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, a borehole gravity logging system, specifically designed for mining applications. The mining applications of such a tool include detection of an off-hole orebody; determination of the excess mass of bodies, both remote and intersected by the hole; 3D modelling; the follow-up of surface and airborne gravity anomalies; and bulk density measurement of the intersected formations.

The gravity sensor is constructed of fused quartz, quite similar in concept and resolution 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 target sonde length is 2 m.

The relative vertical positional accuracy between stations is ± 5 cm, using a combination of pressure sensor, winch encoder, and inclinometer.

The data will be acquired by 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 plot it in real time.

There are several corrections, such as depth, latitude, atmospheric pressure, instrumental drift, earth tides, surface topography and regional gradient, that have to be applied to borehole gravity data in order to achieve meaningful results.

Modeling software has been developed under a subcontract by Giroux and Chouteau at École Polytechnique de Montréal.

Initial field tests of the Gravilog are planned for October-November of 2007. The sponsors' boreholes are scheduled to be logged, starting in mid-2008.

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 is developing 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 sonde diameter, borehole gravity will now be available for applications that previously could only be investigated with other methods either geophysical or non-geophysical.

Applications of borehole gravity include remote detection of orebodies; determination of excess mass; 3D modeling; follow-up of surface and airborne gravity anomalies; and determination of the bulk density of the intersected geological formations.

DESIGN OF THE GRAVILOG

The sonde has a target 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 1)

Figure 1: Copper Ball housing the gravity sensor

TARGETED SPECIFICATIONS

The target specifications for the Gravilog are as follows:

Sensitivity:	better than 5μGal
Operating range:	7000 mGals
Maximum sonde diameter:	48 mm
Maximum sonde length:	2 m
Maximum operating depth :	2000 m (water filled hole)
Maximum hole deviation from the vertical:	60°
Operating temperature :	0° C to +70° C (sonde) -40° C to +50° C (surface components)
Relative vertical position determination in borehole:	± 5 cm using a combination of pressure sensor, winch encoder and inclinometer

Figure 2 illustrates the layout of the Scintrex Gravilog System

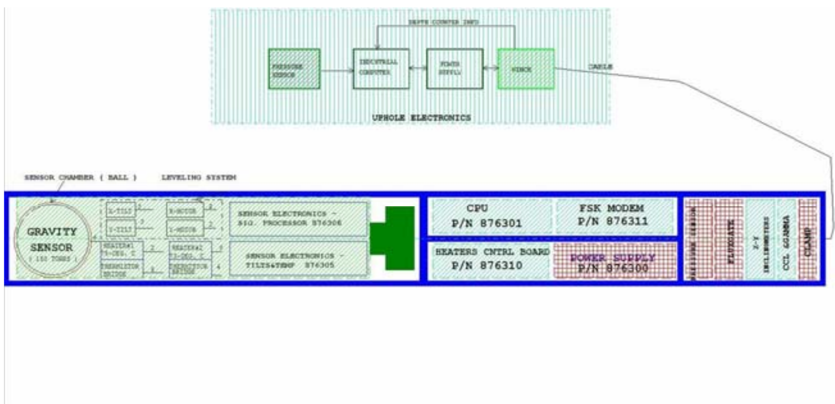

Figure 2: Layout of the Scintrex Gravilog System

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 ruggedised PC on surface and continuously monitors and records the gravity signal. Figure 3 illustrates the BGES interface.

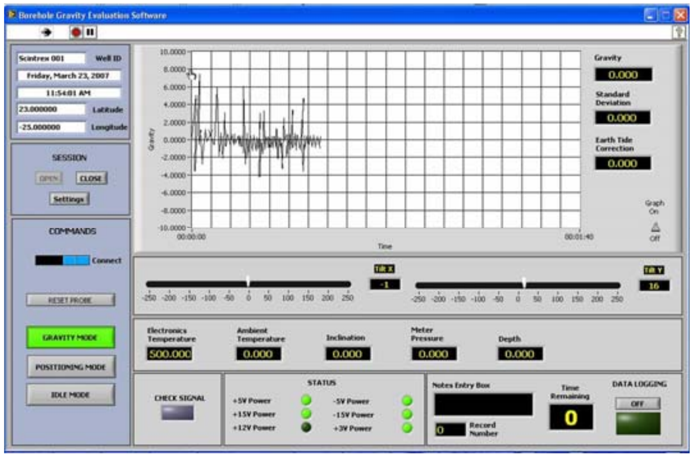

Figure 3: The BGES Interface

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 Δg, between two stations Δz apart vertically, is given by:

$\Delta g/\Delta z = (0.3086 - 0.0838d)\,\Delta z$ in milliGal/m……………..(1)

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

If the inclination of the mining boreholes is □ϕ degrees, then

Δz□ = □$\Delta L \sin\phi$ …………………………………….(2)

where ΔL 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. For example, a pressure gauge (on the sonde); a sheave wheel counter (for cable length ΔL) 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 (1) 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 θ. These variations are given by:

$\Delta g/\Delta x = 0.813 \sin 2\theta - 1.78x10-3\sin4\theta$ in μGal/m……(3)

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.

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:

$\Delta g/\Delta P = -3.6$ μGal/kPa ....(4)

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:

$\Delta g/\Delta P = -12.2$ μGal/kPa ....(5)

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, initial in-house field tests of the Gravilog are planned for October-November of 2007. The results of the initial field test will be the subject of future presentations. The sponsors' boreholes are being scheduled to be logged in mid-2008.

ACKNOWLEDGEMENTS

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REFERENCES

Smith, N.J, 1950, The case for gravity data from boreholes: *Geophysics 15 (4), 605-636*.