Edge detection and depth estimation using 3D Euler deconvolution, Tilt angle derivative and TDX derivative using magnetic data of thrust fold belt area of Mizoram

G. K. Ghosh* and R. Dasgupta

Summary

The stratigraphic and tectonic setting in the north-eastern part of Himalayan belt is complex, thrusted and faulted due to the collision of Indian plate and the Burmese plate. Subsurface heterogeneity in such kind of geologically complex and logistically hostile terrain of Assam-Arakan Basin specifically in the area falling in Mizoram state is one of the key factors for the hydrocarbon exploration. The study area is located in the Mizoram state and forms a part of Arakan-Yoma mountain fold belt. Seismic technique is the best among the other geophysical techniques for hydrocarbon exploration; however seismic imaging in such kind of complex mountainous, thrusted and faulted terrain have always problems for both the acquisition and data processing point of view to map the deeper basement configuration. This happens due to the very meager energy transmission in this complex area with dipping beds. To overcome such type of problems, it was always recommended to carry out some passive geophysical survey to provide value added constraints for integrated interpretation.

In this paper, attempt has been made to study the complex basement depth estimation and source-edge detection using 3D Euler deconvolution (ED) technique, Tilt angle derivative (TDR) and Horizontal Tilt angle derivative (TDX) using total magnetic field data. Various derivatives of the magnetic field data have been studied to enhance the anomalous features for identifying the structural lineament. The TDR obtained from the magnetic anomaly is reduced to pole (RTI) data taken for study of the geologic contacts. The Euler deconvolution is applied to estimate the basement depth using structural index and window size. It is inferred that the basement depths are varying more than 10 km. The structural lineament patterns are oriented in the N-S direction. The results derived using these three methods have resembled each other for detecting the location of magnetic lineament. The faults demarcations studied through the geological field work are superimposed to the results carried by Euler deconvolution, TDR and TDX suggested well correlation and good approximation. The results derived from these methods are helpful for delineating the basement and identifying the structural boundaries for better hydrocarbon exploration.

Keywords: Euler deconvolution, TDR, TDX, magnetic lineament, basement.

Introduction

Mizoram state is among the seven sisters in the north-east India shearing borders with Assam, Tripura, Bangladesh and Myanmar. The area of study is situated in geologically complex and highly thrusted/faulted area falls in the Mizoram state. The elevation is noted more than 1800 m and most of these vary in between 900m to 1300m. Most of the hillocks are steep slopes ranging between 60 to 80 degrees and intervening deep gorges in the study area.

Mapping of magnetic basement depth is most important for hydrocarbon exploration in a sedimentary basin because basement impact on the geology of the overlying sedimentary rocks plays an important role for the formation of oil and gas pools. Conventional 2D/3D seismic survey is not possible due to this gigantic elevated area and hence crooked line seismic survey has been carried out. Despite of fair quality of crooked line seismic data, mapping of basement depth is difficult task using the available seismic data. In this context, Oil India Limited (OIL) has carried out ground gravity-magnetic
survey work in this area and acquired 2500 observations at an interval of 0.5 to 1.0 km along the available roads and tracks for better delineation and demarcation of causative source bodies.

Figure 1. (a) Location map (b) Elevation plot of the study area.

Magnetic data was recorded by deploying Geometrics magnetometer with an accuracy of 0.1 nT. In this present study, magnetic data has been used for further interpretation for depth and edge estimation.

The study area consists 3200.0 Sq. Km. and located in between Mizoram thrust-fold belt in between Bangladesh and Myanmar. Eastern part of the area has noted more elevation compared to the western part of the study area.

Figure 2. (a) Map shows the stratigraphic column of Mizoram thrust/fold belt. (b) Map shows the different geological formations at the surface and the different anticlines, synclines, thrusts and faults locations.

However, most of these elevations vary in between 900 m -1300m. Most of the hillocks are very steep slopes ranging between 60-80 degrees and intervening deep gorges. The study area is shown in Figure 1a and the general surface elevation is shown in Figure 1b respectively.

In this present study, estimation of complex basement depth and source-edge detection have been carried out using total magnetic field anomaly data by using three well known methods. These are 3D Euler deconvolution (ED) technique, Tilt angle derivative (TDR) and Horizontal Tilt angle derivative (TDX). Apart from these techniques, various magnetic derivatives have been studied to enhance the anomalous features and identifying the structural lineament. The TDR and TDX obtained from the magnetic anomaly is reduced to pole (RTP) were used to interpret for the geologic contacts. TDR and TDX derivatives are restricted within the range +π/2 to -π/2 at the vertical contacts of geologic bodies. The Euler deconvolution is applied to estimate the complex basement depth using structural index and window size. Based on the Euler deconvolution technique, it infers that the basement depths vary more than 10 km. The study suggests that the lineament patterns are oriented in the N-S direction. The results derived using these three methods have resembled each other for detecting the location of magnetic lineament. The faults alignment studied through the geological field work are superimposed to the results carried by Euler
deconvolution technique, TDR and TDX derivative suggest well correlation among each other’s.

Theoretical approach: Tilt angle derivative (TDR), Horizontal Tilt angle derivative (TDX) and 3D Euler deconvolution.

The complex analytical signal can be expressed (Thurston and Smith, 1997) as 

\[
T(x, y, z) = |A| \exp(i\Phi) 
\]

\[
\Phi = \tan^{-1} \left( \frac{\partial T / \partial z}{\partial T / \partial x} \right) 
\]

\[
|A| = \sqrt{\left( \frac{\partial T}{\partial x} \right)^2 + \left( \frac{\partial T}{\partial y} \right)^2 + \left( \frac{\partial T}{\partial z} \right)^2} 
\]

Where \( T \) is the Total Magnetic Intensity, \( |A| \) is the Analytical Signal, \( \Phi \) is the local phase, \( \partial T / \partial z \) is the vertical derivative, \( \partial T / \partial x \) and \( \partial T / \partial y \) are the horizontal derivatives.

Tilt Angle Derivative (TDR) is first proposed by Miller and Singh (1994) and later by Verduzco et al., (2004).

\[
TDR = \tan^{-1} \left( \frac{VDR}{THDR} \right) 
\]

Where Tilt is varying with an angle \( +\pi/2 > Tilt > \pi/2 \), THDR is the Total Horizontal Derivatives and VDR is the vertical derivative. The Total Horizontal Derivative (THDR) can be defined as 

\[
THDR = \sqrt{\left( \frac{\partial T}{\partial x} \right)^2 + \left( \frac{\partial T}{\partial y} \right)^2} 
\]

The Horizontal Tilt angle derivative (TDX) was introduced by Cooper and Crown (2006) by using Total Horizontal Derivative (THDR) using absolute value of vertical derivative (VDR).

\[
TDX = \tan^{-1} \left( \frac{THDR}{VDR} \right) 
\]

TDX is varying with the angle \( +\pi/2 > TDX > \pi/2 \) similar to TDR. Both the methods TDR and TDX show a contrast variation along the sharper boundary.

3D Euler deconvolution technique was introduced in the potential field data to estimate the position of structural lineament. In this technique no prior source magnetization direction required and does not affect by the presence of remanence (Ravat, 1996). In these methods gradients are calculated, well traced the edges and characterized the depth of the source bodies. Reid et al., 1990 and Thompson 1982) define the 3D Euler deconvolution as mentioned in the equation (7)

\[
(x-x_0)\frac{\partial T}{\partial x} + (y-y_0)\frac{\partial T}{\partial y} + (z-z_0)\frac{\partial T}{\partial z} = N(B-f) 
\]

Where \( x_0, y_0, z_0 \) are the source locations; magnetic field is \( F \) measured at \( x, y, z \) points; \( B \) is the regional value of the Total Field; \( N \) is the Euler’s Structural Index (SI) which characterizes the source geometry. The structural index categorizes the anomaly attenuation rate at the observation point and depends on the source geometry.

Geological setting

The study area is situated in the Chittagong, Cachar, Tripura, and Mizoram Hills region along the western extension of the convex-westward Indo-Burmese fold-thrust (Assam-Arakan) belt. The Indo-Burman orogenic belt defines the transpressional collision boundary between the Indian plate to the west and the Burmese micro-plate of Eurasia to the east. The central Mizoram hills in the area include a number of NW-SE oriented oblique shear/fault/fracture systems that cut across the dominant N-S structural systems. This is described by the expansion of a frontal structural system of well-developed sub parallel fold-trains with N-S oriented culminations. The high amplitudes of folding are observed towards the eastern boundary of the study area and gradually decrease towards the Bangladesh in the western part.

These sub-verticales to high-angle oblique faults have been interpreted as tear-faults. These tear faults are acted left-lateral force of motion across the fold belt, that have allowed the development of independent N-S oriented structural systems on either side of the faults. These tear-fault systems are believed to be originated along the Jenam-Laisong detachment surface developed coevally with the N-S oriented structures that either merge with, or are truncated by the oblique fault systems. The Thenzawl and Pangzawl faults are the two most significant oblique fault systems within the study area, while the Lunglei fault is situated in the southern part. The Champhai Plateau defines a structural zone which has apparently undergone greater tectonic uplift than the central Mizoram hills. The N-S orientation of structural trends within central Mizoram becomes more complicated. The various geological formations are Upper Bhuban, Middlie Bhuban, Lower Bhuban, Renji, Jenam, Laisong and Basement. The general stratigraphic column of the Mizoram thrust fold belt and the surface...
geology of the study area are shown in Figure 2a and 2b respectively.

**Magnetic data acquisition, processing and Interpretation**

Ground magnetic data of 2500 stations were acquired at all the possible roads, tracks, valleys within the study area and its periphery. The magnetic survey was conducted using the Geometrics make proton precession magnetometer (PPM) with an accuracy of 0.1 nT. As the earth’s magnetic field is varying with time, another magnetometer was kept always at the base for studying the diurnal variation. This base station should be free from cultural noise and kept in automatic recording mode at regular interval and should always aligned in N-S direction for better signal and noise ratio. Acquired magnetic data is passed through the diurnal correction and International Geomagnetic Reference Field (IGRF) prior to processing and interpretation for subsurface geological structures. Magnetic data is uniformly gridded in a regular interval for further interpretation. Qualitative interpretation provides general ideas about the source depth and the strike of the causative source bodies. Sharper and larger magnetic anomalies suggest shallow depth while smoother anomaly suggests the deeper causative bodies. Generally sedimentary rocks are presumed to be non-magnetic but due to the presence of magnetic large wavelength anomaly represent the magnetic basement rocks lying beneath the sedimentary layers. The main objective of the magnetic survey is to estimate the basement depth and the structural magnetic lineament. The total magnetic intensity anomaly map is shown in Figure 3a and the IGRF corrected reduced to pole map is shown in Figure 3b. Analytical signal map is shown in Figure 4a.

Euler depth solution map and the trends are well correlated. It is seen that the Euler depth solution and the derived results from the geological study are similar. After studying the Euler deconvolution, it seems that there are many trends identified through Euler deconvolution study indicated by the locus of source points as the structural lineaments.

The Tilt angle derivative analysis (TDR) (Miller and Singh, 1994) (Figure 4c) suggests the features like thrusts/faults which are depicted as magnetic lineaments. This method is used as a tool for locating magnetic source for profile and gridded data. Tilt angle derivative values are restricted from $-\pi/2$ to $+\pi/2$. At the source edge location of a vertical-sided source, Tilt angle derivative crosses a zero value and negative outside the region and helpful for estimating the strike. This technique is also performing an automatic gain control filter (AGCF) which equalizes for weak and strong anomalies. Figure 4c shows the Tilt angle derivative map facilitates the horizontal location with extent of edges. It is suggested that the zero contour marked in the Tilt angle derivative map is the abrupt changes between positive and negative anomalies that is particularly at the sharp gradient. Zero contours can be identified as light yellow colour which is separating the green colour (negative value) and red colour (positive value) can be seen from the colour scale bar (Figure 4c). The Tilt angle derivative of reduced to pole field data shows N-S lineament trend from northern part to the middle part of the study area and terminating at Thenzwal fault. It is noted that from Thenzwal fault to the southern part, the trends are similar to N-S orientation but different in nature (Figure 4c). It can be abridged that the lineament trends from the northern part to the Thenzwal fault is diverging in nature and from the Thenzwal fault to the southern part is converging in nature.
Figure 3 (a) Total intensity magnetic field. Higher magnetic field observed at the northern part compared to the southern part (b) Magnetic field with IGRF corrected reduced to pole (RTP) of the study area.

Figure 4. (a) Analytical signal, (b) 3D Euler depth solution map shows the cluster of source depth locations positioned at the boundaries (c) Tilt angle derivative map (TDR) facilitates the recognition of the extent of edges anomalous sources assuming vertical contact. The zero contours calculate approximately the horizontal location of abrupt lateral changes in susceptibility (d) TDX derivative map also represents the anomalous sources. All the maps are superimposed with the identified known fault/thrust locations (black colour) carried through the geological field work.
The TDX derivative (Cooper and Cowan, 2006) analysis (Figure 4d) suggests much sharper gradient at the contact. Like Tilt angle derivative methods, TDX derivative also constrained in between $-\pi/2$ to $+\pi/2$. Tilt angle derivative is relatively smoother and positive value over the sources. TDX derivatives have less texture compared to Tilt angle derivative. The sharp edges are oriented in the N-S direction and are noticed by both Tilt angle derivative and TDX derivative map. The identified fault and thrust locations from the geological filed studies are superimposed on the Tilt angle derivative (TDR) and TDX derivative maps (Figure 4c and Figure 4d). The results derived by these techniques provided more additional information regarding faults and thrusts lineament which are yet to be marked and not identified from field mapping study. The zero value contours in the map in the TDX derivative represents the source edges locations (Figure 4d). It should be noted that results derived from these methods viz. Euler deconvolution, TDR and TDX derivatives techniques have agreed adequately in detecting the depths and the horizontal locations of the magnetized source and very well correlated among each other.

Summary and conclusion

In order to better interpretation of the source edge location and depth estimation, the results are compared with the Euler deconvolution, Tilt angle derivative and TDX derivatives. The performances of these three techniques are well correlated and supported among other results. The results suggest that the structural trends are elongated in the N-S direction. The lineament trends are similar in the northern part and southern part of the Thenzwal fault, however northern faults are diverging in nature and southern part is converging nature. The basement depths estimated through Euler deconvolution technique is varying from 5 km to 12 km. The central part of the study area, which is situated in between the Thenzwal fault and the Penzwal fault, the basement depths calculated more than 12 km. The more suitable depth solutions are derived by using structural index 3 and window size 20x20. However, many cases have been studied using various combinations of structural indices and window sizes which are not mentioned in this text. At the source edge location of a vertical-sided source, Tilt derivative crosses at zero contour value. The negative contour suggests the outside the region against the source and helpful for estimating the strike. The fault sections demarcated by geological field work are superimposed on the derived results of Tilt derivative and TDX derivatives. However, using these above mentioned techniques, the derived results suggest additional faults/thrust locations. Tilt derivative shows the positive contour value above the source bodies and edges are marked by zero contour value. Similarly, the TDX derivative analysis suggests much sharper gradient at the contact with zero contour value. Both the methods; Tilt angle derivative and TDX derivative vary in between $-\pi/2$ to $+\pi/2$. It should be noted that the Euler deconvolution, TDR and TDX derivatives have agreed adequately for detecting the horizontal locations and edges of the magnetized source bodies are well correlated. It is observed that the Euler depth solution and the derived results from geological study are similar trend, however more thrust / fault can be identified from this study to delineate the source edges and basement depth for hydrocarbon exploration.

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References


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