Structural mapping using ground magnetic data and enhanced derivative techniques in the Assam-Arakan Basin, northeastern India

Gopal Krishna Ghosh[1], Dharm Raj Yadav[1], Aditya Amber[1] and Rama Shankar Ram[1]

ABSTRACT

The study area lies in the structurally complex and tectonically active northeastern margin of India, near the Himalayan foothills and within the Belt of Schuppen of the Upper Assam foreland shelf. Accurate mapping of subsurface structures is critical for hydrocarbon exploration in this region, where conventional seismic methods are challenged by rugged topography and poor signal penetration-particularly in shallow zones dominated by boulder-sandstone formations. To address these limitations, ground magnetic data are less influenced by surface conditions and can provide valuable insights into lateral lithological variations, structural discontinuities, and the geometry of magnetic source bodies. Ground magnetic data were analysed using a suite of enhanced derivative techniques aimed at delineating both shallow and deep-seated structural features. Methods such as Total Horizontal Derivative (THDR), Analytical Signal (AS), Tilt Derivative (TDR), Horizontal Derivative of Tilt Derivative (HD-TDR), and Theta Map Analysis (TMA), were applied to processed magnetic anomalies to highlight fault trends, lithological contacts, and magnetic source boundaries. THDR emphasized sharp lateral contrasts, while the TDR and HD-TDR enhanced edge detection and improved delineation of structural boundaries. The AS further contributed by producing amplitude maxima directly above causative bodies, reducing ambiguity linked to magnetization direction and thereby supporting depth estimation. These results facilitated improved structural clarity in the areas where seismic imaging remains inconclusive and provided with a valuable framework for guiding further exploration in the Assam–Arakan Basin. The integrated application of these methods reveals a structurally complex framework, marked by multiple fault systems, basement highs, and possible intrusive bodies, many of which correlate with known geological trends. These findings not only refine the understanding of the subsurface architecture but also identify geologically significant targets that warrant further investigation. The study demonstrates the value of combining reduced to pole (RTP), derivative filters, and cos (θ) analysis to strengthen magnetic interpretation in structurally complex regions for lineament analysis. The insights gained not only enhance the understanding of the subsurface framework in the Assam–Arakan Basin but also support the identification of new exploration targets for hydrocarbons and other resources.

KEYWORDS

Ground magnetic data, structural mapping, derivative techniques, Assam-Arakan Basin, magnetic interpretation, tectonics

INTRODUCTION

Understanding the subsurface architecture of the Assam–Arakan Basin is critical due to its strategic importance as a proven hydrocarbon province in northeastern India. This region, which encompasses complex tectonic elements including thrust belts, folded sedimentary successions, and deep-seated faults, presents both exploration potential and interpretational challenges. While traditional seismic surveys are widely employed in basin analysis, their effectiveness is often compromised in areas where surface conditions disrupt signal transmission. The presence of rugged topography, boulder-strewn zones, and highly compacted lithologies significantly attenuates seismic energy, leading to weak reflections and ambiguous structural images in deeper sections. Additionally, pressure conditions play a critical role in the propagation characteristics of seismic waves.

Given these limitations, magnetic methods offer a viable complementary approach to refine subsurface interpretations, particularly in terrains where seismic data quality is insufficient. In this present study, ground magnetic surveys were conducted across the structurally active corridor of the Upper Assam foreland shelf, extending into the frontal parts of the Himalayan orogenic belt. The location map of the study area is shown in Figure 1a and the proposed survey area covered is outlined in Figure 1b. Two representative seismic stacked sections show the poor quality of seismic signal in this study area (Figure 2). Figure 3 shows photos taken from above the ground in the study area. These photos are not shown at their actual size (not to scale). They focus on the rocky, uneven ground where parts of the seismic survey lines AB and CD are located.

[1]Geophysics Department, Oil India Ltd, Duliajan, Assam

Emails: gopal_ghosh@oilindia.in; dharmraj_yadav@oilindia.in; aditya.amber@oilindia.in; rsram@oilindia.in

The exact positions of these lines were already shown in Figure 1.

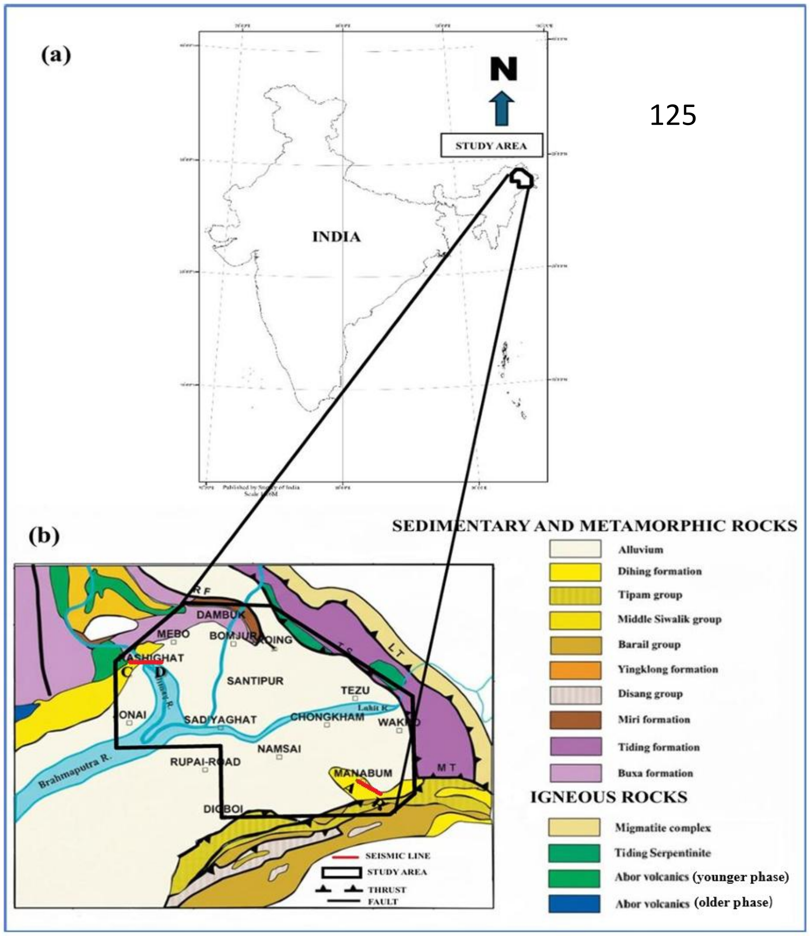

Figure 1: (a) Location map of the study area; (b) Various geological formations like alluvium, Dihing formation, Tipam group, Middle Siwalik group, Barail group, Yingkiong formation, Disang group, Miri formation, Tiding formation, Buxa formation and igneous rocks (Migmatite complex, Tiding Serpentinite, Abor volcanics of both younger and older phase) and thrust-fault locations are marked (after Ghosh et al., 2010). Two seismic lines, AB and CD, are shown in red colour, oriented along the NW–SE and W–E directions, respectively.

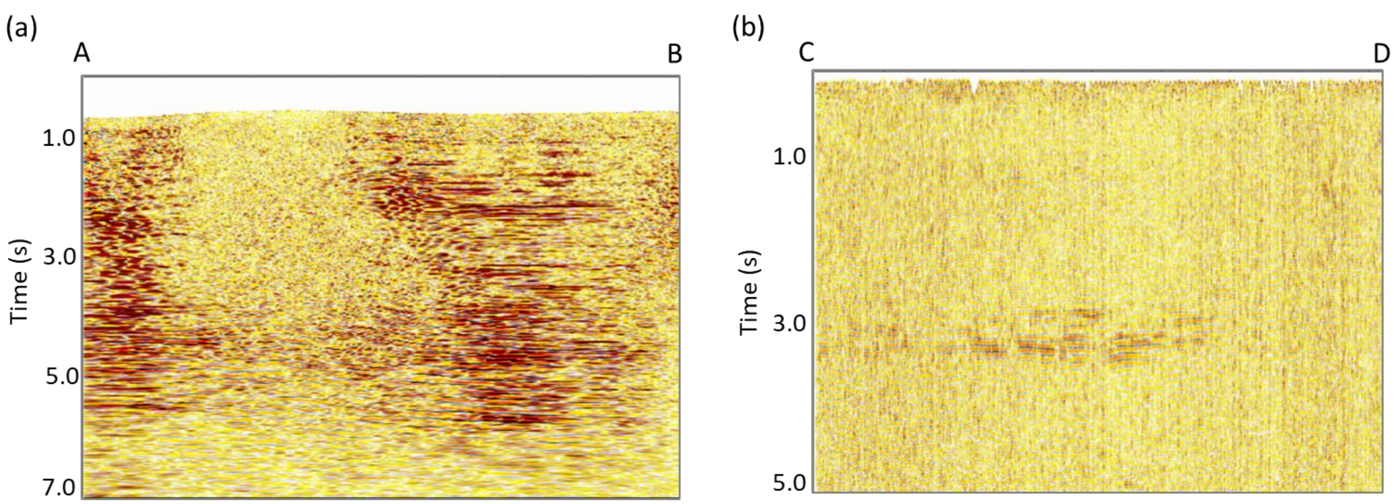

Figure 2: Stacked seismic sections (a) AB oriented NW-SE, and (b) CD oriented W-E across the study area. Both sections exhibit poor data quality. The horizontal axes represent CMP locations on both sections.

(a) (b)

Figure 3: *Top surface photographs (not to scale) of representative surface conditions within the study area, highlighting the boulder-strewn bed where seismic profiles AB and CD are partially covered.*

The magnetic data were acquired by Oil India Limited in collaboration with the National Geophysical Research Institute (NGRI) between 2002 and 2004. Approximately 2,500 ground magnetic observations were recorded, with station intervals ranging from 0.5 to 1.0 km, depending on the terrain accessibility and logistical feasibility covering nallas, river tributaries, foot track and canals where many parts of the area cover dense forest.

The survey utilized magnetometers with an accuracy of 0.01 nT. A Scintrex magnetometer installed at the base station near the OIL camp at Chowkham monitored diurnal variations, while a Geometrics magnetometer was deployed for field measurements. The base station was strategically located away from potential sources of magnetic interference, such as power lines, buildings, and metallic objects. All necessary precautions were taken to ensure the collection of high-quality and reliable magnetic data.

Geological context for the magnetic interpretation is provided by integrating existing maps and stratigraphic information (Ghosh et al., 2010), which outline a wide range of litho-units-from recent to Proterozoic. The geological sequence of the region comprises both sedimentary and igneous formations spanning from the Proterozoic to the Quaternary. The sedimentary and metasedimentary units include the Buxa Formation (Proterozoic), Tidding Formation (Precambrian–Cambrian), Disang Group (Late Cretaceous–Eocene), Yingklong Formation (Eocene–Oligocene), Barail Group (Oligocene–Early Miocene), Miri Formation (Middle–Late Miocene), Tipam Group (Miocene), Middle Siwalik Group (Miocene–Pliocene), Dihing Formation (Pliocene–Pleistocene), and Alluvium (Quaternary). The igneous formations of the region are represented by the Migmatite Complex (Archean to Proterozoic), Tiding Serpentinite (Precambrian–Cambrian), Abor Volcanics (Older Formation) (Precambrian to Early Paleozoic), and Abor Volcanics (Younger Formation) (Permian). These units are intricately deformed and disrupted by multiple thrust systems, whose subsurface continuities remain poorly constrained in seismic records.

By correlating magnetic interpretation results with prior geological and geophysical reports, including the OIL exploration report (2002**),** this study aims to refine the regional structural model. The identification of new fault orientations, lineament patterns basement highs, and possible trap structures highlights the utility of magnetic methods in augmenting exploration workflows in geologically complex settings.

GEOLOGICAL SETTING

The Assam–Arakan Basin represents a classic peripheral foreland basin that has evolved under the influence of ongoing tectonic interaction between the Indian Plate and the Burmese Plate. This interaction is most prominently expressed along the Arakan–Yoma fold belt, where processes of subduction and subsequent collision have given rise to a highly complex structural framework. The region is characterized by multiple phases of deformation, resulting in a series of thrust belts, folds, and fault systems that strongly control the basin architecture and its sedimentary evolution.

The survey design involved systematic data acquisition at an interval ranging from 500 to 1000 meters, adapted to terrain accessibility and geological exposure. At the surface, geology displays a mosaic of sedimentary and metamorphic units, intricately dissected by numerous thrust faults, as illustrated in Figure 1(b). The Assam valley itself is extensively blanketed by Quaternary alluvium, which obscures much of the underlying geology. However, subsurface investigations reveal thick accumulations of Tertiary sediments that constitute the primary basin fill. These deposits not only record the basin's tectono-sedimentary history but also provide vital information for understanding its petroleum system and crustal evolution."

The terrain within the study area exhibits considerable elevation variability, ranging from approximately 110 m to prominently 598 m above mean sea level, with a predominant southwest–northeast structural orientation (Figure 4). Higher topographic domains are primarily concentrated in the eastern sector, encompassing regions around Manabum, Wakro, and Tezu, as well as in the northern sector near Mebo, Dambuk, and Roing. In contrast, relatively low-lying terrains are observed in the vicinity of Jonai, Sadiyaghat, and Rupai Road, reflecting the geomorphic transition from elevated structural highs to the adjoining alluvial plains.

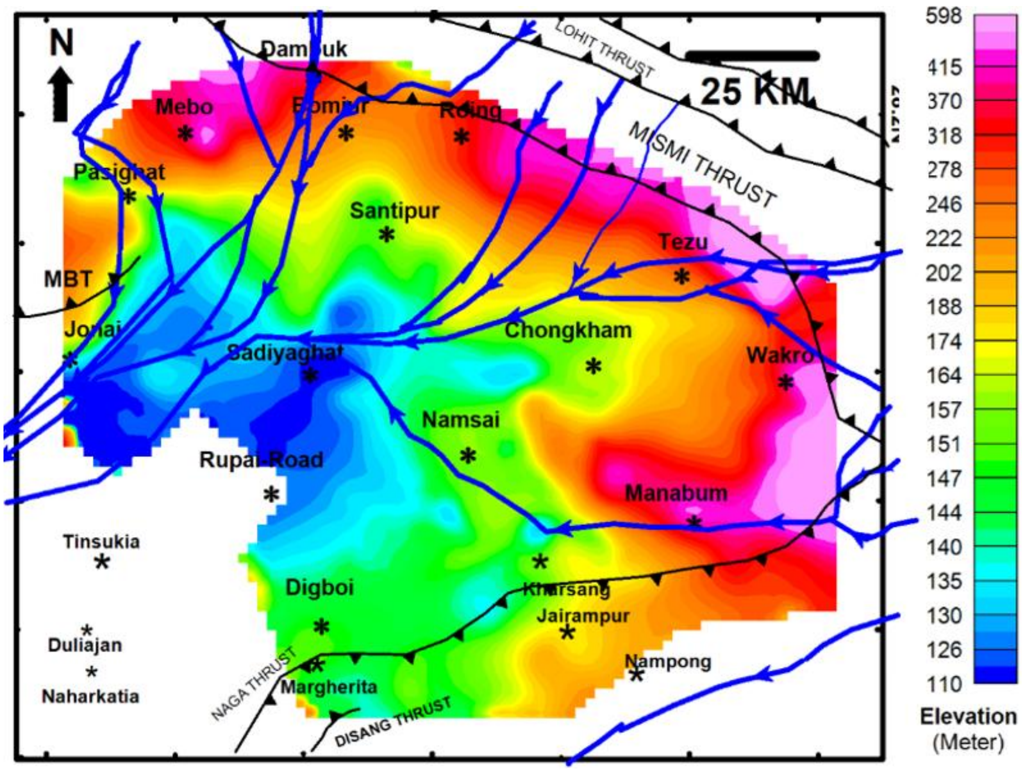

Figure 4: Terrain map shows elevation variation from ~110 m to ~598 m above sea level, with a general northwest–southeast orientation including various thrusts (black lines) and Brahmaputra River's tributaries (blue lines).

The total magnetic field (Figure 5) over the study area exhibits distinct undulations, with values ranging from approximately 47,957 nT to 48,806 nT. These variations highlight significant lateral changes in the subsurface magnetic properties across the basin. The anomalies display a predominant northwest–southeast orientation, which is consistent with the regional tectonic framework and structural grain of the area. Such magnetic fluctuations may be attributed to differences in basement topography, variations in lithology, and the thickness of overlying sediments, collectively reflecting the geological heterogeneity of the basin (OIL Exploration Report, 2002).

Data interpretation was conducted using advanced derivative-based filtering techniques applied to the Total Magnetic Field (TMF). These methods include Tilt Derivative (TDR), Horizontal Derivative of Tilt Derivative

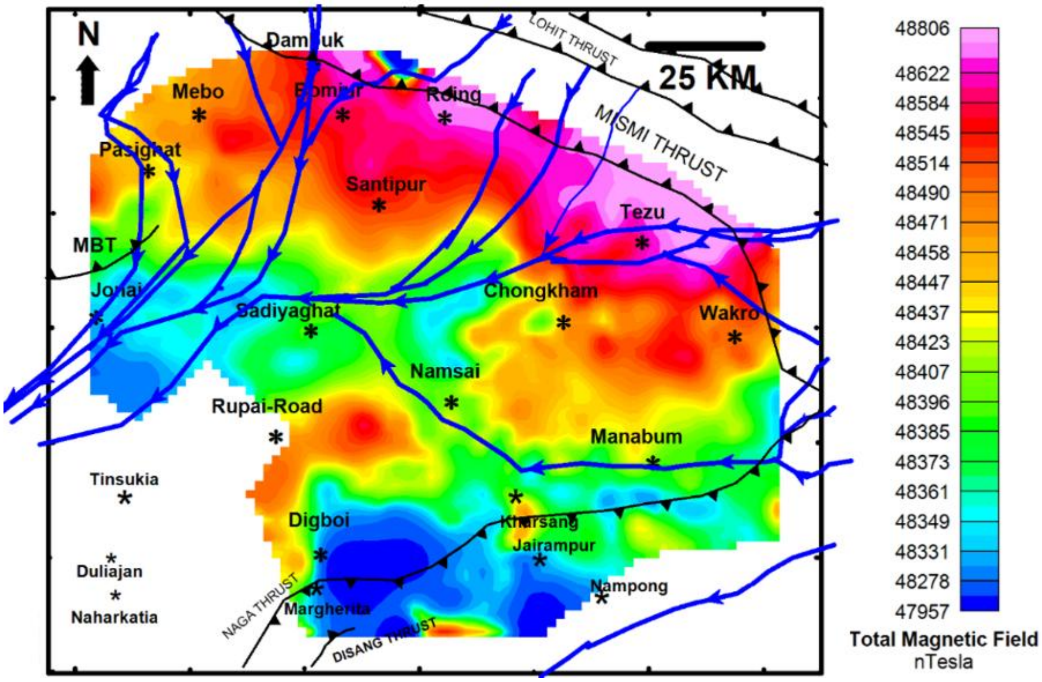

***Figure 5**: Total magnetic Intensity map shows variation from 47957 nT to 48806 nT in the study area, with a general northwest–southeast orientation.*

(HD-TDR), Analytical Signal (AS), and Theta Map Analysis (TMA), each designed to highlight key geological structures such as faults, lithological contacts, and source boundaries. Additionally, these techniques enhance the resolution and clarity of subtle anomalies, allowing for more accurate mapping and interpretation of the subsurface features.

TECHNIQUES FOR MAGNETIC DATA INTERPRETATION

(a) Total Horizontal Derivative (THDR)

The Total Horizontal Derivative (THDR) is a well-established technique in potential field interpretation that enhances lateral variations in the magnetic data. First introduced by (Cooper and Cowan, 2006**)** this method is widely applied to delineate the edges of magnetized bodies and to map geological contacts with greater accuracy (Wang et al, 2009; Francisco et al, 2013**)**. By combining the horizontal gradients of the magnetic field in both x- and y-directions, THDR produces an amplitude measure that is independent of anomaly orientation, thereby providing a reliable indicator of structural boundaries.

The THDR is mathematically defined as:

$$\mathrm{THDR} = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2} \qquad (1)$$

where $\frac{\partial T}{\partial x}$ and $\frac{\partial T}{\partial y}$ denote the partial derivatives of the magnetic field with respect to the *x*- and *y*-directions, respectively.

(b) Tilt Derivative (TDR)

The Tilt Derivative (TDR) method, originally introduced by Miller and Singh (1994) and later refined by Verduzco et al. (2004), is widely applied in potential field studies to accentuate shallow subsurface features. This technique offers a normalized representation of magnetic anomalies, which reduces the dependence on absolute field intensity and helps in isolating closely spaced or overlapping anomalies. By minimizing the effect of deeper sources, TDR emphasizes near-surface structures, making it particularly useful in areas with complex geology. The tilt angle is calculated as the arctangent of the ratio between the vertical derivative and the horizontal gradient of the magnetic field. This ratio-based approach normalizes the magnetic signal and sharpens the edges of shallow features.

$$\mathrm{TDR} = \tan^{-1}\left|\frac{\mathrm{VDR}}{\mathrm{THDR}}\right| \qquad (2)$$

where $\mathrm{VDR} = \frac{\partial T}{\partial Z}$ represents the first vertical derivative of the magnetic field, and

$\mathrm{THDR} = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2}$ is the Total Horizontal Derivative.

(c) Horizontal Derivative of Tilt Derivative

The Horizontal Derivative of the Tilt Derivative (TDR) is an advanced derivative technique employed to improve the resolution of shallow magnetic anomalies and to delineate structural features with enhanced clarity. While the conventional TDR emphasizes the edges of causative bodies by normalizing magnetic responses, computing the horizontal derivative of the TDR accentuates lateral variations in the tilt angle. This process allows subtle boundaries and minor structural features to be more clearly identified, particularly in regions with overlapping anomalies or gradual changes in the magnetic field gradient.

$$\mathrm{HD\text{-}TDR} = \sqrt{\left(\frac{\partial(\mathrm{TDR})}{\partial x}\right)^2 + \left(\frac{\partial(\mathrm{TDR})}{\partial y}\right)^2} \qquad (3)$$

(d) Analytical Signal Analysis (ASA)

The Analytical Signal (AS) technique is a powerful tool in magnetic data interpretation that enhances anomaly signatures and facilitates the identification of source boundaries. Unlike methods that rely on field orientation, the analytical signal is directionally independent, making it especially valuable in regions of low magnetic latitude where reduction-to-pole corrections are often unreliable. The AS is computed by combining the derivatives of the magnetic field in the x, y, and z directions, which results in a measure of the total gradient amplitude around the source. This property ensures that the maxima of the analytical signal occur directly over the edges of causative bodies, thereby simplifying structural interpretation.

Mathematically, the analytical signal is expressed as per (Nabighian, 1972; 1984).

$$\mathrm{AS} = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \qquad (4)$$

where $\frac{\partial T}{\partial x}$, $\frac{\partial T}{\partial y}$, and $\frac{\partial T}{\partial z}$ represent the derivatives of the magnetic field in the x, y, and z directions.

(e) Cos (θ) analysis

The Cos(θ) parameter is normally computed from the ratio of the THDR to the AS (Wijns et al., 2005). This parameter provides a normalized measure that is independent of magnetization direction, making it particularly useful in regions of low magnetic inclination where conventional reduction-to-the-pole (RTP) may not yield reliable results. The cos θ approach enhances the delineation of near-surface sources and reduces directional bias, thereby improving structural interpretation of the magnetic field. Mathematically it can be expressed as:

$$\cos(\theta) = \frac{\mathrm{THDR}}{\mathrm{AS}} \qquad (5)$$

QUALITATIVE INTERPRETATION OF GROUND MAGNETIC DATA

The magnetic intensity values within the study region vary significantly, ranging from approximately -47957 nT to 48622 nT (Figure 4a), indicating notable lateral changes in subsurface magnetic properties. The magnetic anomaly patterns reveal a clear NW-SE alignment suggesting structural or lithological trends consistent with underlying tectonic features. It is noted that both the magnetic anomalies and the elevations (Figure 4) are comparatively higher in northern part. In the northeastern zone, magnetic anomalies (Figure 5) are remarkably high compared to the southwestern part. The anomalies are broad and of high wavelength, typically representing deeper magnetic sources or large, magnetized rock bodies. In contrast, the southwestern part of the study area displays narrower, short-wavelength anomalies, pointing to shallower magnetic sources or sharp contrasts in magnetic susceptibility.

Notable zones with elevated magnetic responses include Mebo, Bomjur, Roing, Santipur Tezu, Wakro predominantly located in the northeastern quadrant. These areas likely correspond to zones with higher concentrations of magnetite-bearing rocks or mafic intrusions. Intermediate magnetic values are observed around Jonai, Sadiyaghat, Namsai, Kharsang and Manabum areas which are following the moderate magnetic field (Figure 5) as well as the moderate elevation (Figure 4). Further, Digboi, Margherita, Nampong and southern part of Jonai indicated low magnetic anomalies.

It is observed that in the northern part of the study area, Mebo and Bomjur show both high magnetic and high elevation and high gravity value (Ghosh et al., 2010). However, Digboi -Marghertita and Nampong show low magnetic with moderate elevation and high gravity data (Figures 4, 5 and 6). Manabum and Kharsang show moderate magnetic values with higher elevation and lower gravity data. Areas such as Tezu, Wakro, Roing Bomjur in the northeastern zone show higher magnetic amplitudes, potentially reflecting the presence of magnetic lithologies such as elevated basement cover or altered zones.

A contrasting relationship between topography and magnetism is evident: regions with higher magnetic values correspond to higher elevation, while lower magnetic values in the southern part are associated with moderate elevations. This spatial correlation between magnetic anomalies and topography suggests variations in the underlying crustal structure and composition.

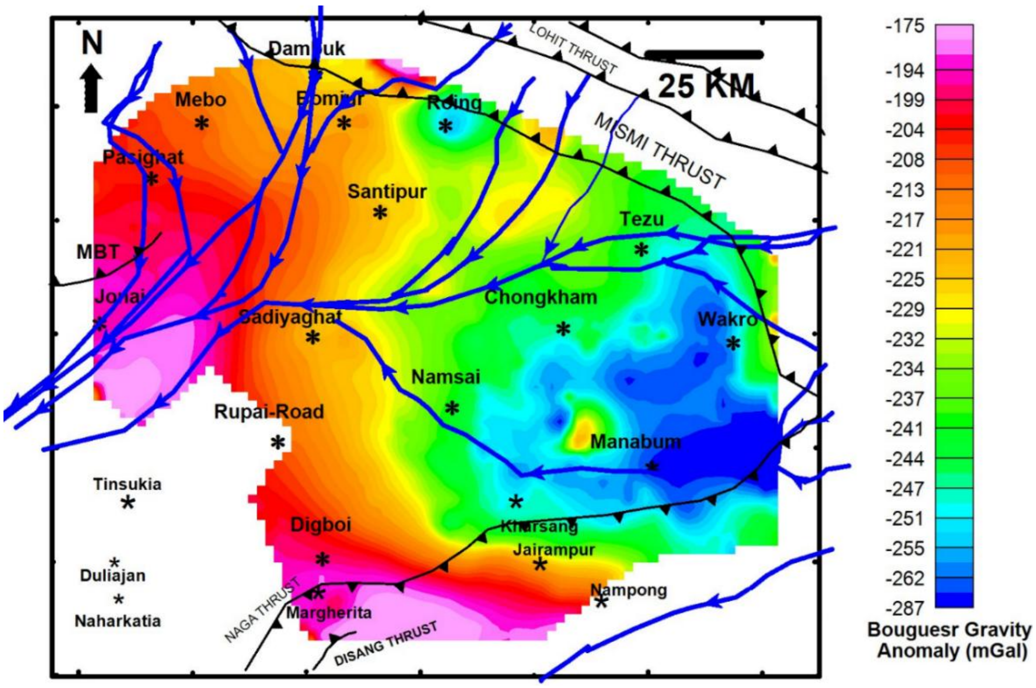

***Figure 6**: Bouguer Gravity Anomaly map shows variation from -287 mGal to -175mGal in the study area, with a general northwest–southeast orientation (After Ghosh et.al., 2010)*

MAGNETIC DATA REDUCTION

The location of the study area is shown in Figure 1(a). To evaluate the regional geomagnetic parameters required for derivative calculations, the inclination and declination values were analyzed. The inclination across the area is found to vary around Inclination ≈ 40° ± 2°E, while the declination ranges from Declination ≈ 0° to +2°E. Given these values, the application of reduction-to-pole (RTP) correction is not essential, as the magnetic field parameters lie within an acceptable range for direct interpretation.

Although Reduced to Pole (RTP) is not essential for interpretation at this mid-latitude location due to the use of direction-independent derivative filters, we have included Figure 7 (RTP map) for completeness. Please be noted that RTP was performed to ensure thoroughness, while the interpretation is primarily based on direction-independent filtering methods.

Accordingly, the analysis has been carried out on the Total Magnetic Field (TMF) data after applying standard corrections. These include base-station correction (to remove diurnal variations), tie-line levelling, and micro-levelling to improve data consistency. The main geomagnetic field contribution was removed using the International Geomagnetic Reference Field (IGRF) for the survey epoch, yielding the Total Magnetic Anomaly

(TMA) data, which was subsequently used for derivative computations and interpretation. These operators are

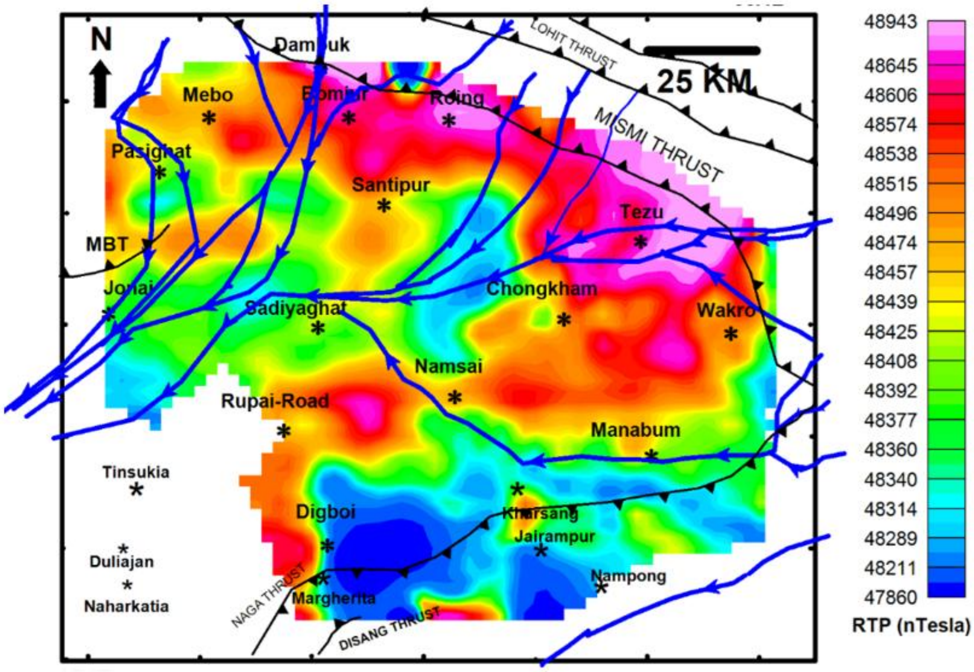

Figure 7: Reduced-to-Pole (RTP) magnetic anomaly map showing the distribution of magnetic sources corrected for inclination and declination.

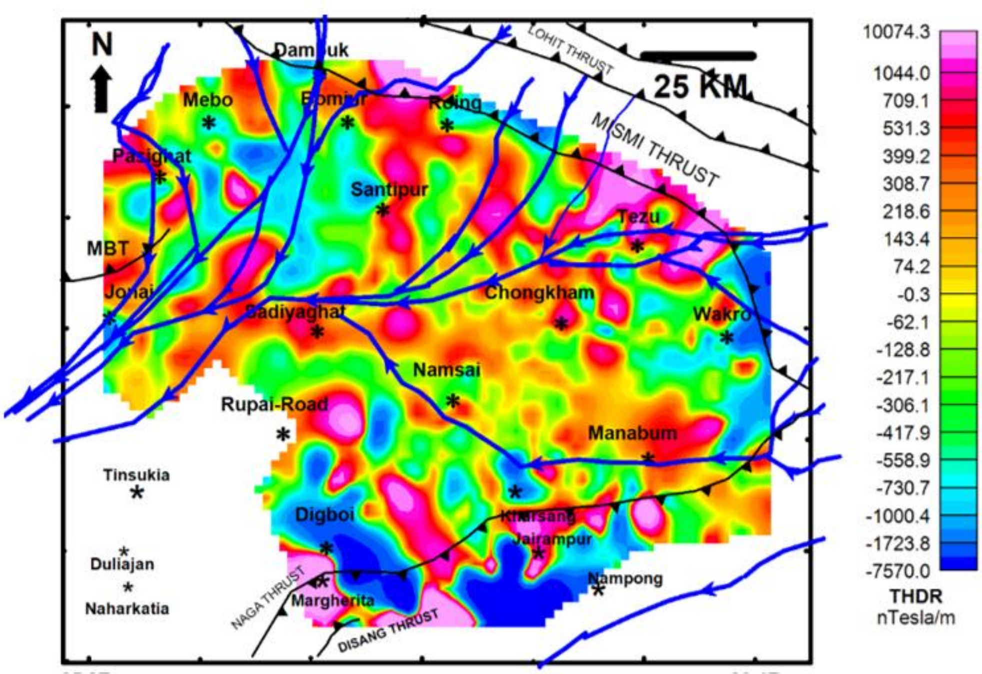

Figure 8: THDR anomaly map highlighting variations in contrast, with high gradients marking thrust/fault zones and lateral discontinuities.

direction-independent (or nearly so). Therefore, Reduced to Pole (RTP) (Figure 7) is not required and can introduce artifacts if magnetization/remanence varies. As the study area is not very large so a single inclination and declination is reasonable.

DATA INTERPRETATION

High THDR values are typically associated with sharp lateral contrasts such as fault zones, dyke boundaries, or lithological contacts, while lower values indicate smoother variations in the subsurface. Because of its sensitivity to shallow sources, THDR is particularly effective for highlighting near-surface structures (Figure 8). When applied in combination with other enhancement filters such as the tilt derivative or analytic signal, it significantly improves the interpretation of basement architecture and assists in evaluating zones with potential for mineral or hydrocarbon accumulation.

The zero-contour of the tilt derivative frequently aligns with the edges of causative bodies, providing a reliable means to delineate structural boundaries such as faults, dykes, and shallow basement highs (Figure 9).

From a mathematical perspective, the horizontal derivative of TDR (HD-TDR) is obtained by differentiating the tilt angle along both the x- and y-directions, generating gradient maps that highlight areas of maximum lateral change. Peaks in these maps typically correspond to the edges of buried structures, lithological contacts, or fault zones, whereas zero-contours often mark structural boundaries (Figure 10). By comparing TDR with its horizontal derivatives provides geophysicists with a powerful tool to accurately map shallow subsurface structures, refine structural interpretations, and support exploration efforts for resources such as hydrocarbons or mineral deposits. The resulting amplitude map is particularly effective for delineating the geometry and edges of magnetic bodies such as dykes, faults, or basement highs.

When used in conjunction with techniques like TDR, HD-TDR, and THDR, the analytical signal (AS) provides a complementary perspective—offering more robust edge detection and depth estimation of magnetic sources (Figure 11).

An AS anomaly map is a valuable technique in magnetic data interpretation, particularly for identifying subsurface geological features in a complex terrain. It is derived by combining the horizontal and vertical gradients of the magnetic field, producing a scalar function that highlights the edges of magnetic sources. The key advantage of the AS method is that its amplitude peaks are positioned directly above the boundaries of magnetic bodies, regardless of the direction of magnetization. This characteristic enables more accurate mapping of geological structures such as faults, contacts, and lithological boundaries. By emphasizing these transitions in magnetic properties, AS maps offer improved resolution and clarity over conventional magnetic anomaly maps, making them highly effective for delineating structural and lithological features in both mineral exploration and regional geological studies.

The spatial distribution of cos (θ) values highlights subtle variations in the geometry and position of magnetic anomalies. Areas with higher cos (θ) values generally indicate regions dominated by horizontal field components, which are commonly associated with shallow or elongated sources. Conversely, lower values point to vertically oriented magnetization or deeper-seated structures. This contrast allows for improved discrimination of linear trends, contacts, and potential fault or shear zones within the study area.

By comparing the cos (θ) map with conventional derivative products such as THDR and tilt angle, we observe that cos (θ) offers smoother and more stable anomaly patterns, especially over areas with complex geology. This property makes it a valuable tool for qualitative interpretation as well as for guiding quantitative modeling. Notably, regions of consistently high cos θ correlate well with known structural alignments, whereas anomalous isolated lows may indicate localized intrusive or deeper magnetic sources.

Overall, the application of cos (θ) analysis to the total magnetic intensity (TMI) data provides a robust framework for understanding the underlying structural fabric. When integrated with other filtering techniques and geological constraints, this parameter enhances our ability to infer source depth, shape, and continuity. Such insights are essential for refining subsurface models and for identifying geologically significant targets for further investigation.

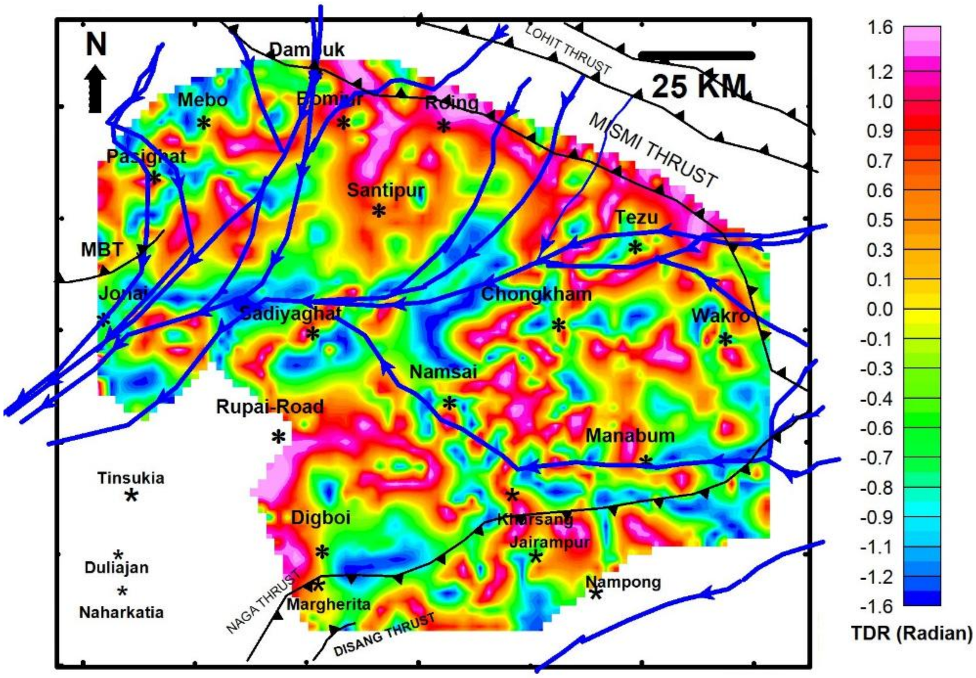

Figure 9: Tilt Derivative (TDR) illustrating edge responses, with zero-contours marking possible faults, thrusts, and lithological contacts.

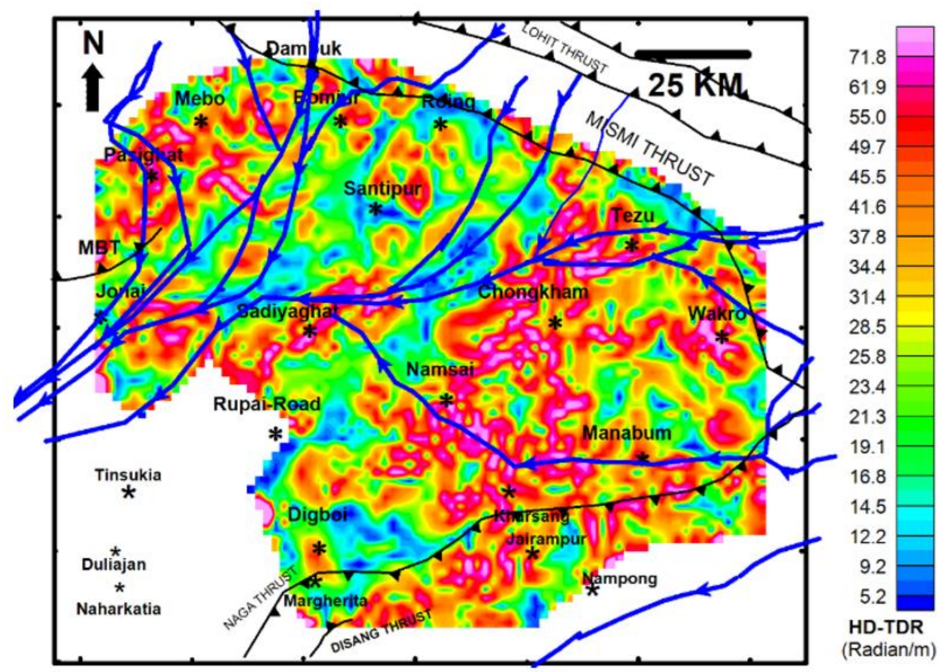

Figure 10: Horizontal Derivative of Tilt Derivative (HD-TDR) anomaly map highlighting lateral variations in tilt values, which enhance the definition of structural edges and boundaries.

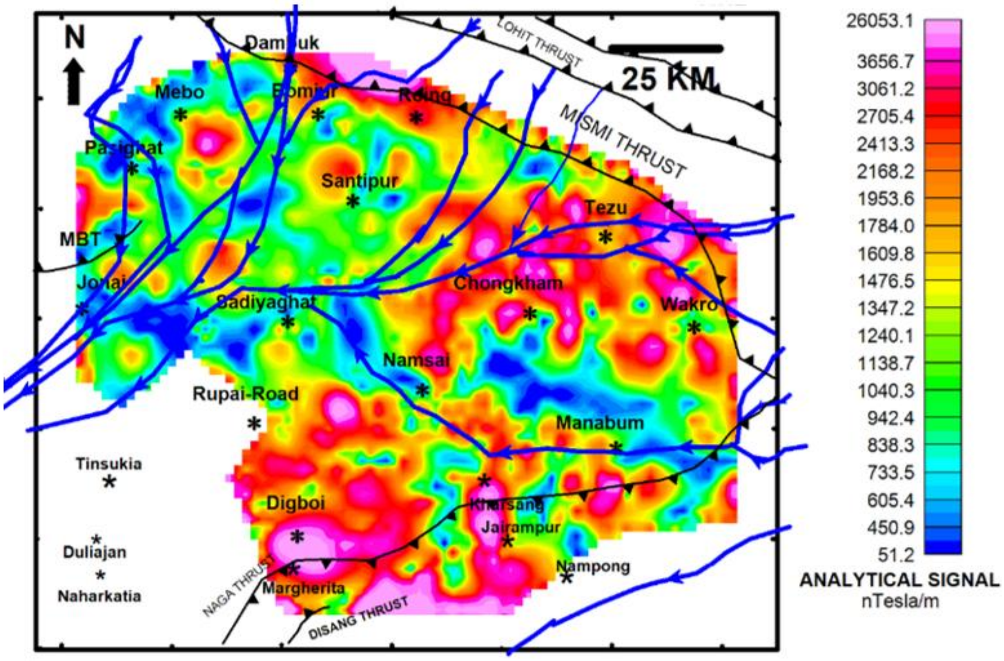

***Figure 11**: Analytical Signal (AS) anomaly map displaying amplitude maxima located directly above the edges of magnetic sources, effectively highlighting structural features and lithological boundaries.*

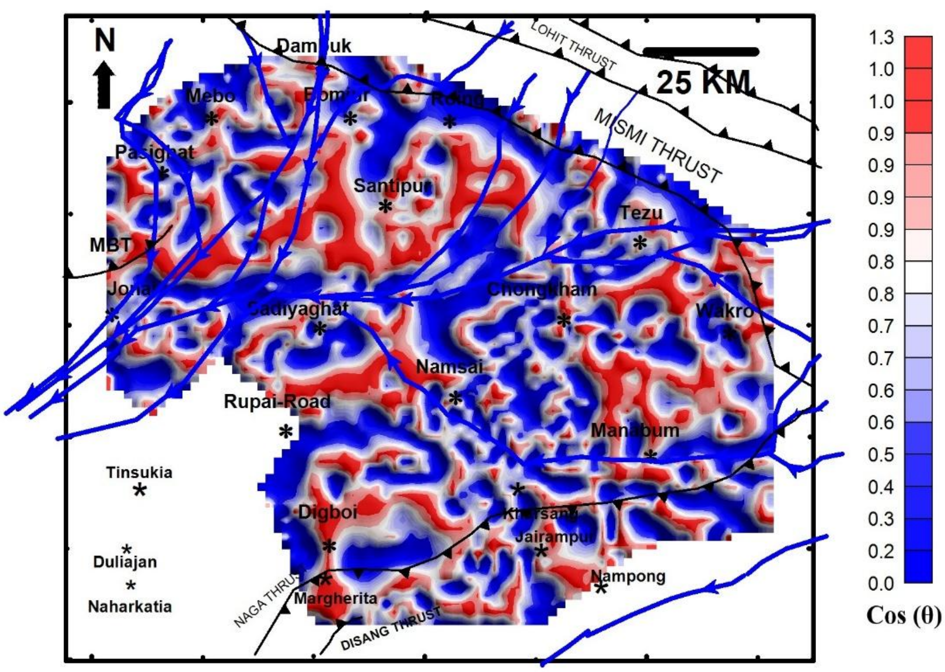

***Figure 12**: Cos (θ) map derived from total magnetic field highlighting structural trends and source geometries in the study area.*

The cos (θ) parameter (Figure 12), derived from the ratio of THDR to Analytical Signal, offered additional insights into the magnetization characteristics and source geometry. Unlike conventional filters, cos (θ) produced anomaly patterns that were smoother and less sensitive to magnetization direction, making it a robust tool in areas where magnetization vectors vary significantly. High cos (θ) values indicated shallow or elongated sources dominated by horizontal magnetic components, while low values reflected deeper or vertically oriented sources. When compared with THDR and TDR maps, cos (θ) consistently enhanced the continuity of linear

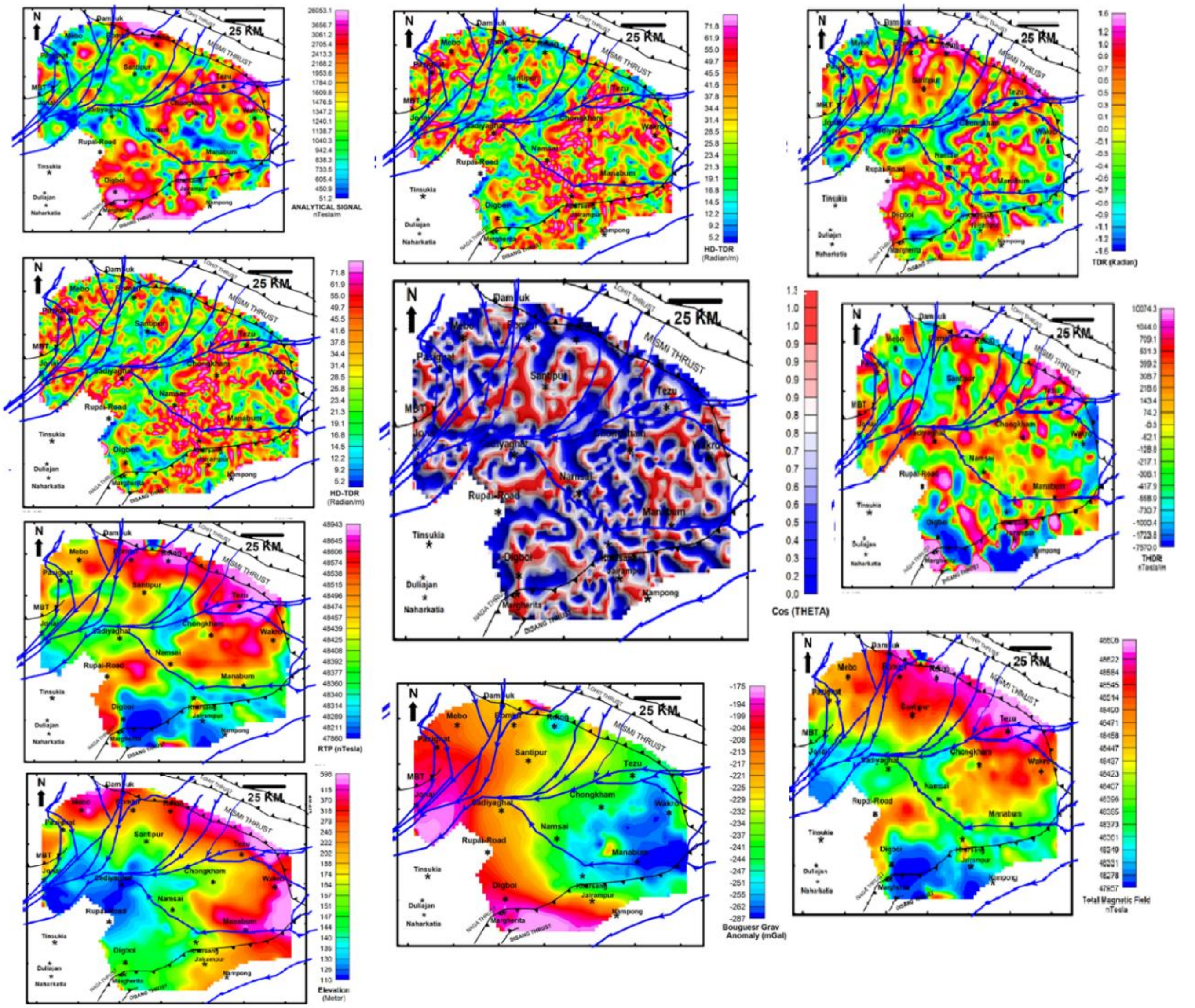

***Figure 13**: Integrated analysis of various derivatives alongside the Bouguer gravity anomaly, total magnetic anomaly, and elevation map. The combined interpretation demonstrates strong correlations, providing enhanced insights into the geological features and supporting improved understanding of the study area.*

features and provided improved discrimination of subtle geological trends.

Taken together, these techniques demonstrate the advantage of adopting a multi-attribute approach in magnetic interpretation. RTP establishes the anomaly geometry free from inclination effects, while derivative methods (THDR, TDR, HD-TDR) sharpen structural boundaries. The analytical signal and cos θ provide magnetization-independent perspectives that reinforce and refine structural interpretation.

The cos(θ) map reveals significant spatial variability in structural orientations across the region. High values (red to pink) indicate areas of consistent structural alignment, notably near Antiup, Chongkham, and the Mismi Thrust, suggesting uniform deformation. In contrast, low values (blue) around Digboi, Kharsang, and the Naga Thrust reflect greater angular deviation, implying complex or localized deformation. Transitional zones with intermediate values, such as around Namsai, Rupai-Road, and Manabum, suggest mixed orientations due to interactions between regional and local tectonic influences. These patterns offer valuable insight into the structural coherence and tectonic activity of the area.

DISCUSSION

The application of different magnetic data enhancement techniques in the present study provides complementary perspectives on the subsurface structural framework. The Reduced-to-Pole (RTP) transformation (Figure 7) serves as a baseline by centering anomalies directly above their causative bodies, minimizing distortions caused by inclination and declination. This correction is particularly important in low- to mid-latitude regions such as the present study area, where magnetic anomalies are otherwise asymmetric and difficult to interpret reliably.

Among the derivative-based methods, the Total Horizontal Derivative (THDR) (Figure 8) proved to be highly sensitive to sharp lateral contrasts, making it an effective tool for identifying shallow structural features such as dike boundaries, fault zones, and lithological contacts. When compared with Tilt Derivative (TDR) results (Figure 9), THDR provided a clearer expression of high-frequency anomalies, while TDR was more effective in mapping broader structural trends. The zero-contour of TDR consistently aligned with causative body edges, confirming its robustness as an edge-detection tool. The horizontal derivative of TDR (HD-TDR) (Figure 10) further enhanced lateral resolution, providing sharper delineation of boundaries that were only faintly visible in conventional TDR and THDR maps.

The Analytical Signal (AS) amplitude (Figure 11) offered a more integrated view of source geometry by producing maxima directly above causative bodies. This characteristic eliminates ambiguity arising from magnetization direction and is particularly valuable in structurally complex terrains. Compared to THDR and TDR, the analytical signal provided a smoother but more geologically consistent depiction of source edges and facilitated depth estimation, which is crucial for both mineral and hydrocarbon exploration.

This integrated magnetic analysis (collage map, Figure 13) enhances our understanding of the subsurface geological framework and identifies key zones warranting further geological and geophysical investigation. The integrated analysis suggests that the study area is structurally controlled by multiple sets of faults and lineaments, some of which correlate with known geological trends, while others represent previously unrecognized features that may warrant further investigation through ground surveys or drilling. It is also providing improved structural clarity in the areas where seismic imaging remains unconclusive and offer a valuable framework for guiding further exploration in the Assam-Arakan basin.

Limitation

Nevertheless, the interpretation of magnetic data is subject to inherent limitations and uncertainties that must be carefully considered. Ambiguities may arise due to several factors, including the complexities involved in the data acquisition process, external influences such as cultural noise from nearby infrastructure, and the methodological constraints associated with derivative-based filtering techniques applied to the magnetic dataset. These factors can affect the resolution and accuracy of the interpreted geological features. By explicitly acknowledging these potential sources of error, the study provides a more comprehensive and transparent analysis, allowing for a balanced evaluation of the results and enhancing the credibility of the structural interpretations and subsurface models presented.

CONCLUSIONS

The integrated application of magnetic data transformation and derivative-based enhancement techniques has provided a detailed understanding of the subsurface structural configuration in the study area.

Derivative methods proved highly effective in delineating shallow structural features. The Total Horizontal Derivative (THDR) highlighted sharp lateral contrasts, while the Tilt Derivative (TDR) and its horizontal derivative (HD-TDR) offered precise edge detection and improved definition of structural boundaries. The Analytical Signal (AS) further complemented these methods by producing amplitude maxima directly over causative bodies, reducing ambiguity due to magnetization direction and aiding in depth estimation.

The cos (θ) parameter, derived as the ratio of THDR to AS, demonstrated particular utility in mapping both shallow and deeper sources while minimizing the influence of varying magnetization. Its smooth and stable anomaly patterns enhanced the recognition of linear trends, structural discontinuities, and intrusive features that were less distinct in conventional derivative maps. Overall, the combined use of THDR, TDR, HD-TDR, AS, and cos (θ) has proven effective in refining the structural interpretation of the study area. The results indicate the presence of multiple fault systems, basement highs, and potential intrusive bodies that are consistent with regional geological trends. Such insights are particularly valuable in geologically complex regions like the northeastern part of India, where structural interpretation is challenging. The application of various magnetic derivative techniques facilitates the delineation of lineaments, thrusts, and fault orientations, contributing to more accurate structural mapping and offering implications for both mineral and hydrocarbon exploration.

ACKNOWLEDGEMENTS

The authors sincerely express their gratitude to Mr. R. S. Ram, Head of GM–Geophysics, for his valuable support and guidance throughout this work. We also gratefully acknowledge Oil India Limited for granting permission to use the available datasets and for their consent to publish this paper.

Disclaimer

Neither the SPG nor OIL, nor the Editors, assume any responsibility for the accuracy, content, or interpretation of the material presented in this article. Full responsibility for the content rests solely with the authors.

REFERENCES

Cooper, G.R.J and D. R. Cowan, 2006, Enhancing potential field data using filters based on the local phase, Comput. and Geosci., **32**,1585–1591. http://dx.doi.org/10.1016/j.cageo.2006.02.016

Francisco, J.F.F., D. S. Jeferson, D. B. Alessandra, and G. D. C. Luís, 2013, Enhancement of the total horizontal gradient of magnetic anomalies using the tilt angle, Geophysics 78(3), J33–J41. https://doi.org/10.1190/geo2011-0441.1

Ghosh, G. K, S. K. Basha, and V. K. Kulshrestha, 2010, Integrated interpretation of gravity, magnetic and seismic data for delineation of basement configuration in Sadiya block, upper Assam, India, 8th Biennial SPG Conference, Paper ID 225, 1-6.

Miller, H. G. and V. Singh, 1994, Potential field tilt-a new concept for location of potential field sources, J. Appl. Geophys., **32**(2-3) ,213–217. https://doi.org/10.1016/0926-9851(94)90022-1

Nabighian, M. N, 1972, The analytic signal of two-dimensional magnetic bodies with polygonal cross-section: its properties and use for automated anomaly interpretation, Geophysics, **37**(3), 507-517. https://doi.org/10.1190/1.1440276

Nabighian, M. N, 1984. Toward a three-dimensional automatic interpretation of potential field data via generalized Hilbert transforms: Fundamental relations, Geophysics, **49**(6), 2143-2158. https://doi.org/10.1190/1.1441706

OIL Exploration Report, 2002, A study on the regional distribution of Paleocene-Lower Eocene sediments and evolution of mega high in OIL's operational areas of upper Assam basin, Chief Geologist, Note No.351, G&R Department, Duliajan (Unpublished).

Verduzco, B., J. D. Fairhead, C. M. Green, C. Mackenzie, 2004, New insights into magnetic derivatives, The Leading Edge, **23**(2),116–119. https://doi.org/10.1190/1.1651454

Wang, W., Y. Pan, and Z. Qiu, 2009, A new edge recognition technology based on the normalized vertical derivative of the total horizontal derivative for potential field data, Appl. Geophys.,**6**(3), 226–233. https://doi.org/10.1007/s11770-009-0026-x

Wijns, C., C. Perez, and P. Kowalczyk, 2005, Theta Map: edge detection in magnetic data. Geophysics, 70: L39–L43. https://doi.org/10.1190/1.1988184

BIOGRAPHIES

Gopal Krishna Ghosh received his M.Sc. (Tech.) and Ph.D. degrees in exploration geophysics from Banaras Hindu University (BHU), Varanasi, and an M. Tech. in mining geophysics from IIT (ISM), Dhanbad. Gopal currently works as Deputy General Manager (geophysics) at Oil India Limited, bringing over 25 years of combined experience in both academia and industry. His expertise spans a wide range of geophysical applications, including thrust fault delineation, estimation of sedimentary thickness and basement depth, seismic attribute, curvature analysis, micro-seismic and macro-seismic monitoring, roof-fall prediction, and stress zone analysis in coal and gold mining environments. He has also worked extensively on digital seismic data management, GIS applications, and machine learning.

Gopal began his research career at the National Institute of Rock Mechanics and the Wadia Institute of Himalayan Geology, before transitioning to industry with Tata Consultancy Services and later Oil India Limited. He is a member of SEG, EAGE, and a life member of SPG, AEG, and IGU.

Dharm Raj Yadav received his M.Sc. (Tech) in exploration geophysics from Banaras Hindu University (BHU), Varanasi. He is currently serving as Deputy Chief Geophysicist (geophysics) at Oil India Limited (OIL), and involved in seismic data acquisition, processing, and management. He has worked in planning and executing 2D and 3D seismic surveys, handling large-scale seismic, AGG-GM datasets, and ensuring quality control of field deliverables.

Dharam is engaged GIS, and data-driven technologies to enhance seismic survey planning and execution. He is a life member of SPG and served as Treasurer of its Duliajan Chapter from 2022 to 2024.

Aditya Amber received a 5-year Integrated M. Tech. in applied geophysics in 2019 from IIT (ISM), Dhanbad and joined Oil India Limited in 2020. He began his career with field assignments in frontier OALP areas and now manages seismic and other geophysical datasets, supporting field operations and processing through GIS-based analysis and mapping. His interests include leveraging GIS and digital tools to optimize exploration workflows, and he is a life member of the Society of Petroleum Geophysicists (SPG), India.

Rama Shankar Ram graduated from the Institute of Science, BHU Varanasi with an M.Sc. Tech in exploration geophysics in 1992. He began his industrial career with Oil India Limited in 1993, where he currently holds the position of General Manager (geophysics). With over three decades of experience, his work spans various disciplines of exploration, with a special focus on 2D/3D seismic data acquisition, processing, and interpretation. His involvement also extends to a range of other geophysical surveys, including gravity, magnetic, AGG, and passive seismic surveys. He is a life member of the Association of Exploration Geophysicists (AEG) and a member of the Society of Petroleum Geophysicists (SPG).