

Imaging Techniques for Full Tensor Gravity Gradiometry Data

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ABSTRACT

Full Tensor Gravity Gradiometry has previously been demonstrated to be an effective tool in both the minerals and oil and gas industries. Full tensor data is a richer source of information than standard single tensor gravity. This extra information can be used by tensor imaging techniques to enhance target anomaly definition.

These imaging techniques include the use of rotational invariants, lineaments, strike angles and tensor coordinate rotations. The correct application of these techniques improves the interpretability of the data.

This paper describes the application of these techniques to a hydrocarbon example in the Barents Sea.

Key words: FTG, Gravity, Imaging, Lineaments, Invariants

INTRODUCTION

Full Tensor Gradiometry (FTG) is a multi-component gravity surveying technology that measures different components of the Gravity Gradient Tensor (Murphy, 2004). This system has been demonstrated to be effective on both airborne and marine platforms. The system can be utilised in both the minerals and oil and gas sectors for target prospecting. Information in the individual tensor components can be related to geological attributes including edges defining a structural trap or isolated ore bodies.

This study presents the value of full tensor techniques for both minerals and hydrocarbons projects and will use a survey acquired offshore Norway as an example.

The dataset underwent the following data preparation: levelling of FTG data, full tensor noise reduction, and appropriate bathymetry corrections.

METHOD

Rotational Invariants

Pederson and Rasmussen (1990) introduced the use of the Rotational Invariants. Murphy & Brewster (2007) demonstrated the application of this technique to FTG data. Invariant imaging techniques exploit the full tensor in order to enhance features not easily identified in single tensor component data. These representations are

independent of the observer's axis of choice. The two representations are:

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

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

I_1 is used in regional scale mapping exercises and pulls out dominant regional density trends. I_2 highlights the 3D shape of anomalous targets. This is particularly useful for mapping fault block geometries and igneous intrusives.

Horizontal Invariant Lineaments

The horizontal invariants can be used to map linear features within the FTG data, resulting in an effective edge mapper.

This technique uses the invariants described by Murphy (2007). The application of this method to FTG data is described in Murphy & Brewster (2007). The horizontal components are represented as follows:

$$\ln Var_{T_{xz}T_{yz}} = \sqrt{(T_{xz}^2 + T_{yz}^2)} \quad (3)$$

$$\ln Var_{T_{xy}T_{xx}T_{yy}} = \sqrt{(T_{xy}^2 + ((T_{yy} - T_{xx})/2)^2)} \quad (4)$$

Where a negative anomaly in one of the invariance grids it corresponds to a positive anomaly in the other, an associated edge in the terrain corrected T_{zz} grid is mapped.

Strike Lineaments

Pederson and Rasmussen described a technique in their 1990 paper for the calculation of strikes from tensor data. This method utilises the full tensor in the following way, where θ represents the strike angle.

$$\tan 2\theta_s = 2 \frac{T_{xy}(T_{xx} + T_{yy}) + T_{xz}T_{yz}}{T_{xx}^2 - T_{yy}^2 + T_{xz}^2 - T_{yz}^2} \quad (5)$$

This technique produces strike directions which are used to identify linear features in the gravity field. Neighboring consistent strike directions within a defined tolerance are chained together to form lineaments.

Strike angles produced from these calculations can be used to produce extra geological information. For example these can be used to generate a rose diagrams to show the dominant trends in the area.

Tensor Rotation

FTG data is typically rendered in a fixed coordinate frame such as North-East-Down (NED). This is largely an arbitrary choice used to conform to mapping conventions. Many geological scenarios are better served using alternative coordinate frames.

By recomputing the tensor components with a different reference frame we can align the primary axes of the tensor with underlying geology. This can produce enhanced imaging of target features.

The underlying transformation of the tensor is a relatively simple process. This means that the process can be performed in near real-time for small or medium sized data sets. By evaluating these coordinate rotations visually, the interpreter can select a transformation, which optimally images the target features.

Once a coordinate transformation has been selected a full set of tensor components can be calculated for further processing.

$$T_{xz}' = T_{xz} \cos \theta + T_{yz} \sin \theta \quad (6)$$

$$T_{yz}' = -T_{xz} \sin \theta + T_{yz} \cos \theta \quad (7)$$

$$T_{yy}M_{xx} = (T_{yy} - T_{xx})/2 \quad (8)$$

$$T_{xy}' = T_{xy} \cos 2\theta + T_{yy}M_{xx} \sin 2\theta \quad (9)$$

$$T_{yy}M_{xx}' = -T_{xy} \sin 2\theta + T_{yy}M_{xx} \cos 2\theta \quad (10)$$

$$T_{xx}' = -\frac{T_{zz}}{2} - T_{yy}M_{xx}' \quad (11)$$

$$T_{yy}' = -T_{zz} - T_{xx}' \quad (12)$$

Where theta is the angle of rotation about the down axis. The data shown in Figures 1 and 2 were derived from an artificial model of a faulted tilt block structure. Figure 1 shows the Txz response in the standard NED coordinate

frame. The shape of the structure is apparent, but slightly undefined at the edges.

Figure 2 shows the same data set with a rotated tensor coordinate frame. Again Txz is shown, but with a rotation of 45 degrees about the Z-axis applied. This has aligned the X-axis in the Txz component with an axis of interest in the underlying data. This provides clearer imaging of the edge details of the feature.

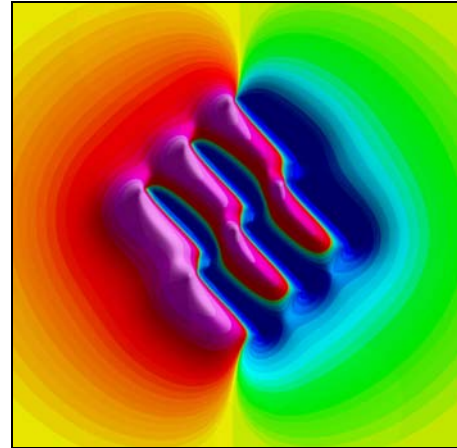


Figure 1: Txz Response of Faulted Tilt Block in Standard NED coordinate system

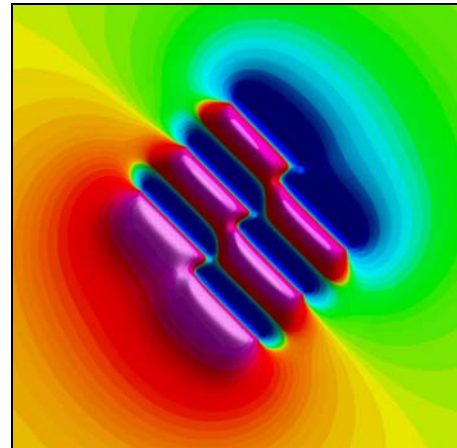


Figure 2: Txz Response of Faulted Tilt Block in a rotated tensor coordinate system of 45degrees about the Z-axis

APPLICATION

These techniques can be used for both mineral and oil and gas targets. Data examples shown here are from a hydrocarbon survey in the Barents Sea.

Rotational Invariants

Figure 3 shows the bathymetry corrected Tzz data filtered for wavelengths 1-30km; the data shows a salt body. The filtered response highlights dominant signature patterns associated with these features.

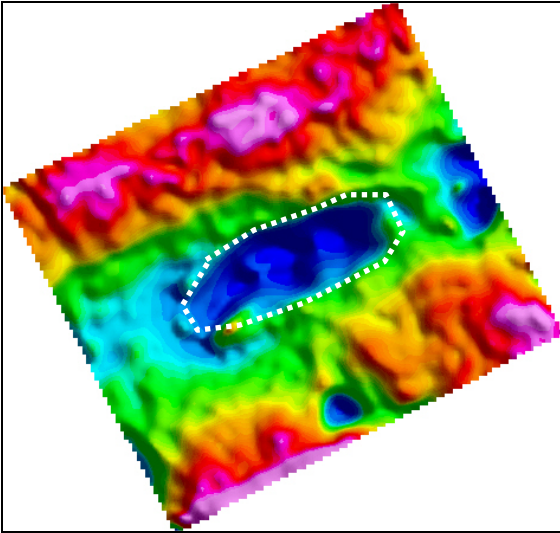


Figure 3: Bathymetry corrected Tzz filtered for 1-30km

On the Rotational Invariant, I_2 , grid (Figure 4) the salt is still present but additional structure can be identified. In particular there are body is broken in to 4 main sections. These are thought to be salt stalks. This technique suppresses background long wavelengths; focussing on isolated features rather than linear features.

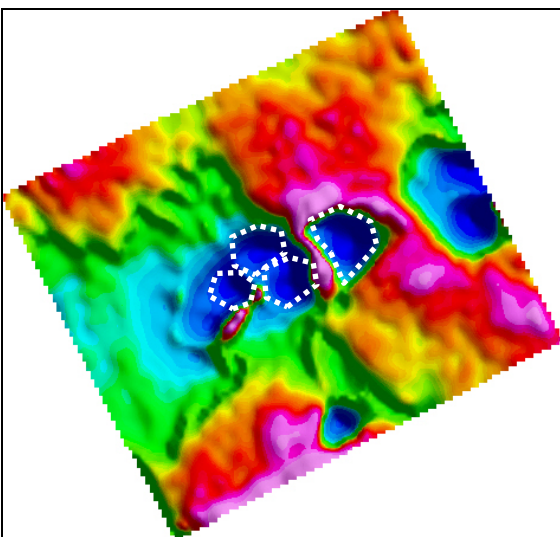


Figure 4: Rotational Invariant 2 (I_2) filtered for 1-30km

Horizontal Invariant Lineaments

Figure 5 shows the Horizontal Lineaments, because this is created using only the horizontal components it is independent of the z-axis. The colour scale is an indication of the intensity of the density contrast between two stratigraphic or structural units. Magenta and red indicate a high density contrast whereas greens and blues indicate a lower density contrast.

This reveals further information about the extent and structure of the salt body, showing potential overhangs with the outer and inner boundaries.

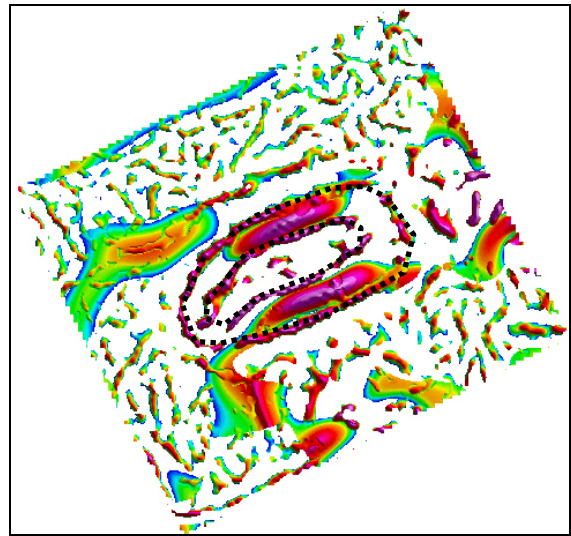


Figure 5: Horizontal Lineaments filtered for 1-30km

Strike Lineaments

Strike directions are calculated from the filtered bathymetry corrected data using equation 5. Figures 6 and 7 show the Strike Lineaments for this dataset. These illustrate the dominant geological signature of the area. These lineaments can be seen to wrap around the salt structure.

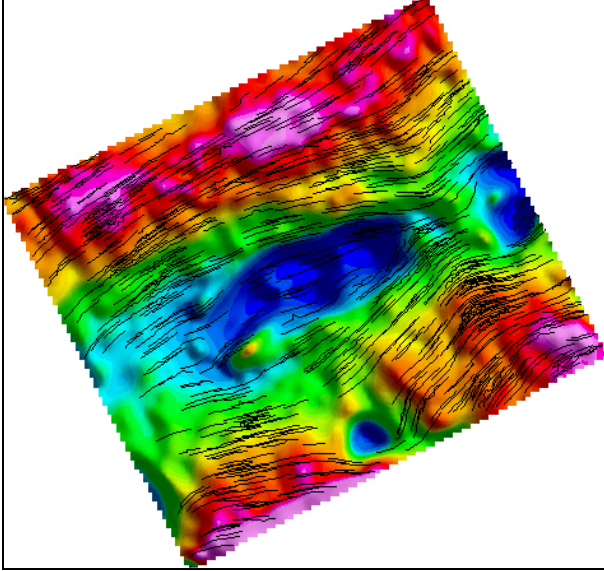


Figure 6: Bathymetry corrected Tzz filtered for 1-30km with Strike Lineaments plotted in white

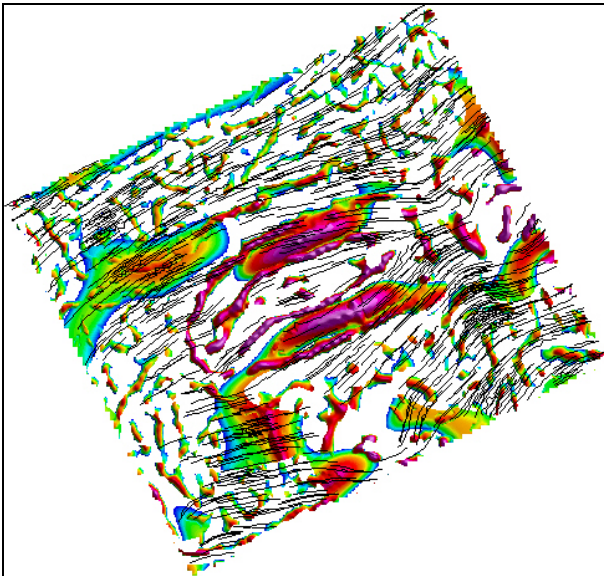


Figure 7: Horizontal Lineaments filtered for 1-30km with Strike Lineaments plotted in black

A rose diagram has been created using the calculated strike angles from equation 5, as shown in figure 8. This confirms the major trend in this area is NNE-SSW. These images are useful for geologist to integrate into their standard analysis workflow and image the results in a way that is familiar to the end user of the data.

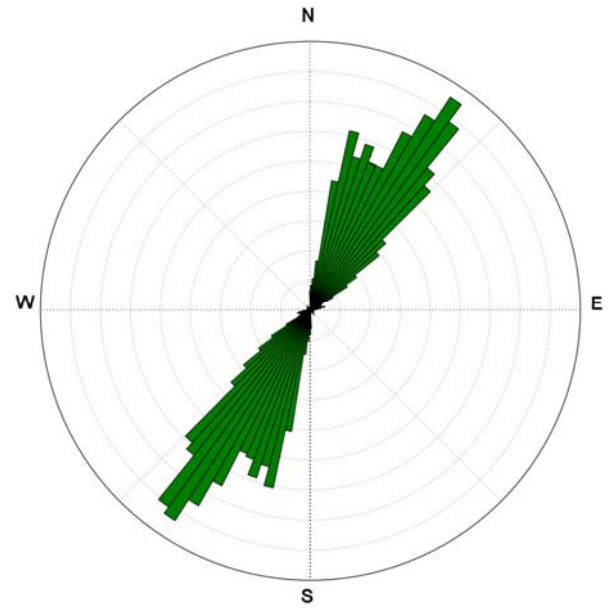


Figure 8: Rose diagram created from strike calculations

Tensor Rotation

Bathymetry corrected datasets were rotated about the z-axis. This enhances the imaging of features not coincident with the standard NED axes.

Figure 9 represents the Txz component rendered in the standard NED reference frame. Figure 10 is a 145degree rotation and emphasises the structure of the north-western part of the salt feature. This allows us to map the edge of the salt as a whole.

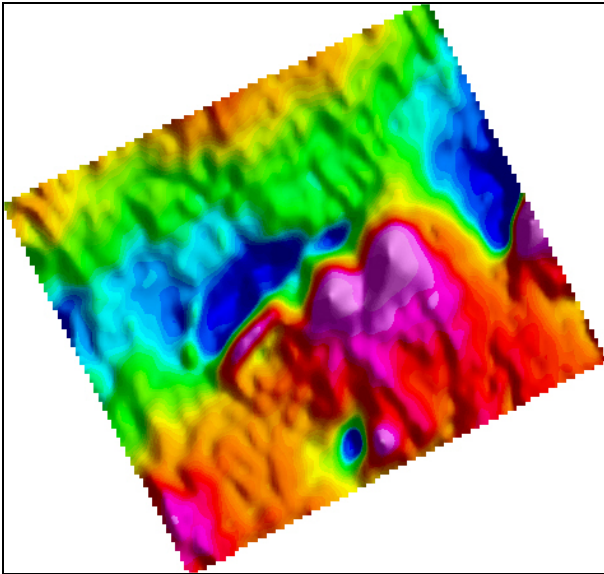


Figure 9: Txz component before rotation

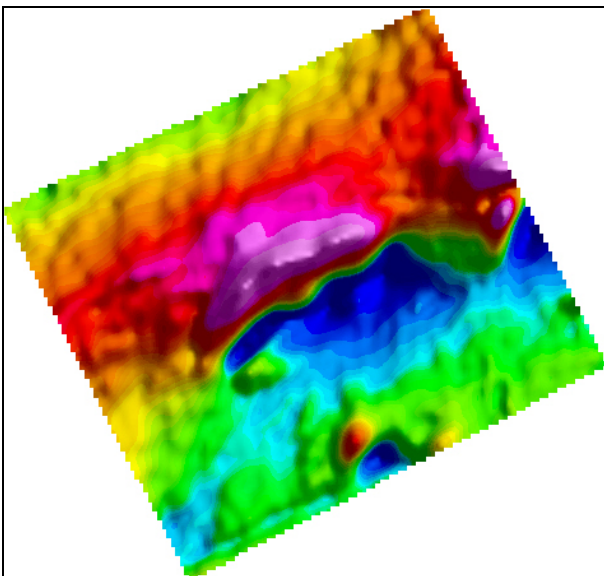


Figure 10: Txz component rotated by 145degrees about the z-axis, clockwise from North

CONCLUSIONS

Air FTG[®] brings more information to the picture than standard single component gravity. This extra information allows us to manipulate the data to visualise it in a way that enhances the features of interest.

Different techniques are used depending on the characteristics of the target and its predicted anomaly. Rotational Invariant I_2 is used primarily for target selection and maps isolated bodies. Horizontal invariant lineaments and strike lineaments can be used as edge mappers and to delineate structural or stratigraphic features. Strikes calculated from the FTG data can be used in standard geological interpretation products such as rose diagrams.

By rotating the tensors coordinate system we can isolate and enhance features of interest in the target geology.

ACKNOWLEDGMENTS

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