Target delineation using Full Tensor Gravity Gradiometry data

Colm A. Murphy
Bell Geospace Limited
Aberdeen UK
cmurphy@bellgeo.com

James Brewster
Bell Geospace Inc.,
Houston USA
jbrewster@bellgeo.com

SUMMARY

FTG Gravity data acquired on airborne and marine platforms measure 5 independent Tensor components that collectively describe a total gravity field. The components capture unique signature patterns related to specific attributes of target geology that when collectively interpreted enable detailed imagery of the target itself in terms of geometry, composition and depth of burial.

The horizontal tensor components Txx, Tyy, Txy, Txz & Tyz are commonly used to identify and map lineaments associated with structural and / or stratigraphic changes or target geometry in a survey area. The vertical tensor component, Tzz, is used to estimate depth and predict compositional information related to target geology. However, these components have traditionally been interpreted separately from one another and often run the risk of missing out on key information.

This paper describes application of a semi-automated approach that combines the individual components into singular representations to best extract the signature pattern common to all components as revealed by the underlying geology. The examples presented are taken from an Air-FTG® survey onshore Brazil to image the structural framework and identify target geology ahead of a seismic programme, and a Marine-FTG® survey offshore Norway to resolve salt body geometries imaging areas of overhang development.

The resultant interpretation enables the end-user to fast-track the exploration initiative by quickly evaluating target geology for detailed follow-up.

Key words: FTG, Gravity, Imaging, Structural geology, Salt.

INTRODUCTION

Full Tensor Gradiometry (FTG) is a multicomponent gravity surveying technology that measures different components of the Gravity Gradient Tensor (Murphy, 2004) on both marine and airborne platforms. Individual Tensor information can each be related to geological attributes be they defining edges of geological bodies or mapping geological contacts (horizontal component information) or defining depth / isopach / density relationships of a body mass in relation to its geological setting (with the vertical component, Tzz). The impact of working with tensor information can be significant in that it facilitates a mechanism to not only identify target geology but also map its geological setting across any survey area.

Murphy *et al* (2005) describe a procedure for working with FTG Gravity data. They make use of conventional potential field techniques such as wavelength filtering to extract signature patterns arising from the underlying geology. The advantage of such an approach is to isolate common signature patterns arising from the same geological sources from each component. However, the approach fundamentally fails as each Tensor component is treated as a separate individual data set and not as part of the same Gravity field. The danger here is the increased likelihood of not being able to see the full picture and lead to misinterpretation of a signature pattern not common to all data sets.

A more accurate means of working with Tensor components is to treat them as a collective entity. One such method is that first described by Pedersen and Rasmussen (1990). They describe a procedure that combines all Tensor components using Invariance to isolate signature patterns emerging from underlying geology. Murphy (2007) uses the same concept to directly work with the horizontal component information to isolate signature patterns arising from geological contacts. In this paper, we will present an additional technique that determines geologic strike direction along such FTG lineaments.

Two examples will be used to demonstrate the advantages of using the Tensor components simultaneously for interpretation. The first is that described by Murphy (2007) (Figure 1) which is a Marine-FTG® survey acquired offshore Norway and the second an Air-FTG® survey from onshore eastern Brazil (Figure 2).

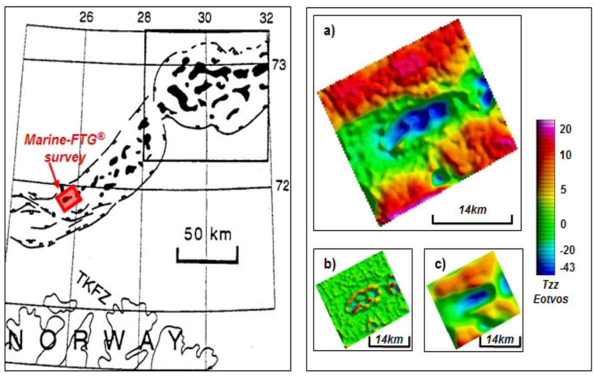

Figure 1. Marine-FTG® data from the Nordkapp Basin (Murphy et al 2002). Inset shows the Bouguer corrected Tzz (a) and wavelength filtered images of Tzz for b) less than 5km and c) 5 to 30km spatial wavelengths.

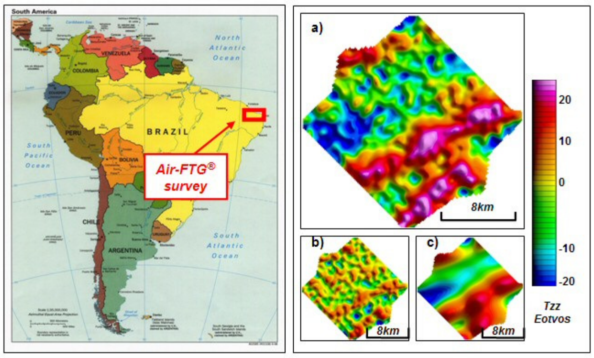

Figure 2. Air-FTG® data from an onshore survey for Aurizonia Petroleum. Inset shows the Terrain Corrected Tzz (a) and wavelength filtered images of Tzz for b) less than 6km and c) greater than 6km spatial wavelengths.

The benefit of such a combined interpretation procedure promotes rapid assessment of survey data to isolate target geology.

METHODOLOGY

Pedersen and Rasmussen (1990) describe the usage of Invariance to compute new tensor representations from Gravity and Magnetic Tensor components. They describe 2 sets of combinations that make use of all components simultaneously. The impact of the resultant computation is that the anomalous signature pattern is independent of the observer's choice of axes. The 2 combinations are:

$$I_1 = \sqrt{(T_{xx}T_{yy}+T_{yy}T_{zz}+T_{xx}T_{zz})-(T_{xy}^2+T_{yz}^2+T_{xz}^2)}$$
$$I_2 = ((T_{xx}(T_{yy}T_{zz}-T_{yz}^2)+T_{xy}(T_{yz}T_{xz}-T_{xy}T_{zz})+T_{xz}(T_{xy}T_{yz}-T_{xz}T_{yy}))^{1/3}$$

I_1 facilitates mapping gross regional stratigraphy across survey areas identifying dominant density contrasts, whereas I_2 concentrates on 3D shaped anomalous targets. This makes it useful for mapping fault block geometries, salt bodies and igneous intrusives directly from FTG Gravity data.

Murphy (2007) describes an Invariance approach that works with the horizontal component data only. He describes 2 equations:

$$InVar\_T_{xz}T_{yz} = \sqrt{(T_{xz}^2+T_{yz}^2)}$$
$$InVar\_T_{xy}T_{xx}T_{yy} = \sqrt{(T_{xy}^2+((T_{yy}-T_{xx})/2)^2)}$$

The advantage here is the anomalous expression's independence of the vertical axis only, thus increasing confidence of mapping geological contact information with depth. The best result is obtained by combining the results of both through direct comparison with the original Tzz anomaly field, where a positive trend in $InVar\_T_{xz}T_{yz}$ correlating with a negative linear trend in $InVar\_T_{xy}T_{xx}T_{yy}$ maps an anomalous edge in Tzz.

The impact of these 2 techniques is an improved method for mapping subsurface geology in FTG Gravity data in a qualitative way. Quantitatively, these equations can be resolved into a different form. The result is a measure of the strike angle the lineaments identify from sub-surface geology.

Pedersen and Rasmussen (1990) derived a formula for estimating the strike direction from a Gradient Tensor:

$$tan2\theta_s = 2\frac{T_{xy}(T_{xx}+T_{yy})+T_{xz}T_{yz}}{T_{xx}^2-T_{yy}^2+T_{xz}^2-T_{yz}^2}$$

The expression is obtained by rotating the coordinate system about a vertical axis so as to minimize the sum of squares of the three tensor components that involve a derivative in the x-direction. A qualitative argument for equating this to the strike direction can be made based on the sense that this is the direction in which the field is changing the least rapidly.

The above method yields an estimate of θ_s at every observation location. The estimated strike directions at each point are assessed based on their geological significance and continuity along line with a simple rule of thumb that if 2 estimated strike directions at 2 observation points on neighbouring survey lines match the angle of the vector connecting them within a pre-defined threshold (say 10 degrees), then the 2 points are joined together to form a segment of a lineament. If more than 4 points can be joined then the resulting lineament line is drawn on the map.

APPLICATION

Figure 1a shows the Bouguer corrected Tzz image for a known salt feature offshore Norway. The anomalous low in the centre of the survey data corresponds to the salt body. Figures 1b and 1c demonstrate the complex structure of the salt body where a multi stalk salt body geometry was proposed by Murphy *et al (*2002).

Figure 3a shows the I_1 and I_2 Invariant Tensors computed using the Pedersen and Rasmussen (1990) technique. The images highlight the distribution of the dominantly lower density salt body comprising 4 prominent density lows within the centre. These are interpreted as areas of thickened salt development forming sub-salt stalk structures.

Figure 3b shows a plot of the lineaments identified using the Murphy (2007) technique grey shaded on an image of the Bouguer corrected Tzz. The lineaments directly image the edge of salt with an outer rim locating the edge of the salt canopy and the inner rim defining a deeper edge of salt. The darkened shading between the outer and inner salt rims is predicted as an area of overhang development. Supporting evidence for this are the presence of similar overhang geometries on neighbouring salt bodies (Murphy *et al* 2002).

Figure 2a shows a Terrain Corrected Tzz anomaly field for the Air-FTG® survey data acquired for Aurizonia Petroleum in eastern Brazil. The survey was designed ahead of a seismic acquisition program to identify key geological structure at depth beneath low lying mudflats. Figures 2b and 2c separate the long wavelength signature pattern associated with basement from the shallow more complex geology.

Figure 4 shows a plot of the strike direction estimates using the technique presented in this paper for each filtered image. The underlying basement shows a dominant NE-SW orientation whereas both WNW and ENE trending lineaments are evident in the high frequency image. These are interpreted as overlying cross cutting faults compartmentalising key target horizons.

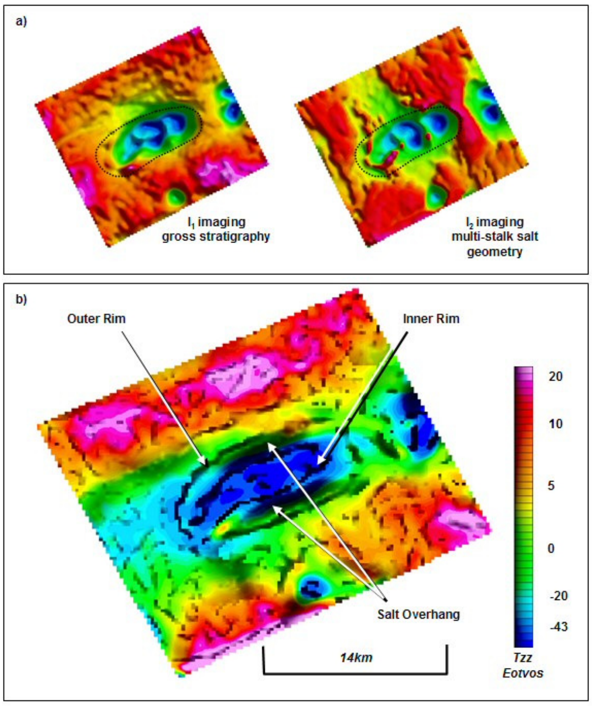

Figure 3. Invariant computation for Marine-FTG® data. I_1 and I_2 are shown on top; lineament plots (grey shade) on Bouguer Corrected Tzz bottom.

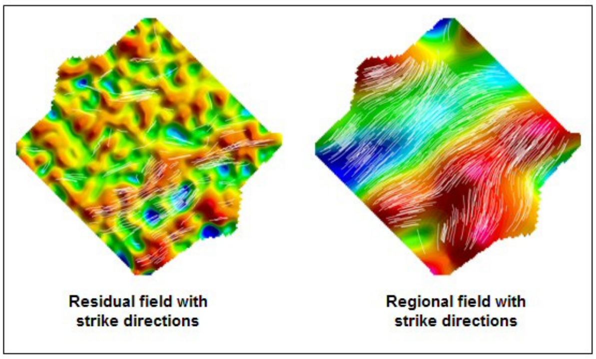

Figure 4. Plot of estimated strike directions from lineaments generated for terrain corrected Air-FTG® data. Residual field (left) shows more ENE to WNW orientation; Regional field (right) shows dominantly NE orientation.

CONCLUSIONS

Innovative interpretation techniques for working with FTG Gravity data have been discussed in this paper. The key advantage of such an approach is its inherent ability to extract signature patterns common to all components. Such anomalous patterns are attributable to sub-surface geology. Individual combinations (Murphy 2007) promote increased confidence when mapping key lithological and structural contacts at depth or estimating changes in sub-surface strike directions (this paper).

This combination of all or some Tensor components from the Gradient Tensor represents a novel approach for interpreting FTG Gravity data. It enhances any exploration initiative providing a mechanism to fast track identification of key anomalous signature patterns in the Targetting stage.

ACKNOWLEDGMENTS

Statoil ASA, Norsk Hydro and Gaz de France are acknowledged for their permission to show the Marine-FTG® data; Aurizonia Petroleum for the Air-FTG® data.

REFERENCES

Murphy, C. A., 2004, The Air-FTG® airborne gravity gradiometer system. In R.J. Lane, editor, Airborne Gravity 2004 – Abstracts from the ASEG-PESA Airborne Gravity 2004 Workshop: *Geoscience Australia Record* 2004/18, 7-14.

Murphy, C. A., 2007. Interpreting FTG Gravity data using horizontal Tensor components: EGM 2007 International Workshop – Innovation in EM, Grav and Mag methods: new Perspective for Exploration.

Murphy, C.A., Mumaw, G.R., Fotland, B., and Sollid, K., 2002, Utilising FTG data to resolve salt development in the Nordkapp Basin offshore Norway: 64th Meeting, EAGE, Florence, Expanded Abstracts, D006.

Murphy, C.A., Mumaw, G.R., and Zuidweg, K., 2005, Regional target prospecting in the Faroe Shetland Basin area using 3D FTG Gravity data: 67th Meeting, EAGE, Madrid, Expanded Abstracts, P503.

Pedersen, L.B., and Rasmussen, T.M., 1990, The gradient tensor of potential field anomalies: some implications on data collection and data processing of maps: Geophysics, 55, 1558-1566.