure

An increase of atmospheric pressure will decrease the observed gravity values because of the increased mass of the column of air above the hole. The effect is given by:

$\Delta g/\Delta P = -3.6\ \mu Gal/kPa$ ............................................................(5)

Correction for this possible error may be achieved through the use of a microbarometer at the collar of the hole.

In addition, when a pressure gauge is employed to measure depth, the increased atmospheric pressure will be interpreted as an increase in the depth of the station and give rise to an overcorrection for depth. These effects are additive and the total effect is given by:

$\Delta g/\Delta P = -12.2\ \mu Gal/kPa$ .........................................................(6)

### Gravimeter Drift

Correction for linear drift of the gravimeter will be made by tying back to base, normally at the collar of the hole, at the beginning and end of the logging process

### Earth Tides

Tidal gravity effects will be removed using standard software-based formulae based on time and longitude.

### Surface Topography and Underground Workings

Borehole gravity readings will be affected by surface topography and underground mine workings in the vicinity. Corrections may be calculated using forward modeling routines included in the École Polytechnique software, local digital topographic models and three dimensional digital representations of the mine workings.

### Regional Gradient

In some circumstances there may be substantial regional gravity gradients due to large scale geologic features. Their effects may be removed either by reference to available regional gravity maps, or by running orthogonal, wide spaced gravity traverses on surface, centered on the hole. These corrections will require knowledge of the dip and azimuth of the borehole, in the same manner as for the latitude correction.

## TIMELINE

Based on the current progress of the project, field tests of the Gravilog are planned for October-November of 2007. The results of the field test will be the subject of another presentation.