# Depth estimating Full Tensor Gravity data with the Adaptive Tilt Angle method


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## SUMMARY

Depth estimation procedures for potential field data are well recognised techniques. Both Euler and Werner methodologies are typically used as a series of automated steps and applied to both gridded and profile data. The Tilt Derivative Depth method works on gridded data and has been used extensively on magnetic data. Its advantage is its ability to produce a focused set of solutions and is now being commonly adopted for potential field data.

This paper describes an Adaptive Tilt Angle method for depth estimating Full Tensor Gravity data. The method is an adaptation of the Tilt Derivative depth estimation procedure adopted for magnetic data.

The procedure works on 4 of the independently measured Tensor components and produces sets of solutions that are more easily interpreted. The tilt angle method is defined as a ratio of the Tensor components in each of the X, Y and Z directions and assumes a vertical contact geological setting. The implementation of a scaling factor allows the technique to work on horizontal contacts. The scaling factor is essentially similar to the concept of a Structural Index as used with Euler depth estimation methods.

The technique was tested successfully on an Air-FTG® survey data set over a shallow salt feature onshore USA and is now being routinely deployed. The benefits of the direct depth estimation technique are immense in that it not only provides constraint on other interpretative processing techniques, but quickly establishes a starting depth model for any detailed forward / inverse modelling exercises.



**Key words:** FTG, Gravity, depth estimation


## INTRODUCTION

Full Tensor Gravity (FTG) data are routinely acquired aboard airborne and marine vessels for exploration programs worldwide (Murphy, 2010). The high precision, highly accurate measurements of the gravity field are achieved by direct measurement of the Gravity Tensor components, Txx, Tyy, Txy, Tzx and Tzy.

Murphy and Dickinson (2009) describe the usage of an Invariant Analysis performed on these measured Tensor components that extracts detailed information related to sub-surface geology. Their methodology exemplifies the advantage Tensor measurements have in not only direct imaging of geological contact information but also of targeted prospective geology. However, such interpretational procedures are chiefly restricted to qualitative reasoning and do not offer significantly to determining an anomalous response's depth.

Depth estimation techniques for potential field such as Euler and Werner methods are well established and have more commonly been applied to conventional gravity and magnetic data, but little has been published for FTG data. Zhang et al (2000) and Mikhailov et al (2007) adopted the Euler method for Tensor Gravity data, but their application tends to be rather restricted in that generated solutions are numerous and unfocussed. Automated inversion procedures have also been developed (Zhadanov, 2004), but the method is not simple and benefits most with some initial constraint.

The method described in this paper is the Adaptive Tilt Angle Depth method described by Salem et al (2011) and how it is used for FTG data. The procedure is an adaptation of Salem et al's (2007, 2010) Tilt Angle approach for depth estimating magnetic data. The procedure makes usage of a ratio of the derivatives of the field in each of the X, Y and Z directions, or in the case of FTG data, it works directly with the Tzz, Tzx and Tzy components. As Tzz is the negative sum of Txx and Tyy (Murphy 2010), then the procedure works with 4 of the measured FTG components. The method enables accurate estimation of the X & Y position of both vertical and horizontal targets and their corresponding depth.

The procedure is first described and then a working example is presented. Air-FTG® data from a survey onshore USA will be used. The results correlate remarkably well with known drill results from the area.

The benefits of the procedure are its rapid ability to produce detailed sets of focussed solutions that lead to a more enhanced workflow for integrating FTG data into ongoing exploration programs.

## ADAPTIVE TILT ANGLE DEPTH ESTIMATION

Verduzco et al (2004) defines the Tilt Angle for potential field data as:

$$\theta = \tan^{-1}\left[\frac{f_z}{\sqrt{f_x^{\,2} + f_y^{\,2}}}\right]$$

where, $f_x$, $f_y$ and $f_z$ are the derivatives of the field $f$ in the $x$, $y$ and $z$ directions.

Salem et al (2011) defines the Adaptive Tilt Angle as:

$$\theta_a = \tan^{-1}\left[a\frac{T_{zz}}{\sqrt{T_{zx}^{\,2} + T_{zy}^{\,2}}}\right]$$

Where $a$ is a value characterising the source type. It is, in essence, a structural index like that adopted for Euler Deconvolution methods. A value of $a$ = 3 is selected for 3D shaped targets, such as spheres and point masses, where as $a$ = 1 is used for 2D structures such as linear structures, vertical and horizontal sheets. $T_{zz}$, $T_{zx}$ and $T_{zy}$ are the measured FTG components that are derivatives of the gravity field in each of the $x$, $y$ and $z$ directions.

Using the above, the following equations are derived for estimating the location and depth of simplified geometric targets from FTG data:

$$\theta_a = \tan^{-1}\left[\frac{2z_0^{\,2} - h^2}{z_0|h|}\right]$$ for a point mass ($a$ = 3),

$$\theta_a = \tan^{-1}\left[\frac{z_0^{\,2} - h^2}{2z_0|h|}\right]$$ for a horizontal line of mass ($a$ =1),

$$\theta_a = \tan^{-1}\left[\frac{z_0}{|h|}\right]$$ for a vertical sheet ($a$=1), and

$$\theta_a = \tan^{-1}\left[\frac{h}{z_0}\right]$$ for a horizontal sheet (a=1)

Where $h$ is the horizontal distance from the source and $z_0$ is the depth to the source. To check the consistency of the derived equations, we calculated vertical tensor gravity data over a sphere, horizontal line of mass, vertical sheet and horizontal sheet. All models were placed at a depth of 5 km. Adaptive tilt angles were calculated from the vertical tensor components and are displayed in Figure 1.

For the sphere, horizontal line of mass, and vertical sheet models, the horizontal position of the source ($h$=0) can be obtained at the location of the adaptive tilt angle of $90^0$. Only the location of the horizontal sheet model is associated with the zero adaptive tilt angle. For sphere and vertical sheet, the depth can be obtained by measuring the distance between the $90^0$ and $45^0$ adaptive tilt angle values (h= $z_0$). For the horizontal line of mass, the depth is estimated between the $90^0$ and $45^0$ adaptive tilt angle values (h= $z_0$). For the horizontal sheet model the depth is estimated between values of $0^0$ and $45^0$ of the adaptive angle similar to the vertical contacts from magnetic data Salem et al (2007).

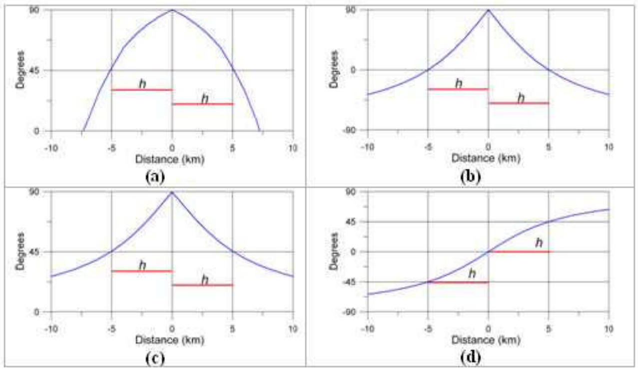


**Figure 1. Adaptive tilt angle calculated from vertical tensor gravity data over simple gravity models (a) sphere, (b) horizontal line of mass, (c) vertical sheet, and (d) horizontal sheet.**

## DEPTH ESTIMATION OF FTG DATA

The depth estimation procedure is tested on an Air-FTG® data set acquired over the Vinton Dome salt feature from onshore Louisiana, USA (Figure 2). The airborne FTG data were flown with N-S flight lines with a spacing of 150 m at an average altitude of 75 m. The data were enhanced by band pass filtering all components between 500 m and 2500 m spatial wavelengths. The advantage of the filtering process is to better capture the signal associated with the salt body hosting the high density cap rock (Dickinson et al., 2010). Figure 2 shows the filtered vertical tensor gravity components ($T_{zx}$, $T_{zy}$, and $T_{zz}$) and the computed adapted tilt angle with $a$ =1. The components $T_{zx}$ and $T_{zy}$ identify the NS and EW edges of the cap rock respectively and the $T_{zz}$ shows the overall shape and structure of the high density cap rock near the centre of the dome. The zero contours of the adaptive tilt angle display both the boundaries of the cap rock and the salt features, including enhancing structures at the margins of the salt dome.

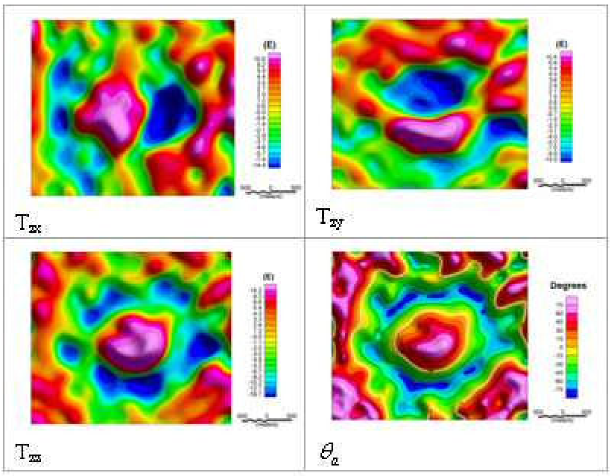


**Figure 2. $T_{zx}$, $T_{zy}$ and $T_{zz}$ component data and adaptive tilt angle for the Vinton Dome survey.**

Figure 3 shows the estimate of the depth from the adaptive tilt method assuming the source model is a horizontal sheet ($a$=1). The southern part of the interpreted cap rock is shallow (180 to 210m) with respect to the northern part (about 280 to 300m). Also the depth estimates show the interpreted cap rock is characterised by an approximately flat surface in the E-W direction with an average depth of 300 m from the surface.

The overall relief of the interpreted cap rock agrees very well with drilling information (Thompson and Eichelberger, 1928). The depth of cap rock at the southern part of the Vinton Salt dome is about 200 m and deepens farther to the north to reach 315 m. Along the E-W direction, the relief of cap rock is generally flat with an average depth of 320 m.

The agreement between the depth results and drilling information supports the use of a horizontal sheet model and adaptive tile value of 1 for this example.

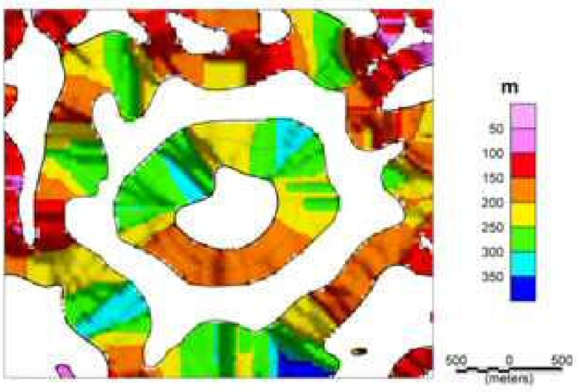


**Figure 3. Depth estimate map for FTG data over the Vinton Dome cap rock.**

## CONCLUSIONS

The Adaptive Tilt Angle depth estimation method is a viable method for depth estimating FTG data. The procedure works directly on 4 of the 5 independently measured tensor components. The estimated solutions are focussed and allow a high degree of confidence in their accepting their validity. The estimated depths predicted for the Air-FTG® Vinton Dome survey are supported by drilling results.

The methodology as presented is fast computationally and only requires the FTG component data as input. The generated solutions facilitate a fast track depth estimation on anomalous sources serving to enhance any exploration program. An added benefit of the method's accuracy is that generated solutions can be used as an initial constraint in any integrated forward/inverse modelling exercises involving FTG and other geophysical data.

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