Identification of Magnetic Anomalies Caused by Cultural Features

Marta Orta*

Resumen

La Geofísica de Superficie ha encontrado considerables aplicaciones en los últimos años, extendiendo sus estudios hacia trabajos de ingeniería, arqueología, hidrología, e incluso, ayudando al diseño de otros levantamientos geofísicos que, por su complejidad, pudieran ser mas costosos si no se contara con una herramienta para discriminar elementos culturales que pudieran interferir en el buen desenvolvimiento del estudio ó, en el peor de los casos, producir daños sobre obras de ingeniería creadas con anterioridad. Tal situación se manifiesta en las explosiones sísmicas en terrenos que posean ductos soterrados de cualquier naturaleza (acueductos, gasoductos, líneas eléctricas, etc.).

Generalmente este tipo de estudio se ha venido realizando con métodos electromagnéticos. Sin embargo, la introducción de nuevas técnicas tanto en la fabricación de equipos geofísicos y sistemas de levantamiento como en el desarrollo de nuevos algoritmos para el procesamiento de datos, han demostrado la ventaja de utilizar levantamientos de Gradiente Magnético para este objetivo, siendo cuatro veces menos costoso que los levantamientos Electromagnéticos.

El presente trabajo muestra el procedimiento utilizado para la detección de anomlías culturales a partir de un Levantamiento Aeromagnético de Gradiente Vertical de alta precisión.

Palabras Claves: *Geofísica de superficie, Levantamientos de Gradiente Magnético, Gradiente Vertical, Anomalías Culturales, Levantamientos Aerogeofísicos.*

* 144 Cormorant Crescent Vaughan, Ontario Canada, L4H 2K4, e-mail: marta@ortatech.com

Abstract

Near-surface Geophysics has recently found considerable applications, including engineering, archeology, hydrology, environmental and other more complex geophysical surveys. The fact of having a powerful tool to accurately locate and remove cultural elements, which could interfere the results or even attempt previous engineering work such as seismic explosions over terrain with underground pipelines of any nature (water, gas, power-line, etc.), represents a cost saving, enhanced safety and higher quality of the application.

This type of study has been generally performed using electromagnetic methods. However, the introduction of new techniques both in geophysical instrumentation and survey systems, as well as new algorithms development for data processing, prove the use of Magnetic Gradient surveys to achieve this objective, been four times less expensive than electromagnetic surveys.

The purpose of this paper is to present a new procedure of detection of cultural anomalies using a high-resolution Airborne Vertical Gradient survey.

Keywords: *Near-surface geophysics, Magnetic Gradient survey, Vertical gradient, Cultural anomalies, Airborne geophysical survey*.

Introducction

Airborne Magnetic Vertical Gradient surveys have always been taking an important roll both in Oil & Gas and Mineral Exploration, showing a superior mapping and exploration tool. Recently, Near-surface Geophysics is using the gradient measurement to address its applications.

The gradient measurement automatically removes the regional gradient of the earth’s magnetic field and diurnal variations from the data, therefore, the resolution of the local near-surface components is increased. Anomalies produced by near-surface features are emphasized with respect to those resulting from more deeply buried rock formations.

“These may include large metal buildings, pipelines and oil well casings, for example. When the survey relies on detecting and interpreting low order (e.g., 1nT) signatures, due to supra-basement or basement structures, then these cultural features may seriously distort such signatures, and create an erroneous interpretation” (Seigel and McConnell, 1998).

The purpose of this paper is to identify the nature of these features. It will provide a useful tool for a quality interpretation of the resulting data.

Theory

Previous studies related to body magnetic behaviors and acquisition techniques of the measured gradient have already demonstrated the accurate response of the measured gradient by showing the magnetization changes of near-surface bodies. See Hood, 1989 for more details.

The following relation is established to identify the presence of pipes, well heads and other cultural interference in the acquisition process of the measured gradient data.

Given a selected anomaly:

$$FACTOR = RALT * \left(\frac{\delta\Delta T}{\delta\Delta Z}\right)_{max\text{-}min} \Big/ (\Delta T)_{max\text{-}min} \quad (1)$$

Where:

RALT : Flight height

$\frac{\delta\Delta T}{\delta\Delta Z}$: Measured Gradient amplitude

ΔT : Total Field amplitude

FACTOR varies from 1 to 3 depending on the source that is producing the anomaly. The following assumptions are valid.

A **Pipeline**, which is considered a body horizontally extended, mostly produces a magnetic effect represented by a dipole at the position where it is crossed, such as:

$$T \propto 1/R \quad (2)$$

Where:

R: Distance between the point of measurement and the target.

Thereby, FACTOR = 1 identifies the presence of a pipeline.

The strength and character of the signature of a pipeline can change along the length of the pipeline and is dependent upon the direction and level of cathodic protection applied.

The magnetic effect of a long (vertical) string of an oil **well casing** may be represented by a single pole at the top end of the casing, expressed as:

$$T \propto 1/R^2 \qquad (3)$$

Thereby, FACTOR = 2 identifies the presence of a well casing.

A “bulls-eye” type circular anomaly is observed if the survey line is flown over the top of the well head.

Other metal sources with limited dimensions, called as **body**, could represent whether another cultural component or a geological body. It produces a magnetic effect expressed as:

$$T \propto 1/R^3 \qquad (4)$$

Thereby, FACTOR = 3 identifies the presence of such bodies.

The following legend is used to graphically represent the mentioned FACTOR through this paper.

■	Pipeline	(FACTOR = 1)
●	Well Head	(FACTOR = 2)
▲	Body	(FACTOR = 3)

Data Acquistion

Data used in this paper was acquired from the High-Resolutio n Fixed-wing Magnetic Vertical Gradient survey carried out by Scintrex Limited in North Dakota on March 1996. See Figure 1.

Figure 1. Scintrex high, sensitivity magnetic vertical gradient system.

Survey specifications:

Mean terrain clearance:	90 m above ground level (300 feet AGL)
Traverse line spacing:	250 m (820 feet)
Control line spacing:	7800 m (25,590 feet)
Traverse line direction:	N55ºE

The acquisition system has two (2) high-resolution magnetic sensors vertically separated and rigidly installed in an airfoil, commonly called “stinger”, attached to the tail of the aircraft.

Type:	Two (2) Scintrex CS-2 cesium magnetometer sensors.
Vertical separation:	2.22 m
Sensitivity:	0.001 nT (1 pT)
Sample interval:	10 readings / second.

Real-time compensation software Scintrex MEP-2110 is utilized to reduce noise of various magnetic elements, at 0.001 nT resolution, 10 times per second.

GPS controlled NovAtel real-time navigation system is utilized to provide accurate positional information. Including 12 channel receivers installed in the aircraft and base station, this system is capable of providing accuracy of ± 5 meters. Flight lines are monitored, video recorded and differentially corrected afterward.

Radar altimeter with 15 cm resolution and sample interval of 10 readings per second is utilized to register and control flight altitude.

Calibration tests and compensation flights were performed according to survey requirements.

For a more adequate spatial resolution, in order to detect a magnetic source in an airborne vertical magnetic gradient survey, it should be flown at line spacing equal to the distance between the sensor and the top of the magnetic source (Reid, 1980). Unfortunately, the optimal parameters were not used during this test survey. Hence, to avoid the risk of aliasing, only cultural features intersected by the survey line or located ± 45 meters on each side of the survey line, will be detected.

Data Processing

Geosoft OASIS-Montaj is the data processing system employed together with Scintrex proprietary software developed for the applications of new processing techniques, as the case of this paper.

A procedure applied to the geophysical channels involved in the calculation of the FACTOR is presented as follows.

Total Field

Data quality check was accomplished by computing the fourth difference. This technique permits tracking the performance of the magnetometer sensors as well as the noise levels.

As the purpose of this paper is to identify small anomalies even in the order of less than 1nT, it is important not to apply any filter to the raw magnetic data. Manual editing was limited to the occasional elimination of single reading spikes. Gaps created by the elimination of these spikes were filled using an Akima spline interpolation procedure.

A lag correction is applied to account for physical delays (distance between sensors and GPS antenna) and electronic delays (time taken to record the value in the data acquisition system). A value of 0.8 seconds was used. A heading correction is applied to remove DC offsets in the magnetometer data due to aircraft orientation.

Data taken from the lower sensor is utilized to compute the total field amplitude.

Measured Vertical Gradient

As previously mentioned, an advantage of measuring the vertical gradient is the ability to automatically remove the regional gradient of the earth's magnetic field and diurnal variations from the data. However, one of the most impressive advantages of the vertical gradient technique compared to total field measurements is its ability to separate the anomalies produced by two adjacent causative bodies due to the fact that vertical gradient anomalies are narrower than their associated total field anomalies. As shown in Figure 2.

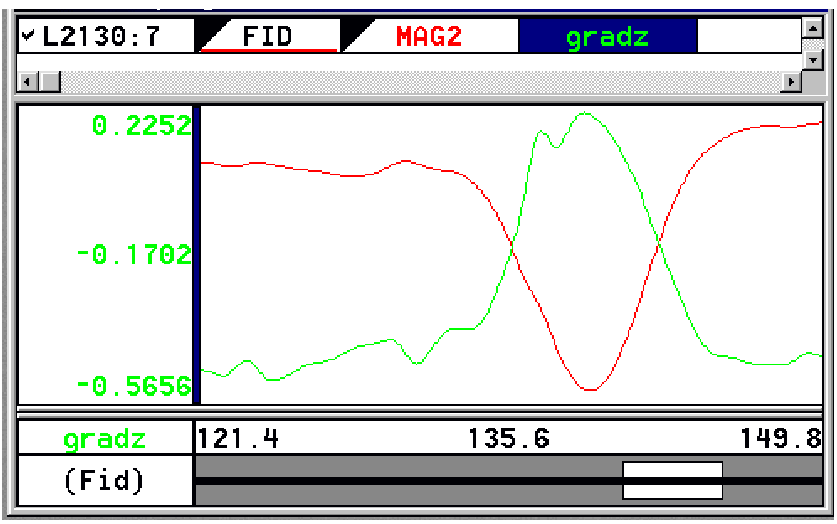

Figure 2. Measured Vertical Gradient (green) showing anomalies narrower than the total field (red) allowing the separation of anomalies produced by two adjacent causative bodies.

Measured Vertical Gradient data (GradZ) depend on the parameters and configuration of the sensors in the aircraft. Using the raw compensated magnetic data, GradZ is obtained by subtracting the lower sensor readings from the upper sensor readings and dividing it by the sensor separation (2.2 meters).

$$\text{GradZ} = (\text{Total Field}_{\text{lower sensor}} - \text{Total Field}_{\text{upper sensor}}) / \text{sensor separation} \quad (5)$$

Ex: 2.22 m

A lag correction of 0.8 seconds is then applied. A band-pass filter is then applied. A certain amount of care must be exercised when preparing a gradient filter because significant resolution will be lost if the filter is too severe. Depending on the aircraft speed of 70 m/sec and the survey altitude of 91.4 m, a short wavelength cutoff value of 1 fiducial and a long wavelength cutoff value of 512 fiducials were respectively applied.

Radar Altimeter

Radar altimeter data should have no spikes produced by any equipment failure or interference. A non-linear filter is applied if it is necessary. In order to avoid removing any real information, a 1.5 second-fiducial filter width with 5% of tolerance is recommended. As radar altimeter data is recorded in feet, if the sensor separation is in meters, the radar altimeter should also be converted into meters.

Analytic Signal

The Analytic Signal will guide the process in recognizing anomalies which will be automatically picked by showing the appropriate Zero Level and the shape of the magnetic field data. It would be applied to the total magnetic field data previously discussed.

"For instance, the main advantage of using the maximum amplitude of the Analytic Signal to determine the location of the structural boundaries is that the result is independent of the earth's magnetic field parameters and of the direction of source magnetization. Such an invariable characteristic is advantageous in magnetic interpretation, especially when the contribution from remanent and induced magneti-zations can not be distinguished." (Shu-Kun *et al.*, 1996).

$$\left|A(x,y)\right| = \sqrt{\left(\frac{dT}{dx}\right)^2 + \left(\frac{dT}{dy}\right)^2 + \left(\frac{dT}{dz}\right)^2} \quad (6)$$

Where,

A(x,y):	represents the amplitude of the analytic signal at (x,y)
T:	is the observed magnetic field at (x,y)
dT/dx:	represents the horizontal longitudinal gradient, along the survey line
dT/dy:	represents the horizontal transverse gradient
dT/dz:	represents the vertical gradient

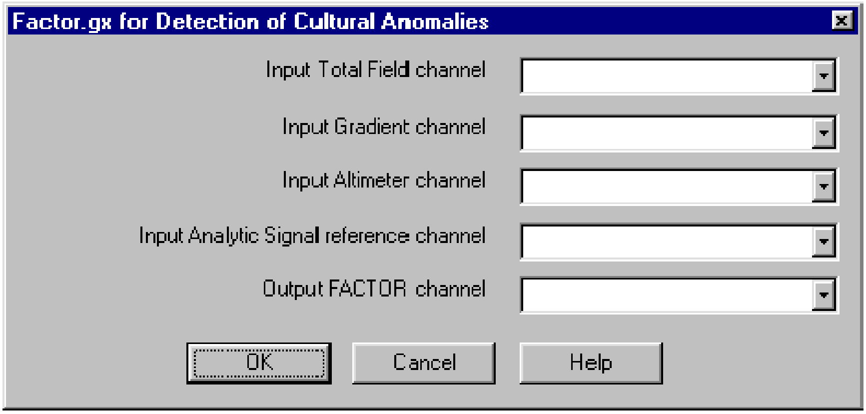

Figure 3. Factor.gx runs in Geosoft Oasis/Montaj.

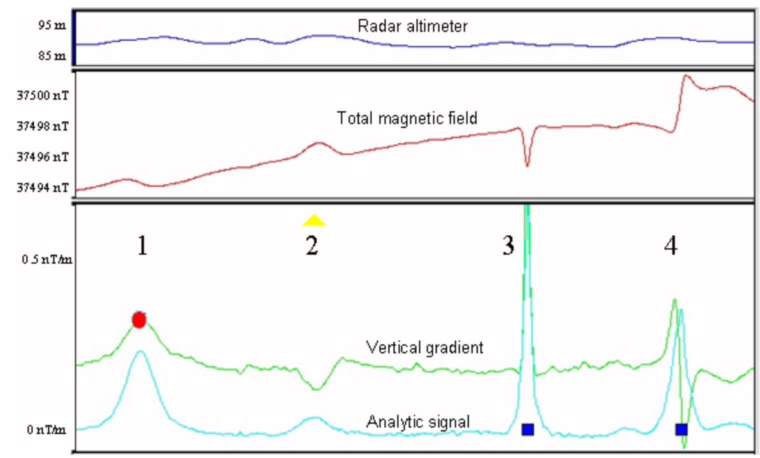

Figure 4. Multi-parameter graphic profiles showing a correlation between the Analytic Signal (cyan) and the Measured Vertical Gradient (green, in the lower panel), the Magnetic Field (red, in the middle panel), the Radar Altimeter (blue, in the upper panel) and the cultural anomalies detected by FACTOR (see legend).

The Analytic Signal can be calculated applying the formula directly into a data-base. In such case dT/dz will be substituted by the measured vertical gradient data, channel GradZ. Taken into account the advantage of measuring the vertical gradient, mentioned above, this solution represents a better approach to the algorithm. The Horizontal gradients dT/dx and dT/dy could be then calculated using the convolution filter FILTER.GX.

A low-pass fliter is recommended to apply over the calculated analytic signal, in order to avoid picking the same point in the selection process.

Software Overview

The software, developed by Scintrex Limited, was written as a Geosoft eXecu-table function (GX) to run under Oasis/Montaj. FACTOR.GX applies the formula described as (1), assigning values of 1, 2 and 3 as it identifies and classifies the magnetic sources. Figure 3 shows the interface of FACTOR.GX.

FACTOR values are calculated as a function of the measured vertical gradient, the total magnetic field and the sensor height. The ability of the Analytic Signal of showing the center of the body in its maximum amplitude is used to identify the potential target and classify its source.

Profile views are generated showing the location of the classified sources relative to the flight lines. Figure 4 shows a sample of the procedure mentioned above.

Figure 4 shows multi-parameter graphic profiles taken from one of the flight line of the High-Resolution Fixed-wing Magnetic Vertical Gradient survey previously described. Note the aircraft performance by maintaining a flight altitude of 90±2 meters. The Total Magnetic field exposes variations from detected cultural components. The measured Vertical Gradient confirms its accuracy by enhancing the effect of shallow micro-magnetic anomalies produced by the mentioned components. Note how the Analytic Signal is mapping the center of each component in its maximum amplitude.

The procedure described in this paper detected several cultural components such as the well head mentioned as 1, an unknown body mentioned as 2, and two pipelines as 3 and 4. As noted from the profile shape, pipelines behave different. It could be due to several causes, including the direction that the survey line is intersecting the pipeline, the material used in the construction of the pipeline, the presence of cathodic protection, and the contribution from other magnetic sources in the immediate area of the pipeline, among other causes.

Conclusions

- Direct delineation of Pipelines, oil Well casing and other cultural interference achieved in the data acquisition process. The discrimination of anomalies due to natural or artificial sources is enhanced by plotting these results in profile form.

- The Measured Vertical Gradient technique has the advantage of separating the anomalies due to two adjacent causative bodies as of compared to total field measurements. This advantage provides better aid in the support of geological mapping than the more conventional total field results.
- This technique is also recommended for Oil & Gas exploration due to its possibility of accurately defining near surface structures and detection of shallow micro-magnetic anomalies which are characteristic of hydrocarbon micro-seepages that overlie the petroleum deposits.
- The methodology introduced in this paper can be applied both for vertical gradient maps useful in areas where contact zones are near vertical, such as Precambrian meta-volcanic areas, and for horizontal component mapping useful in granitoid areas which often have shallow dipping contacts. This is because of the application of the Analytic Signal as mathematical element evaluated from the vertical and horizontal component derivatives.

The basics of the procedure presented in this paper have been successfully implemented in several configurations and acquisition systems to accommodate the needs of each project, such as Environmental, Seismic (McConnell *et al.*, 1999) and Geological Interpretation (Berger *et al.*, 1999).

Recomendations

According to the survey purpose, several sensor configurations can be implementted. Both the sensor mounting and the position of the sensors on the aircraft are important in achieving acceptable noise levels when collecting survey data.

For higher accuracy, a Three-dimensional triangular configuration of the sensors is recommended, allowing measurements from both vertical and horizontal gradients. Cylindrical features located along a flight line are significantly detected only by the horizontal gradient.

A Four-dimensional cross shape sensors configuration is also an option of measuring each gradient independently; with the inconvenience of increasing survey costs due the presence of a fourth sensor.

The use of a geodetic quality differential GPS positioning system is recommended to properly locate components (natural and/or cultural), allowing high quality results.

For more detailed mapping at the prospect level, the use of High-resolution Helicopter system is strongly recommended, allowing maneuvers over rugged mountain terrain while maintaining a constant flight altitude.

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