Interpretation of magnetic anomaly using cos(θ) map and SED for automatic source edge location in Assam-Arakan basin of Mizoram state, India

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Keywords

Magnetic anomaly, Tilt, Horizontal Tilt, Total Horizontal Derivative, Cos(θ), Source Edge Location

Summary

The study area falls in the Mizoram state in Assam-Arakan basin is highly undulating, complex terrain, deprived geometry with complex subsurface geology where basement depth varies more than 12 km. Due to difficult terrain and unapproachability, conventional seismic survey is difficult in this area and hence 2D crooked line seismic survey has been carried out for hydrocarbon exploration. However, due to complex subsurface, the quality of 2D crooked line seismic data is not proven to map the subsurface properly. Hence, to reduce the ambiguity, various geoscientific studies like gravity-magnetic, 3D seisloop seismic survey, geochemical, thermal imaging, geological modelling etc. have been carried out. Nevertheless, mapping of thrust and fault locations in such kind of hilly terrain and geologically complex areas always a difficult task for the geoscientists.

Thrust and fault identifications are extremely useful to enhance interpretation capabilities in shallow structural level for planning and executing hydrocarbon exploration. In this study, attempt has been made to study the ground magnetic data for detecting automatic source-edges location and geological boundaries using Cos(θ) analysis, source edge detection (SED) technique and various derivatives of magnetic data in the study area. The results derived from the magnetic data have played a major role for integrated study to develop confidence level for pursuing exploration in the area by reducing uncertainties and minimizing exploration risk for holistic assessment.

Introduction

In the present scenario, the hydrocarbon exploration in the Mizoram state has negligible in order to integrally tough logistics, ridges and deep gorges with undulating surface varying from 200 m to 1700 m in Indian side. However, the introduction of NELP (New Exploration Licensing Policy) by Government of India which proposals a risk-reward sharing appliance, the hydrocarbon explorer have started shifting their focus towards this relatively new unexplored areas for hydrocarbon prospecting. The very fresh evidences for findings hydrocarbon are noted in and around Mizoram area surrounded by Cacher district of Assam, neighboring state of Tripura and western part of Bangladesh. It is drawing attentions of various explorers and industrialists to divert their exploration focus towards this area (Figure 1).

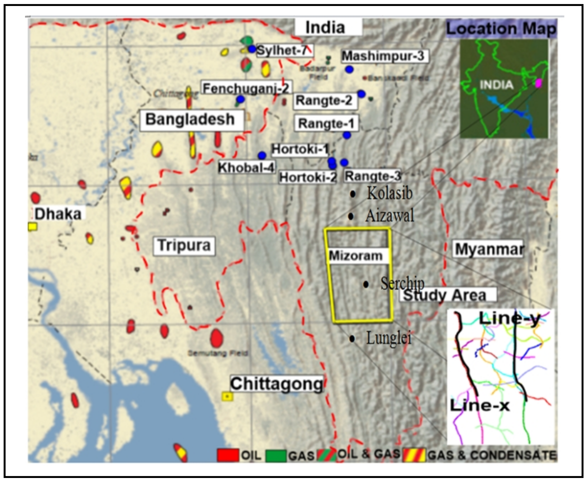

Figure 1. Location map shows the block boundary of the study area and the surrounding's oil and gas discovered fields.

The uncertainty in mapping of the depth through seismic data and topography using geophysical characterization for the basement to understand the basin architecture for hydrocarbon exploration still have a major enigma, mainly due to its deeper depth and resultant limitations for hydrocarbon exploration. The Mizoram block comprises a series of curvilinear east dipping thrust with Oligocene and Miocene sediments mutilated into a series of fault propagation folds.

First time, ONGC (Oil and Natural Gas Corporation Limited), an Indian national upstream company started hydrocarbon exploration work in the Kolasib district of Mizoram state using 2D seismic survey in 2002 and revealed hydrocarbon by drilling. OIL (Oil India Limited), the second largest Indian national upstream company, started its exploration by implementing its first 2D seismic survey campaign in Aizawal, Serchip and Lunglei districts of Mizoram during the year 2007-2011 and acquired more than 1300 GLKM of 2D seismic lines. Apart from this, other geo-scientific data like ground gravity-magnetic, geochemical, geological modelling, thermal imaging etc. have also been acquired. The sparse 2D crooked seismic data acquisition has been continued using 12.5 m group interval and 50 m shot interval contained with huge problems as shot hole drilling, sparse seismic lines, frequent job obstruction, forest fire, limitation in surface transportation and communication etc.

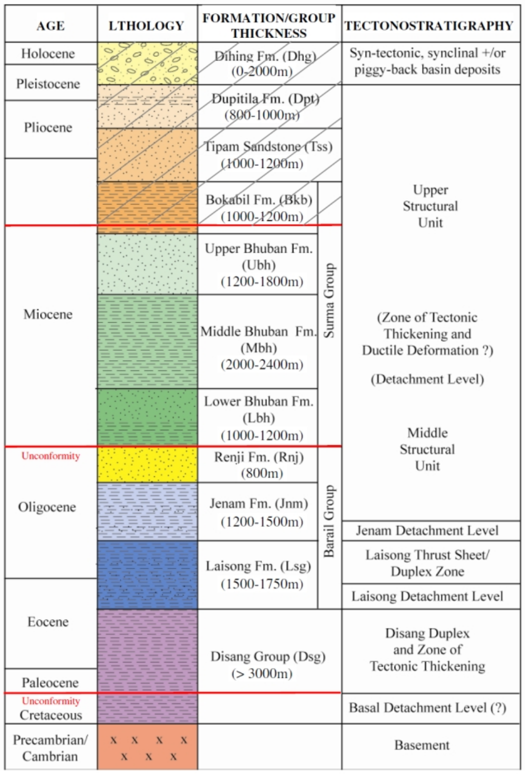

Figure 2. Map shows the general stratigraphy of the Mizoram area.

In this study area fraught with surface, near surface and subsurface constraints, deteriorating the seismic resolution due to deeper basement depth and structural complexities etc., proved inadequate in confident imaging of the subsurface. In this present study, attempt has been made to interpret 2500 ground magnetic observation for automatic source edge location using various derivatives of magnetic data along with Cos(θ) analysis which can help to improve confidence for pursuing exploration in the area by reducing uncertainties and minimizing exploration risk.

Geology and tectonics

There are numerous potential source rocks in this area belongs to Disang Group, Barail Group and Bhuban Formations. Various potential reservoir rocks have been existed in this area specifically Disang Group, Renji Formation, Lower Bhuban Formation, and Middle Bhuban Formations. The Upper Bhuban and Bokabil Formation are the reservoir rocks. The general stratigraphy of the area is shown in Figure 2. The Tripura-Cachar-Mizoram-Myanmar fold belt owes its origin to the collision among the Indian, Tibetan and West Burmese Plates in Late Eocene-Oligocene period. This also led to the advancement of an unconformity in the Mizoram area and development of a large fluvio-deltaic system across the whole Bengal-Assam area. In the Late Eocene to Oligocene, the Burmese Plate closed over the Assam Shelf generates the updated lithological shape. Chittagong-Mizoram-Tripura fold-thrust belt of India, Burma and Bangladesh have been covered an area of about 24000 km^2.

Magnetic data source and theoretical approach

The magnetic data acquired by Oil India Limited (OIL) in collaboration with National Geophysical Research Institute (NGRI), Hyderabad during 2009-2011. The magnetic data acquisition has been carried out at an interval of 0.5 to 1 km along the available roads, foot tracks around the block. Magnetic data has been acquired using Geometrics Magnetometer (GM) with an accuracy of 0.01 nT.

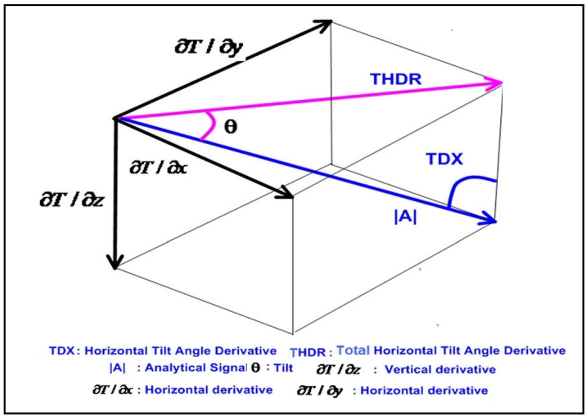

Figure 3. Map shows the various derivatives with the geometric illustration of the TDX, THDR and Analytical signal, |A|, of magnetic data.

The data has been processed further to reduce in mean sea level (MSL). Diurnal and International Geomagnetic

Reference Field (I.G.R.F) corrections have been applied to the magnetic data to study Cos(θ) map and various other derivatives to delineate the thrust / fault boundaries and source edge locations.

A number of filters can be used to enhance the potential field data, such as downward continuation, vertical and horizontal derivatives to delineate the source edges. Magnetic field T can be separated into three components, two horizontal derivative components ($\partial T/\partial x$, $\partial T/\partial y$) and another vertical derivative component ($\partial T/\partial z$). In general, total horizontal derivative (THDR) is used for edge detection. A schematic diagram of the various derivatives with the geometric illustrations of the TDX, THDR and the Analytical signal, |A| are shown in Figure 3.

Total horizontal derivative (THDR) is defined by Grauch et al. (2001) and can be expressed as

$$THDR = \sqrt{(\partial T/\partial x)^2 + (\partial T/\partial y)^2} \qquad \text{(A)}$$

The THDR delineates the edges of the largest amplitude anomaly but it is less impressive for the deeper bodies.

Miller and Singh (1994) first estimated tilt angle filter (TDR) using potential field derivative. Tilt angle is the ratio of the vertical derivative (VDR = $\partial T/\partial z$) (to the absolute value of the total horizontal derivative (THDR) which improves large and small amplitude anomalies.

$$TDR = \tan^{-1}\left(\frac{VDR}{THDR}\right) \qquad \text{(B)}$$

It is noted that TDR is independent of geomagnetic field or the susceptibility of the source bodies. The zero contour of the tilt anomaly or TDR can locate close to the boundary of the causative bodies. Thus, zero contour of the TDR indicates the thrust/fault locations.

The horizontal tilt angle (TDX) has been introduced using THDR and absolute value of VDR by Cooper and Crown (2006) as expressed in equation (c).

$$TDX = \tan^{-1}\left(\frac{THDR}{|VDR|}\right) \qquad \text{(C)}$$

TDX responds for shallower as well as deeper bodies and also delineates the edges of the bodies. Both the methods TDR and TDX show a contrast variation along the sharper boundary.

The application of theta map for the detection of edge of the causative bodies using magnetic data has been discussed by Wijns *et al.* (2005). Cos (θ) is the ratio of THDR and normalized analytical signal |A|.

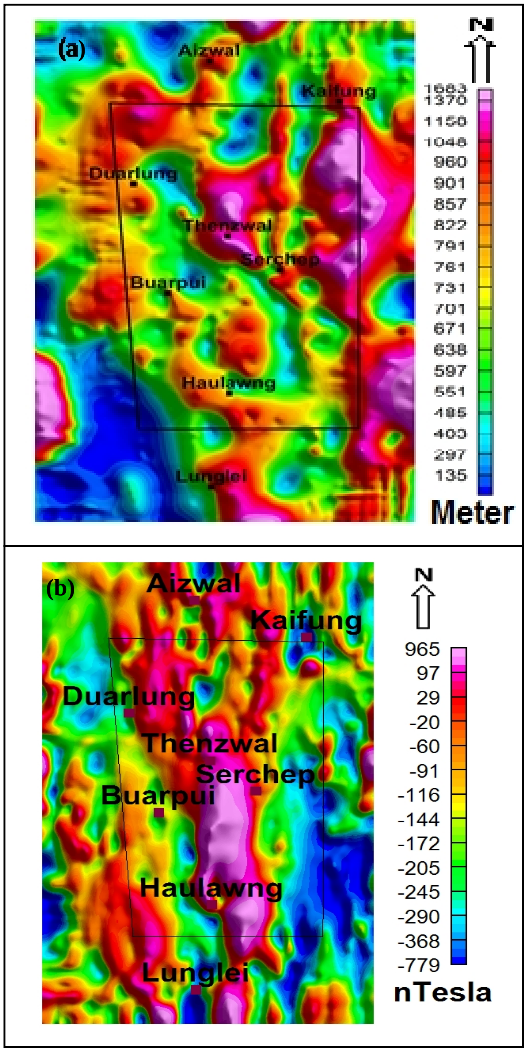

Figure 4. Map shows the elevation profile (a) and magnetic reduced to pole data (RTP) (b).

The THDR effectively delineates the edges of the largest amplitude anomalous bodies; however, it is less impressive in the case of deeper bodies.

$$Cos(¯) = \frac{THDR}{|A|} \qquad \text{(D)}$$

Where $A = \left|\sqrt{(\partial T/\partial x)^2 + (\partial T/\partial y)^2 + (\partial T/\partial z)^2}\right| \qquad \text{(E)}$

The elevation of the study area has shown in Figure 4a and the reduced to pole (RTP) of magnetic data has shown in Figure 4b respectively. The vertical gradient derivative and horizontal gradient derivative maps are shown in Figure 5a and Figure 5b respectively.

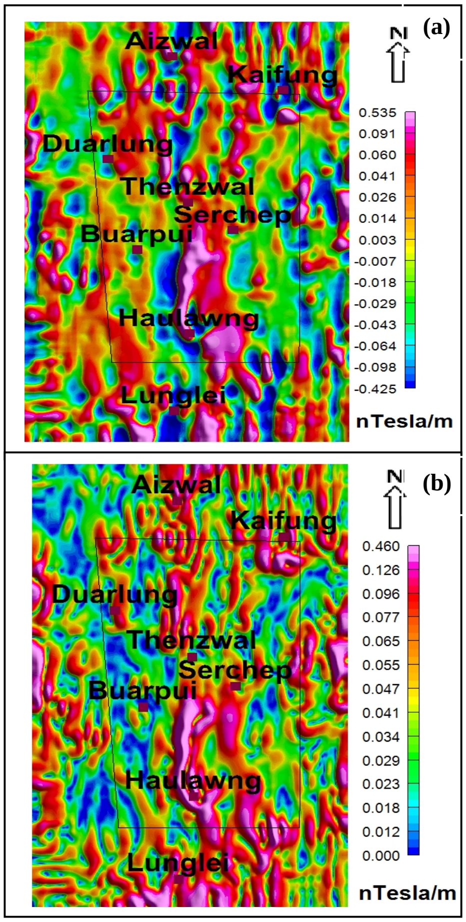

Figure 5. Map shows the vertical gradient derivative (VDR) (a) and the horizontal gradient derivatives (THDR) of magnetic data (b).

Magnetic data interpretation

The block area shows surface elevation varying from 200 m to 1700 m (Figure 4a). The magnetic RTP data shows scattered response and orienting in N-S direction throughout the area (Figure 4b). Magnetic field changes significantly in the southern part which might be due to tectonic resettlement process and the upliftment of crystalline basement rocks (Figure 4b). Map shows the vertical gradient derivative (VDR) (Figure 5a) and the total horizontal gradient derivatives (THDR) of magnetic data (Figure 5b). The tilt angle (TDR) and horizontal tilt angle derivatives (TDX) have been represented the source edges as shown in Figure 6a and Figure 6b respectively.

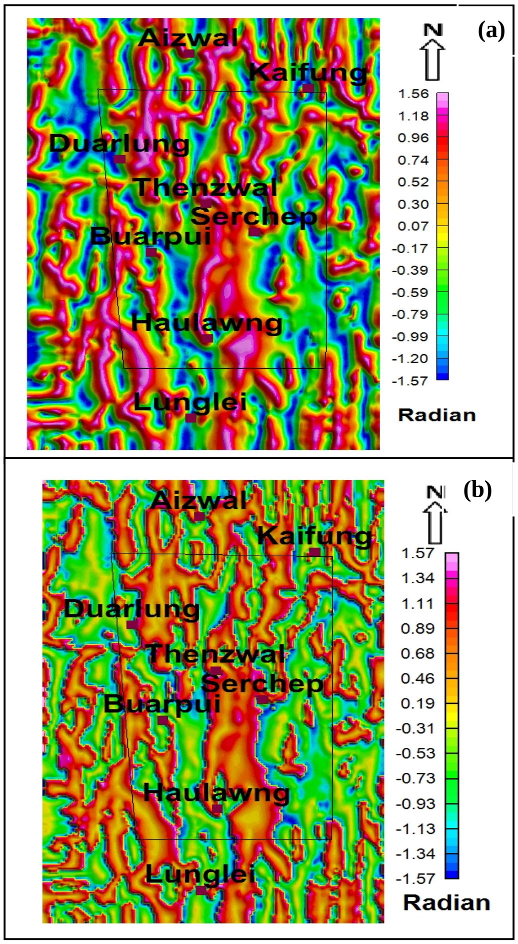

Figure 6. Map shows the Tilt angle (TDR) (a) and horizontal tilt angle derivative (TDX) of magnetic data (b).

The Cos(θ) map derived from the analytic signal |A| and THDR has been plotted as shown in Figure 7 that highlights the magnetic contacts. This method has been applied to RTP data and equally works at low magnetic latitudes, where traditional reduction to the pole is not advisable.

The Cos(θ) map derived from magnetic data oriented in the N-S direction. The color scale suggests the Cos(θ) values changes from minimum 0 to 1. It has been suggested that Cos(θ) is 1 where angle is 90^0. The Cos(θ) plot suggests that the N-S pattern of lineament is discontinued at Durlung, Thenzwal and Serchip locations. This discontinued part has been understood due to be the great active Thenzwal fault (Figure 7).

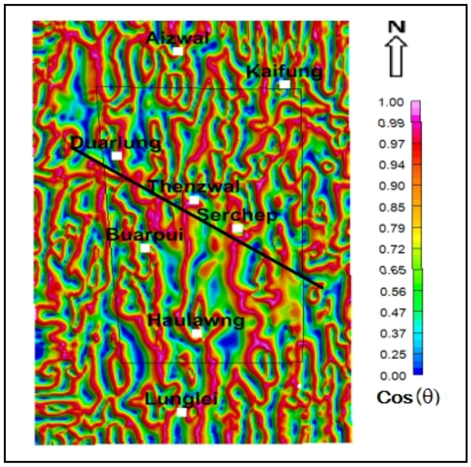

Figure 7. Illustration shows the Cos(θ) map derived from magnetic data oriented in the N-S direction. The color scale suggests the Cos(θ) values changing from minimum 0 to maximum 1.

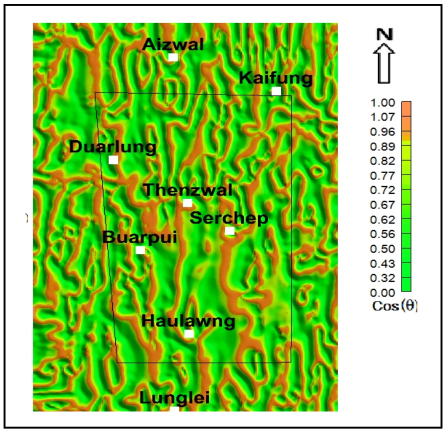

Figure 8. Map shows the Cos(θ) interpretation which varied from 0 to 1 after setting the colour scale.

The Cos(θ) map is further filtered and changed the colour scale dominated by red colour that clearly indicates the thrust and fault locations (Figure 8). This technique may be very useful for direct estimation of thrust and fault boundaries of geological contacts.

An attempt has also been made to study the source edge detection (SED) technique for calculating the approximate edges of the magnetized source bodies and geological boundaries with the help of various derivatives from gridded magnetic data. A map has been prepared based on the studies carried by Cordell and Grauch (1982), which demonstrates the various dip and strike locations (Figure. 9). In this figure, dips are perpendicular to the strike direction as rotates from the clockwise direction.

To correlate the above results, Cos(θ) and SED analysis, both the results have been superimposed for better understanding for indicating geological boundaries (Figure 10). It has been understood that the Cos(θ) and SED are nicely correlated to each other. The dip and strike directions are marked by white lines which is shown in Figure 10.

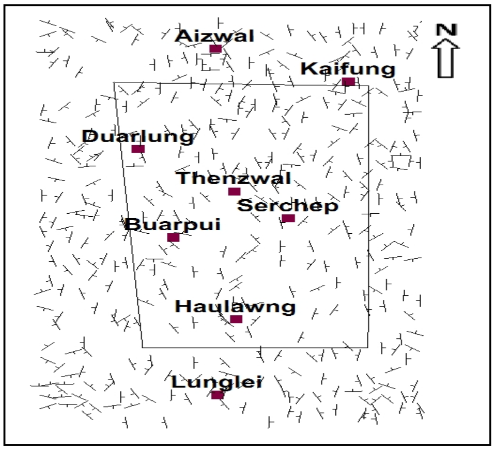

Figure 9. Map shows the various dip and strike locations. Dips are perpendicular to the strike direction in the clockwise direction.

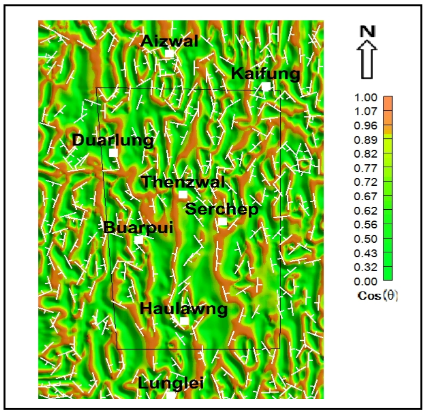

Figure 10. Superimposed map of Cos(θ) to SED map. The dip and strikes are marked with white lines.

As the area of study is geologically complex and completely hilly terrain, the information available is very less. The field studies report (Schielling, 2008) has suggested some major thrust and faults in this study area which has been shown in Figure 11. However, derived locations of thrust/faults are unmarked and unidentified from the field studies. To correlate all these findings, an integrated superimposed map has been produced including

Cos(θ), SED with thrust and faults boundaries through field studies (Figure 12). It has been suggested that the results are well correlated, however, the.

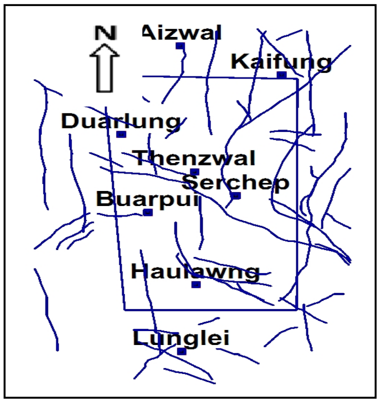

Figure 11. Thrust and fault location have been marked by the field studies (Schielling, 2008).

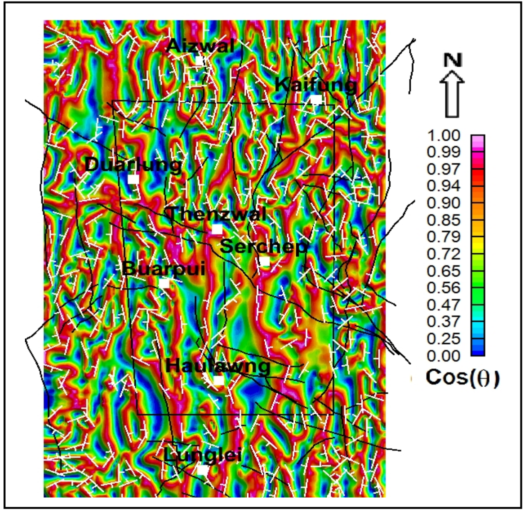

Figure 12. Map containing Cos(θ), SED and thrust/faults locations from field studies (Schielling, 2008) have been superimposed. Cos(θ) produces additional hidden thrust and fault locations.

Cos(θ) interpretation shows better correlation of geological boundaries with additional thrust/fault delineations.

Conclusions

Various derivatives analysis has been carried out to map the geological boundaries and thrust-fault locations. It has been concluded that in such kind of hilly terrain and complex surface formation, seismic methods unable to maps properly the appropriate subsurface imaging and unable to map the thrust and fault locations due to poor penetration of seismic energy. Magnetic data interpretation with vertical and horizontal derivatives, analytical signal, TDR, TDX and Cos(θ) interpretation can play an important role to enhance the interpretation capabilities with proper identification of the geological boundaries. However, Cos (θ) interpretation suggests better demarcations of geological boundaries. The integrated map using Cos(θ), SED and thrust-fault locations marked through field studies are superimposed for betterment for identifying the geological boundaries (Figure 12). Although, Cos(θ) interpretation can produce additional hidden thrust and fault boundaries information that were not marked by the field studies. This additional information can help to understand the area and for identifying the geological boundaries. This information can enhance the interpretation capabilities envisioned for further investigation for hydrocarbon exploration.

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