Correcting for overburden thickness in airborne gravity data using electromagnetic data

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Summary

A new methodology is introduced that corrects airborne gravity data for changes in thickness of glaciolacustrine overburden. The approach is tested for a 35 km-long line from the Quest-West survey in the interior plateau of British Columbia, Canada. A bedrock topography map was created by inverting helicopter transient electromagnetic data. The inversions were conducted independently every 25 m over a 73 x 32 km^2 area including the line of interest using a 2-layer near-surface layered earth model and the depth to bedrock was interpolated across the area. The overburden and bedrock were assigned constant densities of 1.80 and 2.67 g/cm^3, respectively. The gravity correction methodology employs the typical Bullard corrections with the additional step of using the bedrock topography map to correct for the gravitational acceleration contributed by changes in overburden thickness. Along the line of interest, the maximum overburden thickness reached approximately 300 m, corresponding to a gravity correction of up to 15 mGal.

Statement of the Problem

Several prospective areas for mineral exploration in Canada, such as the interior plateau of British Columbia and the Abitibi mining region in Ontario and Quebec, are covered by a thick glaciolacustrine overburden. The presence of overburden reduces the reliability of potential-field geophysical methods by obscuring changes in bedrock topography that vary independently from surface topography. With respect to the gravity method, changes in bedrock topography can create anomalies of the same size and magnitude as those associated with mineral deposited and be mistaken for them (Chen and Macnae, 1997; Caron et al., 2013). This paper introduces a new bedrock topography correction methodology for airborne gravity data, based on near-surface inversion of the overburden derived from helicopter transient electromagnetic (HTEM) data. This is an opportunistic use of HTEM data, which is typically acquired using high magnetic moments of well over 100,000 A/m^2 and processed to resolve deep targets within the bedrock.

Study Area

AeroTEM III System Specifications			
Nominal altitude	30 m	**Transmitter**	
Cable length	53 m	Type	Horizontal Loop
Rx - Tx position	Fixed	Peak Moment	183,131 NIA
In-loop Receivers		Peak Current	455 A
Rx Components	Z, X	Turns	5
1st off-time Ch	21.3 µs	Radius	5 m
On-time	1.83 ms	Base Frequency	90 Hz
Off-time	3.67 ms	Waveform	Triangle

Table 1: Some parameters for the AeroTEM III HTEM system, which was designed to detect a conductive body buried within the bedrock to a similar depth as a 500,000 NIA TEM fixed wing system (Aeroquest Surveys, 2009).

To test the new methodology on field data, we selected an area meeting the following criteria: (1) availability of coincident airborne gravity and airborne EM data; (2) presence of an overburden with lateral variations in thickness; (3) availability of ancillary geological information such as borehole data, technical reports, etc. The selected area is in the Nechako Plateau of the Interior Plateau in British Colombia, Canada (53°50’N and 125°40’W), which was surveyed using the SGL AirGrav airborne gravity system, and the Aeroquest AeroTEM III HTEM system as part of the Quest West project (Meyers and Bates, 2008; Aeroquest Surveys, 2009). The plateau has a high mineral potential but exploration efforts have been hampered by a glaciolacustrine and glaciofluvial overburden that covers 90-95% of the bedrock. Topography is rugged and features eskers, melt water channels, drumlins, glaciofluvial deposits, alluvial fans, and glacial lakes. The overburden is thought to conform to a typical glaciolacustrine and glaciofluvial progression and regression of the Wisconsin-Fraser glaciation (Plouffe and Levson, 2001). Several mines operate in the area, including the Blackdome gold mine, the Gibraltar copper-molybdenum mine, and the Endako molybdenum mine. The bedrock geology in the area is predominantly Eocene aged rhyolitic to andesitic volcanic flows and falls, of the Ootsa Lake and Endako Formation (Grainger and Anderson, 1999), with some occurrences of igneous and sedimentary rocks.

We inverted AeroTEM III HTEM data from a 73 x 32 km^2 area, located near François Lake. The HTEM flight lines were oriented East-West and flown with 4 km traverse line spacing, no control lines were flown (Aeroquest Surveys, 2009). The airborne gravity survey over the same area was flown East-West with a 2 km traverse line spacing and a 17 km control line spacing, flown South-East to North-West, at a drape altitude of 200 m above ground (Meyers and Bates, 2008). We applied our new bedrock topography correction to a single 35-km long airborne HTEM line of

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interest and compared it with conventionally corrected gravity data.

Overburden Modelling

The EM inversions were carried out using AirBeo of the open source CSIRO P223F EM suite (Chen and Raiche, 1998) using the ElectroMagnetic Imaging Technology (EMIT) program Maxwell as an interface. An unconstrained two layer initial model composed of an overburden with a resistivity of 100 Ω·m and half-space bedrock with a resistivity of 2000 Ω·m with elastic constraints of 1500-3000 Ω·m was used for inversions. Resistivities were chosen based on published works (Table 2).

Within the survey area, the overburden was found to vary in thickness from 5 m to over 400 m. The resistivity of the overburden ranged between 2 and 400 Ω·m, with a mode of 85 Ω·m; the resistivity of the bedrock is fairly uniform with a mode of 2000 Ω·m. These results are consistent with the findings of a previous TDEM survey conducted in the southern Nechako plateau (Best et al., 1997).

Once the EM data was inverted, the results were checked for any inconsistencies. To be considered valid, results had to meet the following criteria: (1) symmetric root-mean-square (sRMS) less than 10%, and (2) smoothly varying resistivities and depth to between adjacent stations. Inconsistent data was discarded. A noise floor of 10 nT/s was adopted during inversions. This had the effect of reducing the available off-time channels from 17 to 10 for most lines. A few lines also showed some minor transmitter interference that primarily affected the 1st channel, but on occasion affected the 2nd and 3rd channel as well. These channels were removed for inversion in order to raise the sRMS match between the observed HTEM decay and model curves for that station.

Sources	**Soil Type**			**Bedrock Type**
Resistivity [Ω•m]	**Clay**	**Sand**	**Till**	
FEM: Abitibi, ON	30 - 60	120 - 360	90-155	3000 - 10000 [crystalline]
TDEM: S.Nechako, BC	68 - 157			1500-10000 [volcanic]
THIS STUDY HTEM: Nechako, BC	Range (2 - 430) Median (50-130)			2000-2500 [volcanic]
Density [g/cm^3]	**Clay**	**Sand**	**Till**	**Volcanic rock**
Telford et.al 1990	1.6 - 2.6	1.7 - 2.3		2.35 - 2.8
Balco et.al 2005	2.01	2.13	2.24	

Table 2: Physical properties of glaciolacustrine sediment. Both the frequency electromagnetic (FEM) and the time domain electromagnetic (TDEM) were ground-based surveys.

Figure 2 shows the results of the inversion for a 5 km long portion of the line of interest. Overburden thickness and resistivity are varying smoothly laterally, in a realistic manner. The depths to bedrock are also similar to those determined from area water well data which had a maximum depth to bedrock of 367 m and a mean of 31 m.

A 3D grid of the bedrock topography was created by gridding the 1D inversions and interpolating between flight lines. As the line spacing is large, 4km for the HTEM survey, depth to bedrock information gathered from 512 local water wells were also added to augment the grid.

The bedrock was modelled with a constant density of 2.67 g/cm^3 to match the density chosen to model the Quest West gravity data set (Meyers et al., 2008). The overburden was modelled with a density of 1.8 g/cm^3, an average density for clay and sand (Table 2).

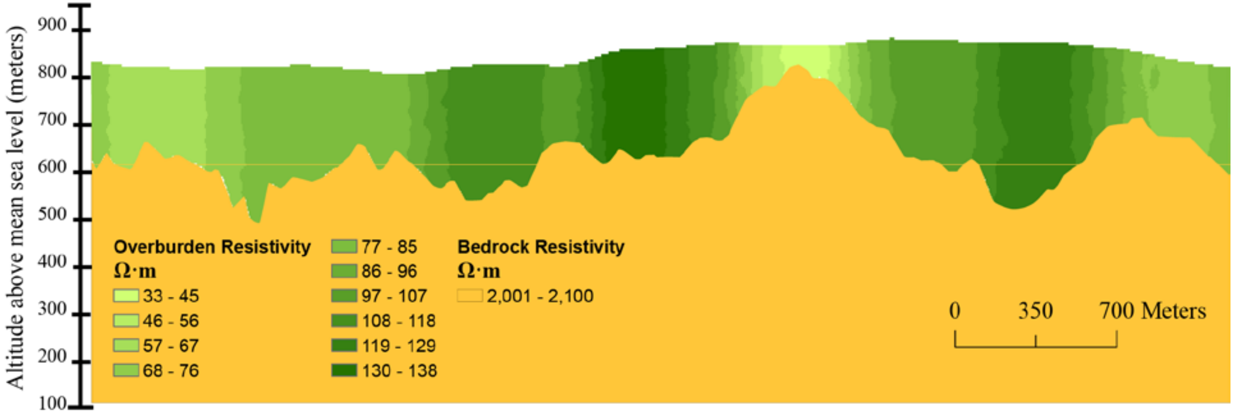

Figure 2: Resistivity-thickness profile created from an unconstrained 2-layer layered-earth inversion of HTEM data. Line is from a portion of an EM line adjacent to the line shown in Figure 4. Overburden resistivity varies smoothly from sounding to sounding. Bedrock resistivities in this area are fairly uniform.

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Gravity Correction Methodology

Traditionally, a three-step methodology is applied to correct gravity data for topographic effects (Bullard, 1936; Nowell, 1999; Hinze et al., 2005). The first step is the Bullard A correction (also known as the simple Bouguer correction) which uses an infinite horizontal slab at the point of each observation to approximate topography. The Bullard A correction is a poor approximation for a highly variable topography as it simply assumes that all geology at a height of *h* above the reference datum (formally mean sea level but more recently the GRS-80 ellipsoid) is composed of bedrock with a constant density ρ_{bed}. It does not distinguish between changes in density and changes in topography.

The second step is the Bullard B correction that takes into account the curvature of the Earth and is important for large survey areas. The Bullard B correction modifies the infinite Bullard A correction to account for the curvature of the earth, resulting in a correction that corresponds to a finite curved cap. The bedrock is assumed to have a constant density ρbed, the same as the Bullard A correction.

The third step is the Bullard C correction (also known as terrain correction) (Figure 3a). The Bullard C correction uses topographic data to calculate the gravitational pull from relief features above or below the datum for distances up to 167 km from the point of observation. The Bullard C correction is applied as an adjustment to the combined Bullard A and B corrections, and it assumes that all changes in topography are due to bedrock and can be modelled using a constant density ρ_{bed}. The Bullard C correction can also account for the presence of significant bodies of water (seas or lakes) provided that bathymetry data is available. The Bullard A, B and C corrections are applied in addition to the conventional airborne gravity corrections that include: instrumental drift, diurnal (Earth tides), latitude, Eötvös, and free-air.

We introduce a fourth correction, the bedrock topography correction, which uses a map based on inverted HTEM depth to bedrock data to correct for the thickness of the overburden (Figure 3b). In Figure 4, the bedrock topography correction is applied to airborne gravity data from our line of interest, and the results are compared to conventionally corrected gravity data.

Discussion

Airborne gravity data from the line of interest were corrected using the Bullard A, B and C corrections (Figure 4, red line). The topography data was obtained from the Shuttle Radar Telemetry Mission (Figure 4, orange line). Finally, the new bedrock topography correction was computed using a 2-layer earth model, where the overburden and bedrock were assigned densities of 1.80 and 2.67 g/cm^3, respectively, and applied to the data (Figure 4, green line). Although the bedrock topography correction has been applied to a single line, it requires the computation of an overburden thickness model over an area to include the impact of the gravitational attraction of material located offline, as is done for the Bullard C correction.

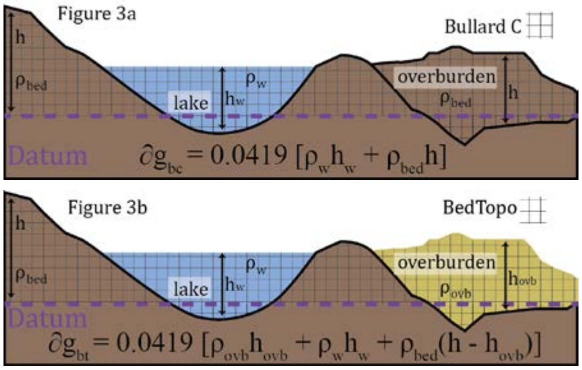

Figure 3. Sketch of a topographic cross-section showing a body of water (blue), overburden (beige) and bedrock (brown). (a) Bullard C correction (δg_{bc}): this correction takes into account variations in topography above the datum, *h*, assuming a constant density ρ_{bed}. Effects caused by the presence of water bodies with a density ρ_w and depth h_w can also be included in this correction. (b) Bedrock topography correction (δg_{bt}): this correction considers the contribution of the overburden with a density ρ_{ovb} and height above datum h_{ovb} as distinct from the contribution of the bedrock.

The agreement between the Bullard corrections (Figure 4, red line) and the new bedrock topography correction (Figure 4, green line) is closest in areas where the overburden is thin. The corrections diverge with increasing overburden thickness. The terrain correction overcompensates in areas where an overburden is present because it assumes that the subsurface is entirely composed of bedrock. An overburden thickness of 300 m or more (such as for the first 8 kilometers along the line) generates significant gravitational responses in excess of 15mGal that will significantly impact the interpretation of the gravity data.

A few cautionary notes about the new methodology must be considered. Firstly, the inversion of HTEM data depends on a layered earth scenario. Inversion results might be adversely affected in geological environments that do not match this model, such as over heterogeneous bedrock, faults, contacts, mines, or conductive mineral deposits. This was mitigated by discarding discrepant data and interpolating across the gaps. The gravity data is of sufficiently large wavelength that local variations in the bedrock topography may be sufficiently well represented based on interpolated values. Secondly, another complication arises from the heterogeneous nature of the overburden. A glaciolacustrine overburden can be

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composed of various amounts of clay, sand, or till and can also quickly change in water content depending on the local terrain and seasonal weather conditions. The current bedrock topography correction that assigns a constant density to the overburden might be too simplistic in some cases and might either over- or under-corrects the gravity data.

The need for correcting airborne gravity gradiometer data for bedrock topography had been recognized by Chen and Macnae (1997). Work by Braine and Macnae (1999) at Elura, Australia, was intended to show that electromagnetic data could be used to estimate thickness and correct gravity data but was not successful. The researchers concluded that the depth of the density contrasts did not correspond to the depth of the conductivity contrasts, that both signals were controlled by different structures within the regolith. They hypothesized that this effect may be due to the mineralizing fluids that created the ore body at the Elura mine.

Conclusion

The case study presented here is a potentially successful implementation of a bedrock topography gravity correction derived from the inversion of HTEM data. The study has shown that data from the AeroTEM III HTEM system can be inverted to determine a reasonable and feasible overburden thickness in the Nechako plateau in British Columbia, provided that the geology matches a layered earth model.

As the acquisition and processing of EM data improve, it may soon be possible to resolve individual layers within the overburden. The next step to gravity corrections would be to create multiple correction grids corresponding to the different layers. In addition, the integration of other sources of geoscientific data could provide the information required to take into account lateral variations in overburden density.

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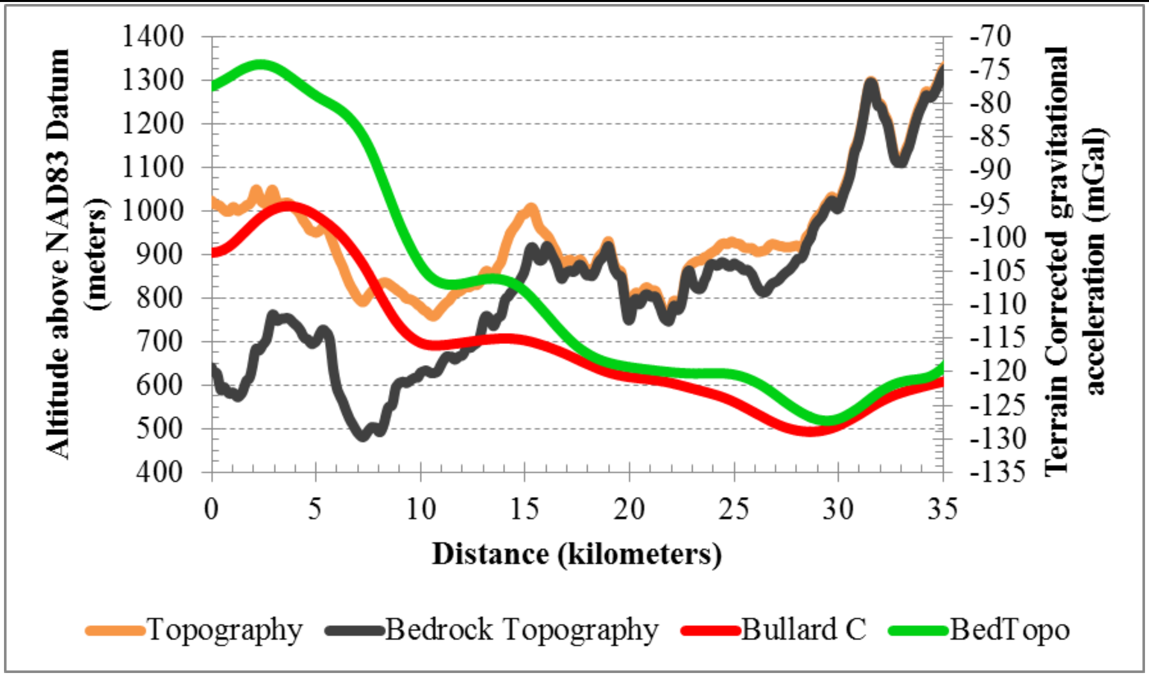

Figure 4: Comparison between the Bullard C terrain correction (red line) and the new bedrock topography correction BedTopo (green line) along an example profile from an SGL AirGrav gravity survey over the survey area. The thickness of the overburden is visible as the space between the bedrock topography (grey line) and the topography (orange line). A Bullard C terrain correction will overcompensate for the presence of bedrock in areas where an overburden is present.

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