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Enhancement and modeling of aeromagnetic data of Akonolinga-Nguinda area, Centre-East Cameroon

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Abstract

Previous works in southern Cameroon have highlighted prominent geological structures, including faults sub parallel to the Central Cameroon Shear Zone and the Sanaga Shear zone, exposed within the Central African Fold Belt along the northern margin of the Congo Craton. However, the relationships between these structures and the regional lithology require updating. Aeromagnetic data from the Akonolinga-Nguinda study area were processed using Oasis Montaj (v.8.4) software. Interpretation of the Reduced-To-Equator (RTE) magnetic anomaly field revealed multiple magnetic targets characterized by both positive and negative intensities. The RTE map provides a robust lithostructural framework, allowing for the correlation of structural faults with regional rock units. Derivative filter grids (horizontal gradient, vertical gradient, analytic signal, and tilt derivative) display an undulatory pattern, suggesting that the study area has undergone complex tectonic deformation, as corroborated by the mapped lineaments and intrusions. Consequently, the resulting structural map reveals a complex network of linear features predominantly oriented NE–SW, N–S, E–W and ENE–WSW. The 2.75D modeling along two NW–SE profiles drawn on the RTE grid indicates a crystalline basement composed of schists, quartzites, micaschists, gneisses and granulites intruded by pegmatite and quartz veins. Combined, these geophysical and structural results demonstrate that the study area has experienced intense, polyphase tectonic activity.

Key points

- The derivative filters highlighted the geologic contours/contacts and the general trend of structures.
- The maxima and multiscale maps helped to draw the structural map which showed lineaments whose main directions are NE-SW, ENE-WSW with variable dip.



- The 2.75D model inferred a subsurface down to 4 km depth with a lithology including sediment, schist, micaschists, gneiss and granulites; some intruded by pegmatite and quartz veins during tectonic movements.
- Beside intrusions, several tectonic discontinuities such as contacts/faults, fractures and folds.

Keywords Akonolinga-Nguinda, Aeromagnetic anomaly, Congo Craton, Lineament, Intrusions, 2.75D data modeling

1 Introduction

Structural and mineral mapping of any region requires detailed geological and geophysical investigations of the subsurface [33]. The result obtained from aeromagnetic maps are an important tools for geological mapping and for identifying mining targets during minerals exploration and subsurface geophysical investigations [31]. Several geological and geophysical studies have been conducted in southeastern Cameroon. For instance, [2] utilized a Bouguer gravity anomaly map to highlight a SW-NE-trending structure associated with a granitic intrusion and the Pan-African basement to the north; this structure is bounded by a steep gradient interpreted as the tectonic boundary between the Congo Craton and the Pan-African Belt. In addition, they identified a high susceptibility dyke (0.041 SI) beneath the Pan-African formations, possessing an approximate lateral extent of 10 km at an average depth of 4148 m. These bodies are assumed to have been emplaced at high crustal levels in a continental collision zone and subsequently metamorphosed to granulite facies during the Pan-African orogeny approximately 620 Ma. Regional geological structures have also been interpreted from the reduction to the equator and derived filtered grids. These structures predominantly display NW–SE, E–W, and NE–SW trends. Field investigations revealed that the regional study area consists of iron formations, amphibolite, gneisses, gabbros, biotite granites, and charnockite [7]. A structural study conducted by [29] in southeast of the study area identified E–W, ESE–WNW and ENE–WSW faults propagating from the basement into the cover sequence. Furthermore, 2.75D modeling, revealed basement blocks composed of magnetite and/or hematite-bearing dolerite, schist and sandstone. Similarly, [22] highlighted adjacent NE–SW, NW–SE, ENE–WSW, and WNW–ESE brittle and folded structures, and observed circular anomalies across the area, which they interpreted as highly magnetic plutonic intrusions or granitic domes. The 2.75D modeling in the same study also highlighted gneissic and granitic intrusions, as well as several domes whose crests occur at various depths not exceeding -1800 m. Previous studies [5, 7, 9, 25, 39] in the surrounding region indicate that tectonic evolution was controlled by a continental collision between the Congo Craton and the Pan-African belt, marked by the underthrusting of the Congo Craton beneath the Pan-African belt. The configuration of geophysical lineaments confirms the tectonic subduction of the Congo Craton beneath the Pan-African belt and identifies the tectonic suture/boundary between the two crustal blocks [8, 19, 29, 39]. In addition, an audio-magnetotelluric study [12] revealed numerous subsurface discontinuities. Delineating a subsurface topography characterized by a major, deep-seated W–E fault. It is therefore necessary to complement this existing regional information with localized structural maps and 2.75D inversion models. While current knowledge and prior geologies /geophysics studies are well-established in surroundings,

the specific characteristics of the Akonolinga-Nguinda area remain poorly constrained via aeromagnetic methods. To address this research gap, aeromagnetic data were processed using Geosoft Oasis montaj software. Aeromagnetism is a potential-field method used for mineral and oil exploration, as well as systematic geological mapping. Specific filtering and processing will help characterize the structural and lithological features of the study area. Consequently, the aim of this study is to map the geological formations and structural architecture in the Akonolinga-Nguinda area using magnetic data. Then, the results of this study providing a foundational framework for identifying minerals exploration targets and guiding future subsurface geophysical investigations [32].

2 Geological background

The study area is located in Centre-East Cameroon, between longitudes 12°00'E–12°30'E and latitudes 3°30'N–4°30'N and has Nyong as a main river. The Geology of the study area (Fig. 1c [29]) predominantly consists of gneiss, quartz, schists and micaschists, structurally by the pegmatite and quartzite veins and the tectonic lines. Figure 1 include a regional tectonic map of the Africa, Cameroon and study area, highlighting cratonic blocks and the mobile zone (Fig. 1a [27]), major geological formations, the regional faults, tectonic boundaries, and structural trends (Fig. 1b [35]) as well as the local lithological formations and tectonics lines relevant to the study area (Fig. 1c [29]). [23] documented Paleozoic and Mesozoic magmatism, previously unrecognized within the Central Cameroon Shear Zone (CCSZ), while [20], underscored their geodynamic significance in the evolution of the PanAfrican formations at the northern margin of the Congo Craton. The geology of central-eastern Cameroon corresponds to an allochthonous thrust sheet obducted onto the Ntem complex and the Dja and Yokadouma series [15, 24]. According to [27, 28] southern Cameroon belongs to the Pan-African Belt and encompasses the Mbalmayo-Bangbis series, the Yaoundé group, the Bafia group and the Lower Dja, Yokadouma, Nola and Mintom series. The Yaoundé group is mainly composed of metasedimentary formations (pelites, meta-grauwackes, quartzites,

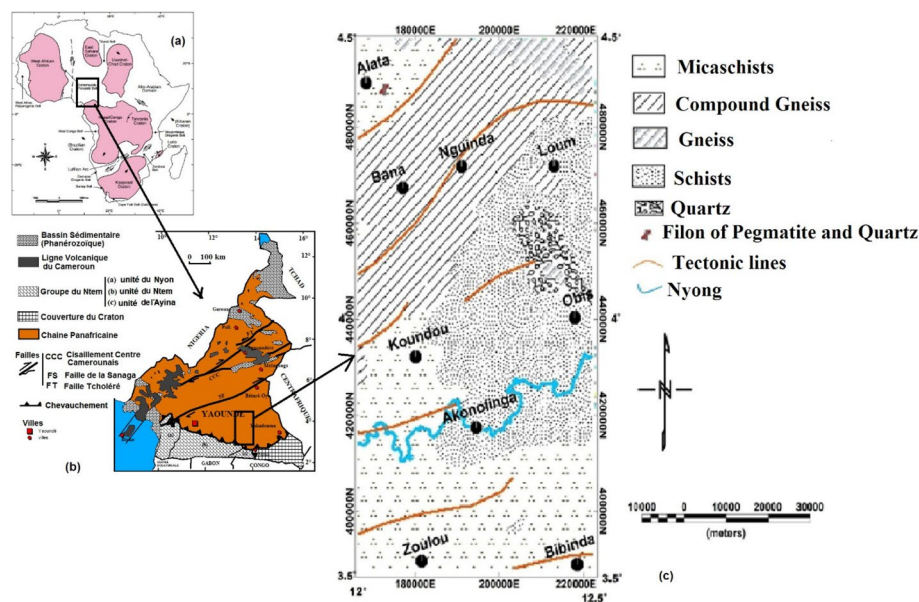


Fig. 1 a Stable zones (Archean cratonic nuclei) and mobile zones of Africa (modified after [27]); b Major geological formations of Cameroon (modified after [35]); c Geological map of the study area (modified after [22])

talc-schists) and a few pre- to syn-tectonic meta-igneous formations (metadiorites and amphibolites) [22, 24]. These formations exhibit a prograde metamorphism from south to north, characterized by the low to medium grade schist unit of the Mbalmayo series, which transitions northward into micaschists and granitic gneisses and ultimately into the granulites and migmatitic gneisses of the Yaoundé series [15]. The Paleoproterozoic component of these metasediments is attributed to the Paleoproterozoic basement of the Adamaoua-Yadé domain, with of depositional ages estimated between 625 and 624 Ma [15, 24]. The location of the Yaoundé tectonic nappe onto the Congo craton initiated at the peak of granulite-facies metamorphism between 616 and 610 Ma [20, 25], and continued under medium to low-grade metamorphic conditions until approximately 600–590 Ma [14, 25]. The Bafia group is a heterogeneous unit composed of relics of high-grade Paleoproterozoic rocks (biotite-garnet or biotite-hornblende gneiss and amphibolite) and Neoproterozoic metasediments, intruded by Neoproterozoic granitoids [10, 26, 30]. The sedimentary series (pelites and quartzites) of the Lower Dja, Yokadouma and Nola are considered Tonian age [4, 37]. They consist of continental tholeiitic basaltic flows and dikes, interpreted to be related to pre-Pan-African extensional tectonics along the northern margin of the Congo Craton [36, 37]. These series were recrystallized under low-grade metamorphic conditions and deformed during the Pan-African orogeny, except in the southern part of the Nola series [13]. The tectono-metamorphic evolution of the entire South Cameroon domain is marked by two major phases of deformation. The first phase, D1 (syn-orogeny Neoproterozoic) is widely recognized but heavily overprinted by the second phase D2 (post-orogeny) of deformation. It probably corresponds to the first stage of formation of the Yaoundé nappe, associated with granulite facies metamorphism [11, 26]. Furthermore, Sm–Nd isotopic data suggest a Paleoproterozoic to Neoproterozoic source and notably lack an Archean signature for the protoliths [34]. Based on this evidence, it has been proposed that the Yaoundé Series was deposited within the internal parts of the Cameroon orogenic belt prior to being thrust onto the Congo Craton [25]. Although rare pre- to syn-tectonic orthogneisses (750–600 Ma) are involved in nappe tectonics, this domain is characterized by a relative scarcity of late to post-tectonic granitoids, which are otherwise widespread throughout the Adamaoua–Yadé Domain. The granitoids of the Yaoundé Domain predominantly comprise high-grade mafic to intermediate granitoids (metadiorite or metagabbro), serpentinitized ultramafic rocks, and/or mafic dikes.

In the absence of borehole data, a simplified lithostratigraphic description derived from the regional geology of eastern Cameroon and previous geological studies has been added at the end of the Geological Setting section to summarize the relative succession of the main lithological units occurring in the study area Table 1.

Table 1 Lithological unit and magnetics susceptibilities

Relative age	Lithological unit	Magnetics susceptibilities($\times 10^{-6}$ SI)
Recent	Lateritic cover and alluvial deposits	100–5 00
Neoproterozoic	Schists and quartzites	300–3 000
paleoproterozoic	Metasedimentary rocks	100–5 000
paleoproterozoic	Migmatitic gneisses	100–25 000
paleoproterozoic	ortogneisses	100–25 000
paleoproterozoic	Granitoids and granodiorites	300–3 000
Basement	Granite	0–50 000
Basement	High grade metamorphic rocks	100–25 000

3 Aeromagnetic data and methodologies

3.1 Aeromagnetic data

The aeromagnetic dataset used in this study was acquired in 1970 through a joint cooperative agreement between the governments of Canada and the Federal Republic of Cameroon. The survey flight lines and tie lines were oriented N-S with nominal line spacing of 750 m. The survey was flown at a nominal terrain clearance of 235 m and monitored via a radar altimeter with an accuracy of ± 20 m. This baseline dataset was previously utilized and validated by [31].

3.2 General methodologies

The Reduced-to-the-Equator (RTE) and Horizontal Gradient Magnitude (HGM) grids were generated following the methodologies outlined by [38, 40]. Spatial derivative filters were applied to the residual magnetic anomaly map to enhance structural lineaments, faults, and lithological contacts. The primary advantages of derivative filtering include: resolving superimposed or closely spaced anomalies, and enhancing short-wavelength signals from shallow sources while suppressing long-wavelength regional trends [8]. By amplifying high frequencies, these filters isolate discrete shallow geological bodies and demarcate zones of intense structural disturbance, sharpening narrow linear and curvilinear features such as contacts, faults, and shear zones.

Upward continuation suppresses high-frequency noise and enhances the long-wavelength responses of deeper anomalies by mathematically elevating the observation plane farther from the sources [3]. The multi-scale edge detection method applied here couples the HGM technique with upward-continued fields at sequentially increasing altitudes. This approach allows for the characterization of the vertical continuity and lateral extent of magnetic sources, while defining the dip direction of identified contacts or faults. Upward continuation altitudes were selected between 1000 and 5000 m (at a 500 m increment) based on geological constraints to clearly delineate deep-seated linear structures and monitor variations in dip from the near-surface to deeper crustal levels.

The local maxima of the HGM extracted from successive upward-continued steps trace the lineaments of the study area; these are interpreted as faults or lithological contacts where they form linear arrays. Conversely, quasi-circular clusters of maxima indicate intrusions. The dip direction of these structures is determined by analyzing the spatial migration of the maxima across increasing continuation altitudes. Quasi-vertical structures exhibit a vertical superposition of maxima, whereas sloping/oblique structures display a lateral shift of maxima systematically oriented in the down-dip direction. According to [41], multi-scale analysis is vital for delineating deep crustal faults and compiling a comprehensive structural map.

The Analytic Signal (AS) amplitude [15–17] map centers symmetrical anomalies directly over the edges of magnetized bodies. The absolute value of the AS over dikes and steep contacts is independent of the magnetization direction (remanent or induced) [15, 16, 28]. [15, 17] demonstrated that the AS exhibits a distinct positive peak directly above thin, linear magnetic sources. Because the AS amplitude is a symmetric function maximizing over the source edges, the half-width of the anomaly peak can be used to estimate source depths. Furthermore, [28] confirmed that the 3D analytical signal maxima align precisely over structural contacts marked by pronounced magnetization contrasts. The analytical workflow adopted in this study maximizes the extraction

of structural data from the aeromagnetic dataset. Derivative filters are uniquely suited for Precambrian basement terrains where structural networks control both the regional geodynamic evolution and localized mineralization.

The 2.75D modeling method is highly effective for constraining the geometry of basement configurations, fault planes, veins, and semi-infinite contacts. Profiles were extracted perpendicular to the strike of key anomalies on the RTE total magnetic field grid to minimize oblique styling errors. Profile extraction and data tabulation were conducted using the “Maptools” and “Database” modules of Geosoft Oasis montaj, while the profile cross-sections were modeled using the “GM-SYS” software package (v.2014). Initial source positions were constrained using HGM maxima, AS peaks, and Euler deconvolution solutions. Initial depth estimates were derived from Euler deconvolution and tilt-angle variations, honors the regional average depth of 2500 m established by [39].

Magnetic modeling requires several parameters reflecting local geomagnetic conditions during the survey period. The core parameters used in this study include: a total magnetic field intensity of 32,697.97 nT; an International Geomagnetic Reference Field (IGRF) value of 32,771.41 nT; a field inclination of -16.99° ; a declination of -6° ; and a flight altitude of 235 m. Magnetic susceptibility ranges were constrained using standard petrophysical tables (e.g., [6]) and the localized estimates in Table 1. The 2.75D modeling was executed along profiles crosscutting the dominant magnetic anomalies, providing quantitative constraints on source geometries and susceptibility contrasts while remaining honors to the known geological framework. The final models were iteratively optimized until an acceptable fit between the observed and calculated magnetic curves was achieved.

4 Results

4.1 Reduced to the equator map

The RTE map (Fig. 2a) displays magnetic anomaly values ranging from -188.09 nT to $+102.24$ nT, reflecting variations in the composition, geometry, and depth of the buried crystalline basement. The structural grain of the underlying sources is inferred directly from the alignment of these magnetic anomalies. The RTE map subdivides the study area into three main SW–NE-trending anomaly domains from south to north:

- Southern Domain: Characterized by heterogeneous, high-frequency anomalies.
- Central Domain: Dominated by high-intensity magnetic anomalies that terminate abruptly and symmetrically along their northern boundary.
- Northern Domain: Marked by a sub-elliptical, low-intensity anomaly along the Bana-Nguinda axis, bounded further north by a very high-intensity ($+102.24$ nT) anomaly.

Fault zones are marked by the sharpest lateral gradients and abrupt amplitude transitions between positive and negative magnetic signatures. These are most prominent along the northern margins along the Akonolinga-Obis, Koundou-Loum, and Bana-Nguinda axes. The residual magnetic map (Fig. 2b) clarifies this regional tectonic zoning. High-amplitude, high-susceptibility residual blocks in the south highlight the shallowing of the rigid, Archean Congo Craton basement. Conversely, alternating, elongated residual lows and highs to the north map the highly deformed metamorphic belts and volcano-sedimentary configurations (like the Lom Series) within the Pan-African Mobile Belt. Spatial derivative filters specifically the analytic signal (AS), horizontal gradient

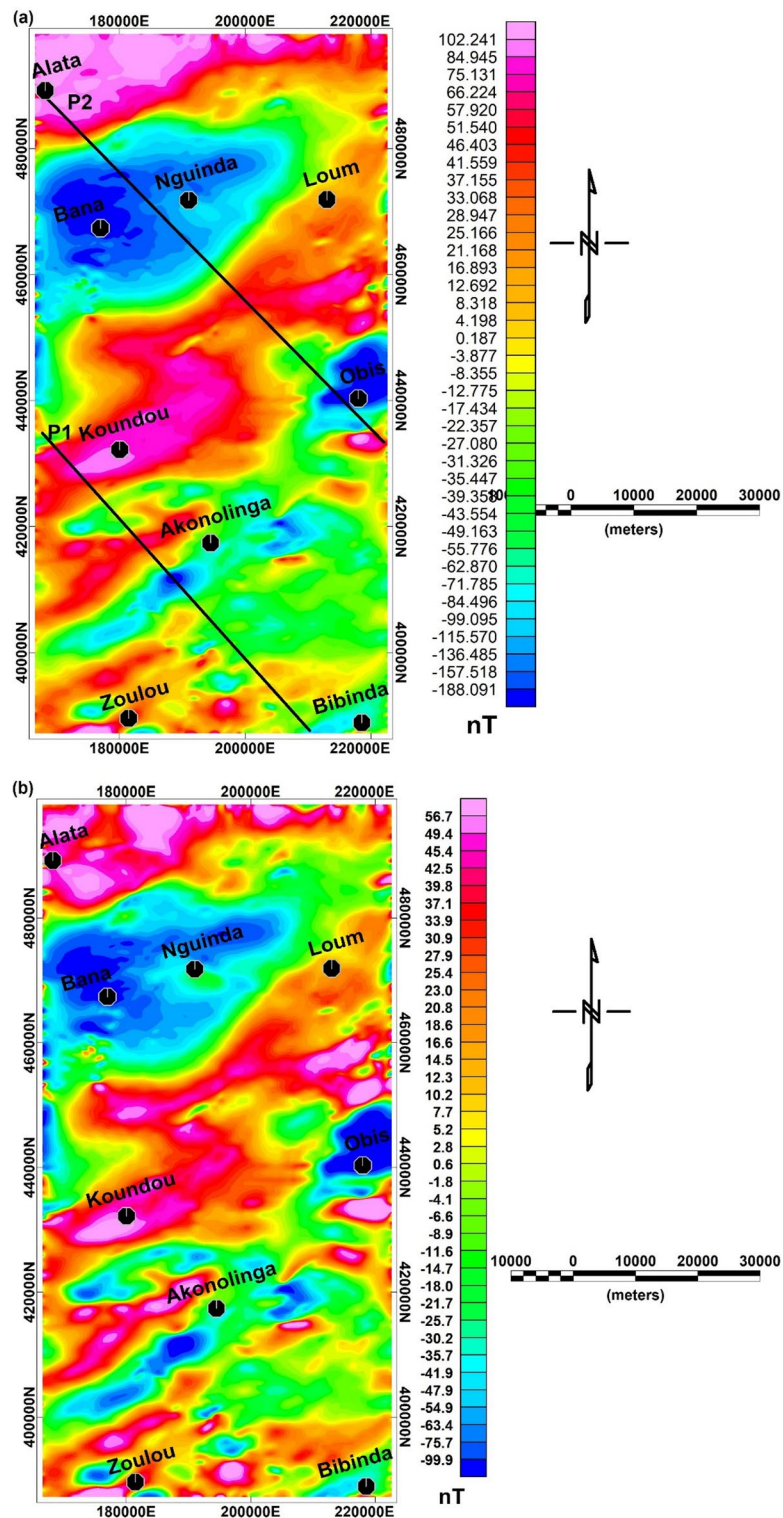


Fig. 2 a RTE grid and b residual grid of the study area

magnitude (HGM), first vertical derivative (FVD), and tilt derivative (TD) were applied to this residual grid to isolate these structures.

4.2 Analytic signal

Figure 3 displays the analytic signal amplitude grid of the study area, exhibiting heterogeneously distributed amplitude dislocations. This high spatial heterogeneity is likely associated with the complex Neoproterozoic rock assemblages of the Bafia Group. A key advantage of the analytic signal is its ability to position anomaly sources directly beneath their respective maxima, independent of magnetization direction. On the AS grid, the broad anomalies observed in the residual map are refined into discrete linear and quasi-circular features. The distribution of major structural trends and contact limits is well defined, highlighting localized high-amplitude peaks reaching 0.101 nT/m. In the Obis, Zoulou, northern Bana, and southern Koundou regions, these structures are oriented NE–SW, ENE–WSW, and E–W. East of Zoulou, around Akonolinga and Bana, and within the northern Obis and NE Nguinda areas, distinct quasi-circular positive anomalies are observed. The morphology of these anomalies strongly points to plutonic intrusions of highly magnetized bodies (such as quartz- and biotite-bearing gneisses) into the basement. Vertical and horizontal derivative filters were subsequently utilized to verify the source geometries of these high-amplitude AS peaks.

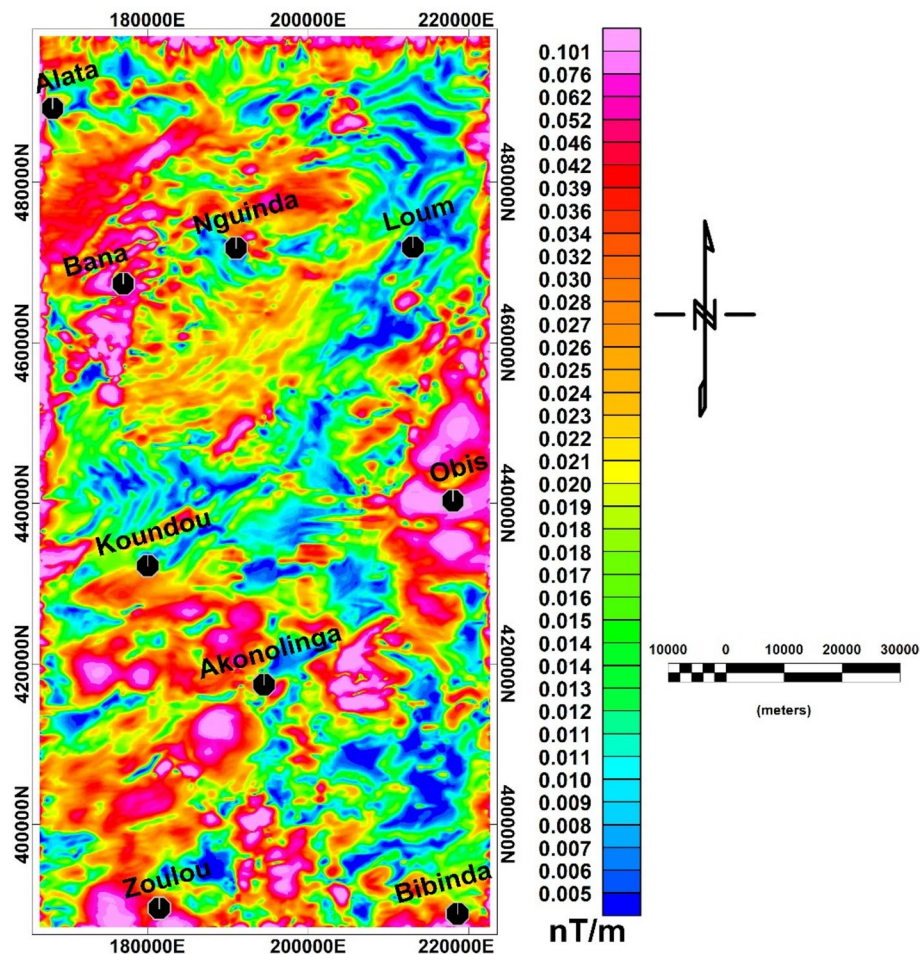


Fig. 3 Analytic signal (AS) amplitude grid of the study area

4.3 Horizontal gradient magnitude

The HGM map (Fig. 4) exhibits derivative amplitudes fluctuating between 0.002 and 0.072 nT/m, successfully enhancing geological contacts and zones of intense magnetic contrast. This map underscores the high structural complexity of the area by delineating both deep-seated and shallow faults and lithological contacts. These structural features are focused northeast of Nguinda, between Akonolinga and Koundou (trending E–W), and south of Akonolinga between Koundou and Nguinda (trending NE–SW, E–W, and ENE–WSW). An abundance of short-wavelength anomalies matches the quasi-circular sites identified on the AS grid (Fig. 3). These features are characterized by high-amplitude gradients, likely representing shallow crystalline intrusions or outcropping magnetic bodies. Along the Akonolinga axis, these structures are interpreted to form the structural boundary between the Congo Craton and the Pan-African Belt. Along the Koundou-Loum axis, numerous elongated, low-intensity anomalies are oriented NE–SW, ENE–WSW, and N–S. The high spatial density of these intersecting anomalies confirms that the subsurface has undergone intense polyphase tectonic deformation.

4.4 First vertical derivative

Figure 5 illustrates the first vertical derivative grid, revealing linear and pseudo-circular anomalies with amplitudes ranging from -0.059 to $+0.044$ nT/m. While these anomalies share structural orientations similar to those on the primary RTE map, the FVD significantly sharpens the anomalies, isolating the discrete edges of the sources responsible for

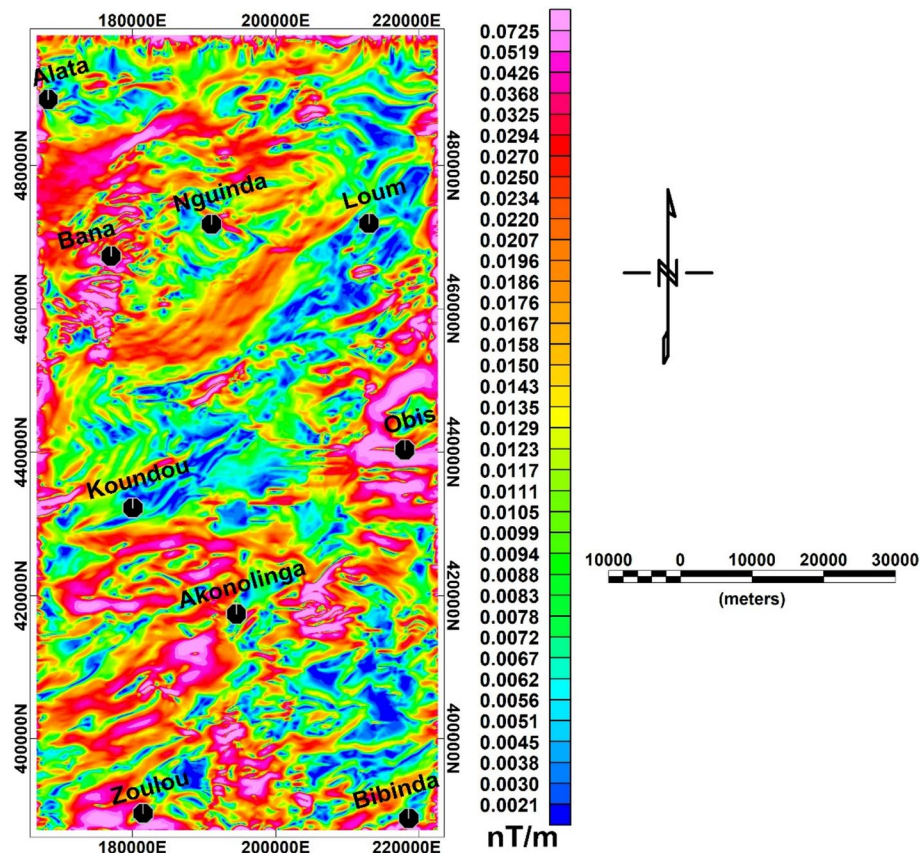


Fig. 4 Horizontal Gradient Magnitude (HGM) grid of the study area

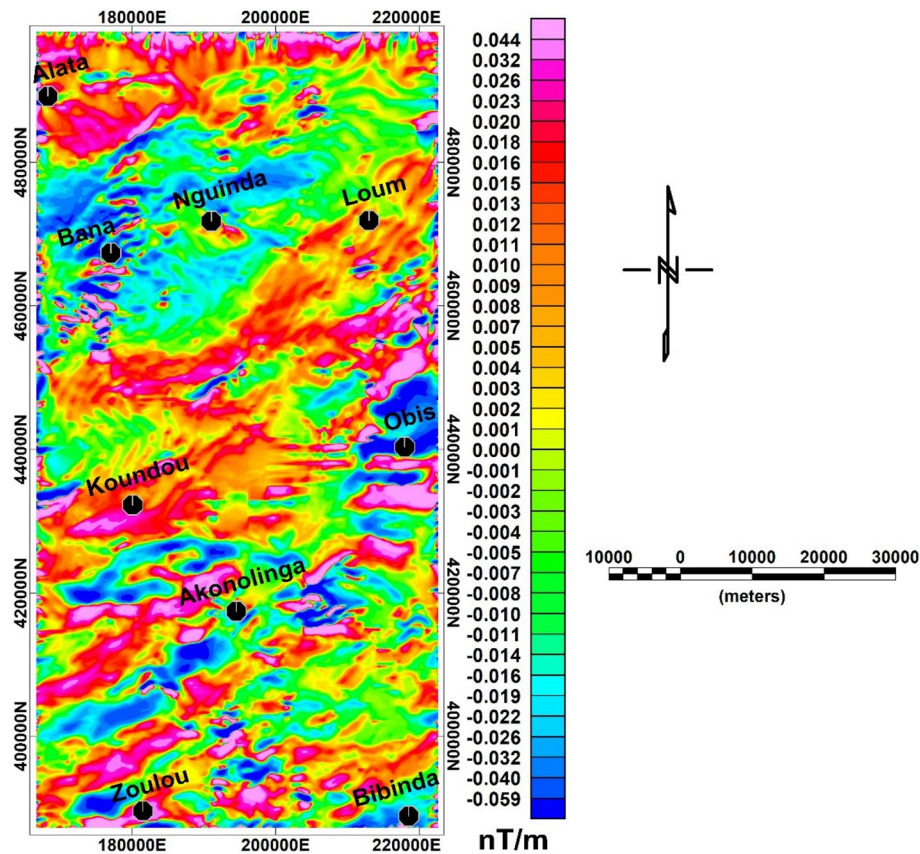


Fig. 5 First Vertical Derivative (FVD) grid of the study area

the regional magnetic response. The FVD grid enhances linear structures oriented NE–SW, ENE–WSW, and E–W, alongside sub-circular and elliptical patterns that mirror the locations observed in the HGM grid. The suppression of broad, regional positive and negative anomalies in favor of alternating, wave-like high-frequency responses confirms that the deeper regional anomalies are composed of complex, individual structural units. Because the FVD acts as an edge-enhancer, it sharpens boundaries between contrasting rock units, facilitating high-resolution structural mapping, fault identification, lineament detection, and shear zone delineation. These highly disrupted signatures reflect an intensely deformed subsurface architecture.

4.5 Multi-scale horizontal gradient analysis

Multi-scale edge detection tracks the vertical continuity and dip of structural lineaments (faults and contacts) and circular intrusions. By overlaying the local HGM maxima extracted from the upward-continued RTE fields across altitudes from 1000 to 5000 m (at 500 m intervals), the multi-scale map shown in Fig. 6 was generated. A tight spatial clustering or near-superposition of maxima is observed along the Akonolinga, Loum, Bibinda, and Zoulou axes, as well as between Bana and Alata. These lineaments trend ENE–WSW, SE–NW, N–S, and NE–SW, and their lack of lateral migration across upward-continuation levels indicates sub-vertical to vertical dipping structures. Conversely, systematically shifted or diverging configurations of maxima are observed between Akonolinga, Koundou, Bana, and Alata, indicating obliquely dipping

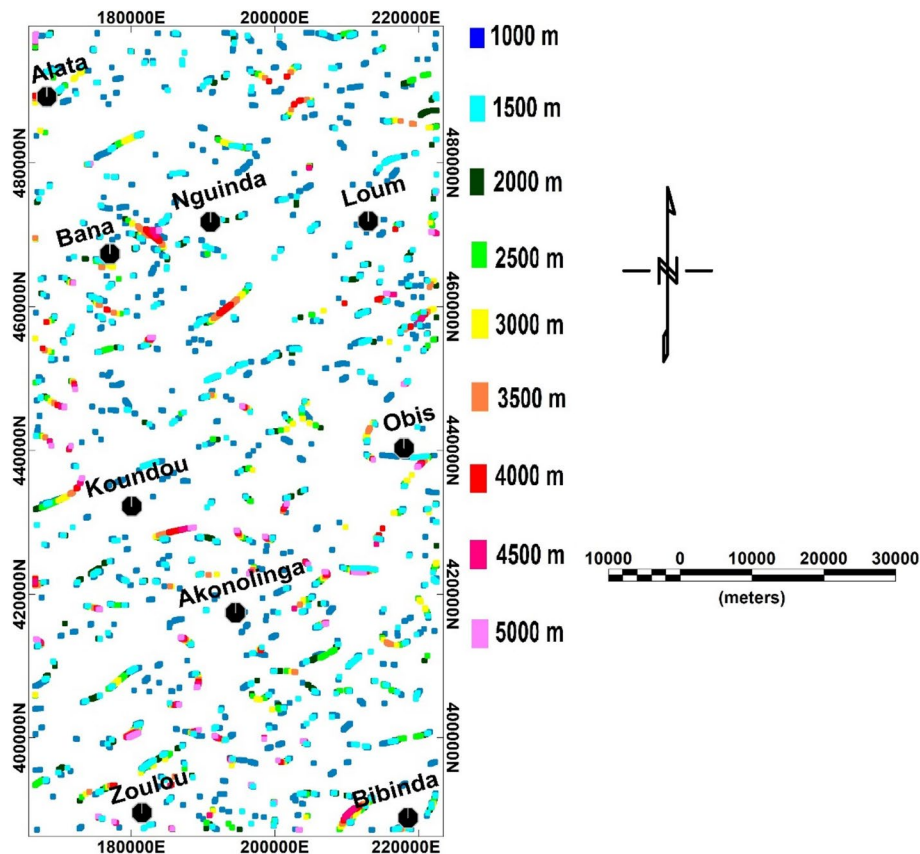


Fig. 6 Multi-Scale grid of the study area

fault planes. Along the Koundou axis north of Obis, a well-defined NE–SW lineament matches the primary tectonic fault represented on the regional geological map. Northeast of Loum, Zoulou, and Bibinda, and south of Bana, a broad array of migrating maxima highlights a major fault system characterized by variable dips and strikes. The primary structural grains inferred across the multi-scale dataset are oriented NE–SW, ENE–WSW, E–W, and NW–SE. The spatial arrangement of these maxima confirms a highly complex structural domain characterized by numerous deep-seated crustal faults. Furthermore, the multi-scale HGM grid clarifies the transition zone between the Congo Craton and the Pan-African Mobile Belt in Cameroon. At shallow continuation scales (1000–2000 m), the map captures the intricate, jagged geometries of the obducted Pan-African metamorphic nappes. At deeper scales (4000–5000 m), these superficial complexities fade, and the HGM peaks realign to map the deep-seated boundary of the cratonic basement underneath. This methodology successfully differentiates massive, deep transcurrent faults (marked by stable, persistent HGM signatures across all altitudes) from shallow, localized strike-slip pull-apart basins and crosscutting brittle fractures associated with late-stage orogenic collapse.

4.6 Overlay map of HGM, TD and AS maxima

The local maxima derived from the Horizontal Gradient Magnitude (HGM), Analytic Signal (AS), and Tilt Derivative (TDR) were superimposed onto a single comprehensive map (Fig. 7). This overlay isolates the filtered magnetic peaks associated with

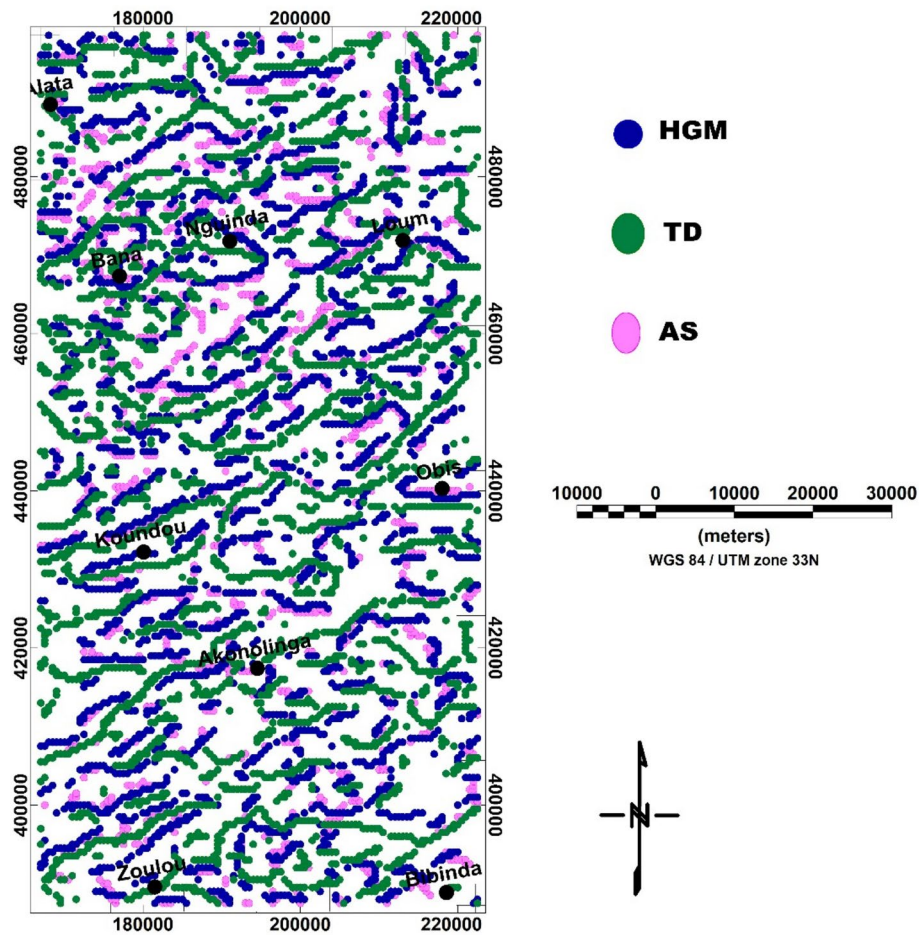


Fig. 7 HGM, AS, and TD maxima Grid of the study area

sharp lithological contacts, fractures, faults, and tight folding. The alignment of these multi-method maxima reveals prominent lineaments, while clustered, sub-circular configurations delineate plutonic intrusions. These intrusive structures are focused north of Bibinda, near Zoulou, east of Akonolinga, between Obis and Loum, and within the vicinities of Bana and Nguinda. Additionally, coinciding ENE–WSW, NW–SE, E–W, and NE–SW lineaments characterize vertically dipping structures, which represent major regional faults or shear zones. A similar structural concentration is observed around Nguinda and Elap, displaying NW–SE, E–W, and NE–SW strikes. In contrast, the northernmost sector of the study area is characterized by obliquely dipping, E–W-trending lineaments. The Koundou area exhibits localized variations in lineament strikes that imply structural folding, aligning with the findings of [14]. The dominant ENE–WSW and NE–SW structural trends represent the primary signature of the continental collision and subduction of the Congo Craton beneath the Pan-African Belt, which was subsequently heavily overprinted by dextral (right-lateral) strike-slip shearing. Tectonic implications of these structural trends include localized crustal thinning and enhanced depocenter accumulation for sedimentary.

4.7 Structural map of the study area

Figure 8 synthesizes the structural features affecting the subsurface of the study area and displays their preferential statistical alignments. The interpreted major lineaments correlate closely with the strikes of the core magnetic anomalies observed on the primary RTE map (Fig. 2a). The structural map (Fig. 8a) reveals 51 principal lineaments, consisting of both quasi-vertical and parallel fault structures. The vast majority of these lineaments dip steeply to vertically, displaying NE–SW, ENE–WSW, E–W, N–S, and SE–NW orientations. Statistical analysis of the 51 lineaments shows that 20 trend NE–SW, 17 trend ENE–WSW, and 14 trend E–W (Fig. 8b), confirming the NE–SW trend as the dominant regional structural grain. Deep-seated versus shallow structural features were differentiated based on their frequency characteristics across the filtered grids; deep structures were extracted from long-wavelength regional anomalies, whereas near-surface structures were identified via derivative-enhanced maps that isolate high-frequency discontinuities. To quantitatively evaluate these structural orientations, independent rose diagrams were generated for deep crustal faults and near-surface structures (Fig. 8b). The statistical distributions confirm that both deep and shallow horizons are dominated by NE–SW and ENE–WSW trends, with subordinate controls along N–S and NW–SE directions. These structures correlate with the combined HGM, TDR, AS, and FVD

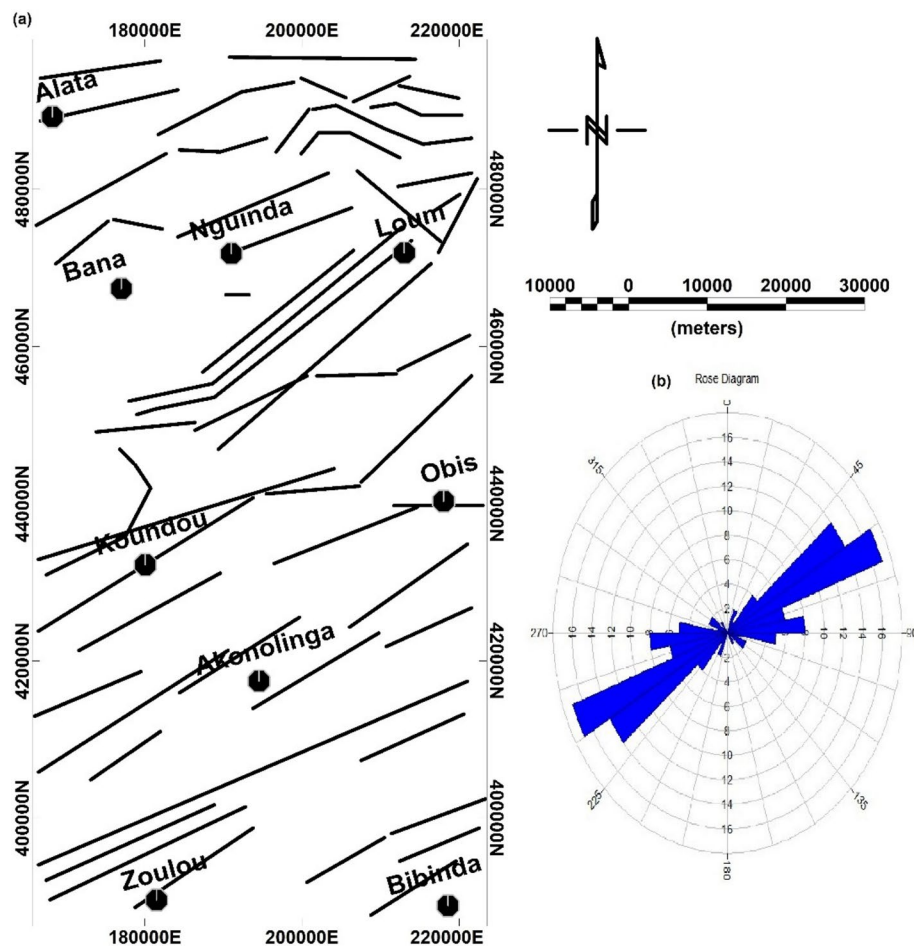


Fig. 8 **a** Structural grid of the study area; **b** Rose diagram

maxima, demonstrating a highly fractured basement that marks the complex transition zone between the Congo Craton and the Pan-African Mobile Belt.

4.8 2.75D modeling

4.8.1 Profile P1

Profile P1 extends NW–SE over a total length of 66 km and comprises 100 digitized data points (extracted along the path indicated in Fig. 2a). The magnetic profile curve (Fig. 9) is characterized by a prominent positive anomaly reaching a peak intensity of +100 nT in the northwest, transitioning to a broad negative anomaly down to −200 nT along the central segment of the profile. The 2.75D modeling resolves four distinct geological units matching the observed anomalies while crosscutting a series of deformed metamorphic and metasedimentary rocks. The correlation between the observed and calculated magnetic curves is excellent, yielding a normalized RMS error of 0.081%. The uppermost layer exhibits an average magnetic susceptibility of 0.026 SI and a depth range of 0–1.2 km; it is interpreted as a sequence of schists. The second layer, interpreted as micaschists (average susceptibility of 0.0158 SI), varies in thickness from 0.1 to 1.8 km along the profile. The third layer, interpreted as gneiss (average susceptibility of 0.011 SI), occurs at depths between 1.2 and 2.7 km. This intermediate crystalline sequence overlies a deep granulite basement characterized by a higher magnetic susceptibility of 0.035 SI. Furthermore, two discrete quartzite bodies with an average susceptibility of 0.044 SI are modeled as steep intrusions, occurring at approximately 7 km along the NW portion of the profile and at 52 km along the SE portion, both originating at a nominal depth of 1 km.

4.8.2 Profile P2

Profile P2 is oriented NW–SE, spans a total length of 82 km, and contains 100 digitized data points (Fig. 2a), extending from Alata in the northwest to the south of Obis. This profile (Fig. 10) is characterized by alternating positive and negative magnetic anomalies. The 2.75D model differentiates five distinct geological layers, interpreted from the surface downward as: unsorted metasediments (0.015 SI), schists (0.026 SI), micaschists (0.015 SI), gneissic basement (0.011 SI), and a basal granulite domain (0.035 SI).

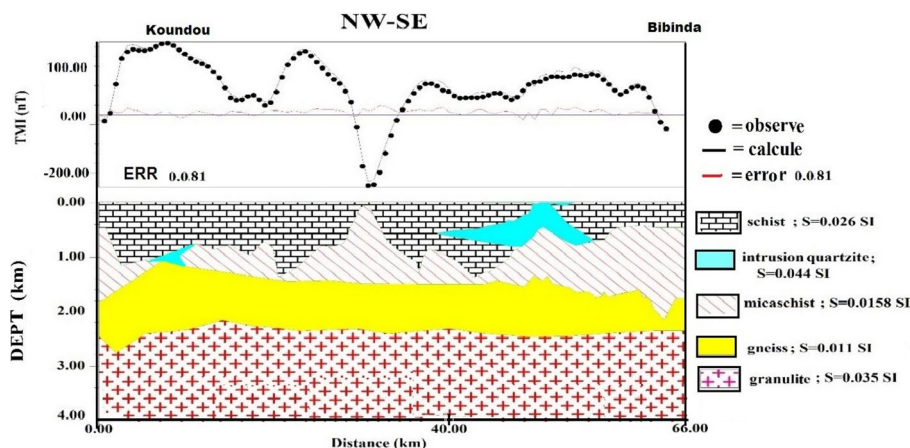


Fig. 9 Cross-section of model 2.75D of profile P1

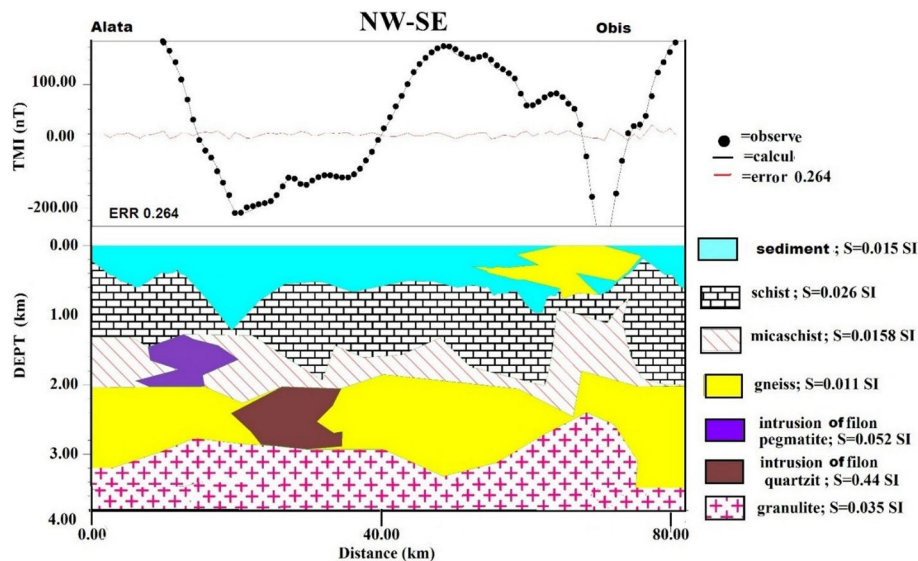


Fig. 10 Cross-section of 2.75D model of profile P2

Two deep-seated intrusions are resolved along the profile: a pegmatite body (0.052 SI) modeled at depths between 1.1 and 2.0 km (located 15 km from the NW origin) and a quartzite body (0.044 SI) modeled at depths between 2.0 and 3.0 km (located 30 km from the NW origin). Additionally, a shallower intrusive body is resolved at a depth of approximately 0.8 km, positioned 70 km from the NW origin.

5 Discussion

This study successfully implemented spatial derivative filtering (FVD, HGM, AS) to map a network of structural lineaments interpreted as faults, shear zones, and localized folds. These features resulted from a complex history of Neoproterozoic tectonic events, including subduction, terraine accretion, and final continental collision. This high structural density produces the wave-like high-frequency signatures observed across the derivative grids and their corresponding maxima maps. The analytic signal mapping effectively localized zones of pronounced magnetization contrast. Faults trace on the final structural map where an HGM ridge perfectly coincides with an AS peak, confirming that the structure represents a major, steep physical contact cutting through the shallow crust. The HGM grid served as the primary tool for constraining the horizontal positions of these fault planes. Major regional shear zones specifically the Sanaga Shear Zone (SSZ) and the Central Cameroon Shear Zone (CCSZ) manifest as highly continuous, high-amplitude, ENE–WSW and NE–SW-trending HGM ridges. This spatial correlation ensures that the major transcurrent fault tracks traced on the structural map are mathematically bound to the sharpest lithological boundaries. These highly conductive and magnetic zones represent structural conduits that host concentrations of ferromagnetic minerals [18].

The characteristic shape and wavelength of each isolated anomaly are fundamentally controlled by the depth, geometry, and susceptibility contrast of the underlying source body. The subsurface of the study area comprises an ancient, intensely folded metamorphic basement composed of schists, gneisses, micaschists, and quartzites, as confirmed by the 2.75D models and regional granitic units making up the Precambrian basement

[2, 41]. The lineament mapping highlighted E–W, ESE–WNW, and ENE–WSW structural trends [7, 25, 38], with the primary regional focus oriented NE–SW [8, 39]. The dominant ENE–WSW and NE–SW fault systems match the structural boundary separating the northern margin of the Congo Craton from the Central African Fold Belt (Pan-African), validating the boundary configurations proposed by prior gravity, magnetotelluric, and regional geophysical studies [8, 12, 14, 29, 39]. This NE–SW fault network directly correlates with fault tracks mapped in adjacent blocks during localized geophysical surveys [8, 25, 39] and matches the published sheet geology [31] of the Akonolinga and Ayos quadrangles. Crucially, delineating these structural trends provides excellent insights into regional mineral exploration. As demonstrated by similar structural workflows in equivalent terrains (e.g., [11]), high-resolution lineament mapping is indispensable for identifying structurally controlled mineralization zones where shear networks focus mineralizing fluids. The structural trends resolved in this study clarify the tectonic evolution of the eastern Cameroon domain. The primary NE–SW and ENE–WSW orientations are expressions of the regional Pan-African collisional framework, whereas the subordinate NW–SE and N–S trends likely record late-stage brittle reactivation phases and localized crosscutting fractures. The close spatial agreement between the interpreted fault network and previously published geological data supports the structural reliability of the geophysical dataset. The 2.75D models are highly realistic, exhibiting normalized modeling errors between 0.081% and 0.26%. In potential field geophysics, an RMS error well below 1% indicates a mathematically sound and highly acceptable fit. The modeled lithological layering and shallow intrusions correlate with independent geophysical and petrological profiles [14, 21, 25] conducted in adjacent sectors of the mobile belt. The identification of buried pegmatite and quartz veins along the f models further corroborates the localized surface mapping conducted by [31]. Additionally, the basement depths (4000 m) and magnetic susceptibility values (0.011 to 0.044 SI) constrained by the 2.75D profiles match the parameters (4148 m depth and 0.041 SI susceptibility) derived via gravity modeling in regional baseline studies [1, 2]. These integrated results successfully reconstruct the deeper structural architecture and lithological variations of the basement. Ultimately, combining derivative filtering with 2.75D modeling represents a robust approach for structural investigations in challenging, soil-covered tropical terrains. Derivative filters provide an empirical, two-dimensional delineation of structural tracks, while 2.75D modeling yields quantitative depths and geometries. Nevertheless, all potential field interpretations are subject to the inherent mathematical non-uniqueness of potential field inversion. The structural models presented here would benefit from future validation via core petrophysical sampling, high-resolution gravity loops, or exploratory borehole calibration.

6 Conclusion

The aim of this study was to map the lithological units and delineate the structural sources of magnetic anomalies within the Akonolinga-Nguinda area using aeromagnetic data. To achieve this, a comprehensive workflow involving spatial derivative filtering (HGM, FVD, TD, AS), multi-scale upward continuation, and profile modeling was executed. The total magnetic anomaly maps successfully localized the responses of individual magnetic sources. Derivative filters enhanced the edges of buried bodies, isolating structural contacts and mapping the regional tectonic grain. Multi-scale HGM and

combined maxima maps facilitated the construction of a new integrated structural map, revealing a dense network of 51 lineaments dominated by NE–SW and ENE–WSW trends with variable, depth-dependent dips. The distribution of these geophysical lineaments matches the known regional geomorphology and structural zones. Multi-scale analysis demonstrated that the ENE–WSW and NE–SW-trending shear zones represent major deep-seated crustal structures, as their tracking HGM maxima persist without spatial disruption across all upward-continuation levels from 1000 to 5000 m. Finally, 2.75D modeling constrained the subsurface architecture down to a depth of 4 km, resolving a complex metamorphic stratigraphy composed of metasediments, schists, micaschists, gneisses, and a basal granulite domain. These basement complexes are heavily crosscut by steeply dipping quartz and pegmatite veins emplaced along active fault zones during peak Pan-African tectonic events. These results provide an updated geophysical framework that can directly guide targeted mineral exploration programs within this sector of southern Cameroon.

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Author contributions

YJ: Wrote the first conceptualization manuscript, formal analysis, investigation, writing—original draft, writing—review & editing; NMT: contributed the conceptualization, formal analysis, investigation, project administration, data curation, funding acquisition; NPC and ASP: contributed to writing draft, writing—review & editing; BBAM and TAW: formal analysis, interpretation draft, writing—review & editing; OAOUI and NJD: reviewed the manuscript critically; NAR: visualization and critically; All authors mutually designed the study, interpreted the results, and wrote the final version of the manuscript.

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Data availability

The datasets used during the current study are available from the corresponding authors on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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