Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development



Mustapha Meghraoui · Narasimman Sundararajan · Santanu Banerjee · Klaus-G. Hinzen · Mehdi Eshagh · François Roure · Helder I. Chaminé · Said Maouche · André Michard *Editors*

Advances in Geophysics, Tectonics and Petroleum Geosciences

Proceedings of the 2nd Springer Conference of the Arabian Journal of Geosciences (CAJG-2), Tunisia 2019

IEREK RESEARCH & KNOWLEDGE ENRICHMENT

Springer

Interpretation of Aeromagnetic and Geochemical Data for Tectonic and Structural Setting of Granitic Rocks Around Bishewa Area, Southwestern Nigeria

Ajadi Jimoh and Olasunkanmi K. Nurudeen

Abstract

High resolution aeromagnetic data of Bishewa area has been analyzed to establish the geometry of its lithologic settings. Magnetic residualization of the total magnetic intensity (TMI) and derivative of resulting magnetic anomalies were enhanced using the fast Fourier transform of Oasis montaj geo-software. The reduced to equator residual anomaly varies within −174.9 to 111.9 nT which revealed the contrasting lithologic units viz: sedimentary and basement complex. The negative magnetic intensities (lows) in the southern and sparsely within the northwestern regions are associated with rocks of lower content of ferromagnetic minerals and are attributable to underlying igneous and metamorphic rocks or intrusive bodies within the schist. The positive anomalies coincide with the predominant migmatite-gneiss complex. Structural relationships between the granites and metasedimentary host rocks suggest that the emplacement of the granitoids is associated with early, large-scale thermotectonic regional deformation within the Nigerian basement complex. This study also revealed a transpressional regime that is characterized by WNW-ESE shortening and large-scale sinistral strike-slip faults associated with the regional NE-SW structural grains in the basement rocks of the area. Regional geologic features and structural correlation show that the area is underlain by the northwestern extension of the Ilesha schist belt in the western sector of the Nigerian basement complex.

Keywords

Aeromagnetic data • Fourier transform • Structural relationships • Regional deformation • Transpressional regime

1 Introduction

The geology of Bishewa area forms part of the northern limit of the migmatite-gneiss complex in the southwestern sector of the Nigerian Basement Complex bordered in the north by the Cretaceous sediments of the Bida Basin which overlies the basement complex rocks. This complex lies within the African crystalline shield believed to be part of the Late Proterozoic to Early Paleozoic Pan African mobile belt, which is bordered to the west by the West African cratonic plate and to the southeast by the Congo craton. The study area lies between latitudes 8° 39′ N and 8° 46′ N, and longitudes 5° 03′ E and 5° 11′ E, underlying an area of about 220 km^2. This area is located in the northwestern sector of the 1:50,000 Lafiagi southwest sheet 203. The main lithologies outcropping in the area have been classified into four major groups. These include early metamorphic tectonites (biotite gneiss and migmatitic gneiss), metasedimentary rocks (quartz-biotite-muscovite schist, tremolite-talc schist, quartzite and amphibolite), the Pan African (Older) Granite (medium-coarse grained biotite granite and pegmatite) and minor intrusives rocks (granodiorite, porphyritic granite, lamprophyre, aplite and quartz vein). The geochemistry and petrogenetic evolution of these rocks have been described in some detail (Ajadi 2017) (Fig. 1).

A. Jimoh (✉)
Geology and Mineral Sciences Department,
Kwara State University, Malete, Nigeria
e-mail: jimoh.ajadi@kwasu.edu.ng

O. K. Nurudeen
Physics and Materials Science Department,
Kwara State University, Malete, Nigeria

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

M. Meghraoui et al. (eds.), *Advances in Geophysics, Tectonics and Petroleum Geosciences*,
Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-030-73026-0_117

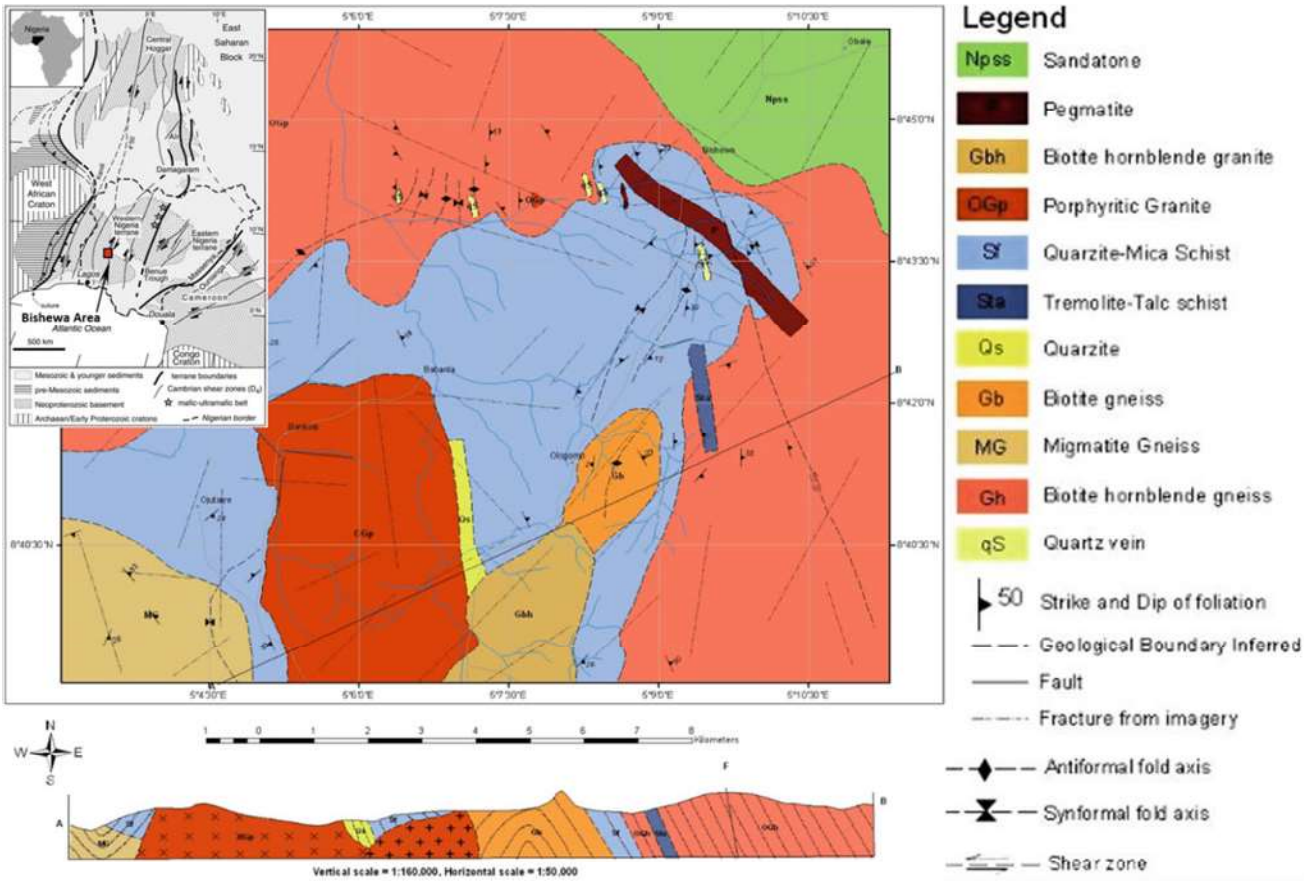


Fig. 1 Geological map of Bishewa area showing lithological distributions (Ajadi 2017)

2 Materials and Methods

2.1 Data Set and Procedure

Total field aeromagnetic intensity (TMI) data of Bishewa were extracted from data sheets 202 and 203 published by Nigeria Geological Survey Agency (NGSA), from high resolution airborne magnetic survey carried out within 2003 to 2006, with a view to using magnetic anomalies to map contrasting lithologies and associated structural elements (Fig. 2). The data were acquired at traverse line spacing of 500 m and tie line of 2 km in NW–SE and NE–SW orientations respectively and at flight height of 200 m. The TMI data was reduced to the magnetic equator using the geomagnetic inclination and declination of −8.59° and −1.69° respectively, in order to correct the asymmetric and lateral shift of measured magnetic total filed, and that maximum magnetic anomalies lies in the middle above the magnetized body. RTE was accomplished by using the step-by-step fast Fourier transform (FFT) filtering procedure on Oasis Montaj software to remove the inclination effects from the grid data and produce magnetic anomalies that seems calculated at the equator.

The derivatives (tilt and total horizontal derivative) take the form (Eqs. 1 and 2) to normalize the signatures in images of residual magnetic data so that weak, small amplitude anomalies can be amplified relative to stronger ones. Normalized derivatives also help to define the locations of magnetic edges, show which side of each edge is likely to have a higher magnetization, and give a qualitative indication of the dip of contacts (Fairhead and Williams 2006). The analytic signal (/A/) used the total magnetic gradient, to approximately estimate positions of magnetic contacts and obtain some depth estimates from the gridded data. The /A/ served as the basis for the definition of the derivatives; where M is total magnetic field. The relationship of normalized gradients are expressed as Eq. 2; where vertical gradient is denoted by VDR and total horizontal gradient as THDR.

$$|A| = \sqrt{\left|\frac{\mathrm{d}M}{\mathrm{d}x}\right|^2 + \left|\frac{\mathrm{d}M}{\mathrm{d}y}\right|^2 + \left|\frac{\mathrm{d}M}{\mathrm{d}z}\right|^2} \tag{1}$$

$$\text{Tilt Derivative} = a\tan\frac{\text{VDR}}{\text{THDR}} \tag{2}$$

Depth to magnetic sources was estimated from the magnetic source parameter imaging (SPI) and Euler deconvolution

at structural indices of zero and one. The Euler deconvolution technique analysis potential field data using Euler's relation for homogenous functions (Eq. 3). With the regional value of the total magnetic field (B) and the position (x_o, y_o, z_o) of the magnetic sources, which produces the total field (T) measured at (x, y, z), the deconvolution employs first order (x, y, z) derivatives to determine location and depth for various idealized targets (sphere, cylinder, thin dyke, contact), each characterized by a specific structural index (Thompson 1982). The SPI automatically calculates source depths from total magnetic field (Thurston et al. 2002; Nabighian 1972).

$$(x - x_o)\frac{dT}{dx} + (y - y_o)\frac{dT}{dy} + (z - z_o)\frac{dt}{dz} = N(B - T) \quad (3)$$

Rock samples were crushed and reduced to 1 mm size using a Geocrusher and pulverizer, and 200 g of samples were ground to −200 mesh using a disk mill. Sample contamination was prevented by carrying out air cleaning at each stage. Hot digestion of 0.5 g of the sample in a mixture of HNO_3, $HClO_3$ and HF was carried out before the XRF analysis for chemical composition of the 20 selected samples. 50 mg of the pulverized rock sample was also subjected to hot digestion in a mixture of HNO_3, $HClO_3$ and HF before being fed into the ICPMS machine for trace element analysis.

2.2 Data Processing

The TMI was reduced to magnetic equator (RTE), since there are no appreciable remmanence effects within low latitude (Paananen 2013) having low geomagnetic inclination value −8.59. THDR has been established as a better edge detection tool as it gives resolution of both vertical derivative (VDR) and horizontal derivative (HDRx and HDRy) (Foss 2011). The RTE residual magnetic anomaly map was further enhanced using fast Fourier transform for total horizontal derivative (THDR), Analytic Signal (AS) and Euler deconvolution at structural index of zero (SI = 0); to reveal the edges/geometry of various geologic models. The geochemistry of the rocks was analyzed and interpreted using Petrograph software to determine the tectonic and structural setting of emplacement of the granitic rocks around Bishewa area.

3 Results

Three groups of structural features have been recognized within the Basement Complex around the study area. These include relict sedimentary structures as well as the ductile and brittle structures. Most of these structures occur on outcrop scale, an interplay of some of which were used to infer a few large-scale features observed in Fig. 1. Most of the fractures encountered in the study area frequently occur as variably oriented joints. The open to tight NNE-SSW trending minor folds in the area particularly in the north central part is suggestive of a transpressional force. Figure 2 shows the rosette plots of joint trends, indicating a NW–SE transpressional force with minor faults and NNE-SSW folds which created the dominant NE-SW fractures in the study area with subordinate complimentary NNW-SSE and WNW-ESE fracture trends. About 40% of the joints in the study area are healed with quartz or pegmatitic materials which are simple or complex in composition (Garba et al. 2019) and trend mostly in the NNW-SSE directions (Fig. 2c, d). These main structural trends are also observable on the reduced to equator residual magnetic anomaly and analytic signal amplitude maps of Bishewa (Fig. 3).

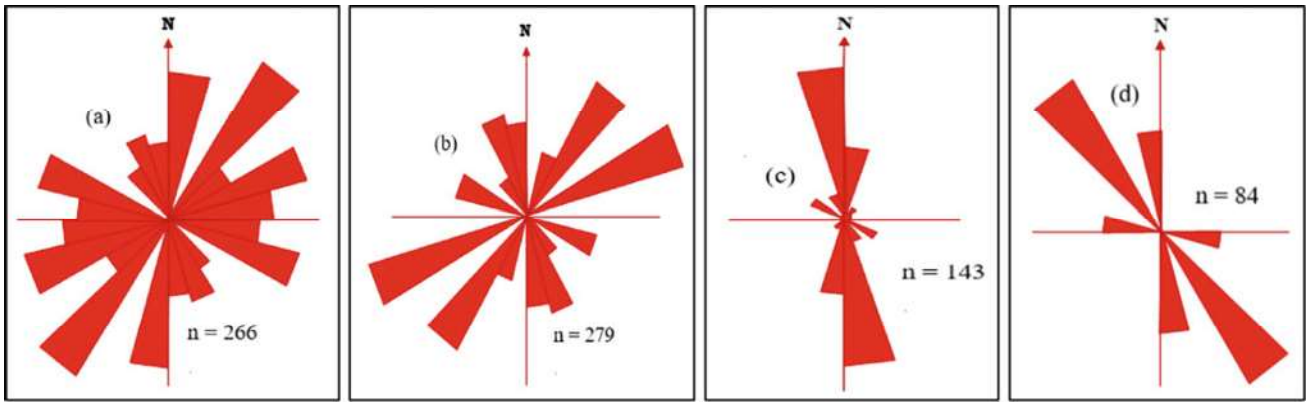


Fig. 2 Rosette plots of joints in the **a** granitic gneisses **b** granites **c** pegmatites **d** vein quartz around Bishewa

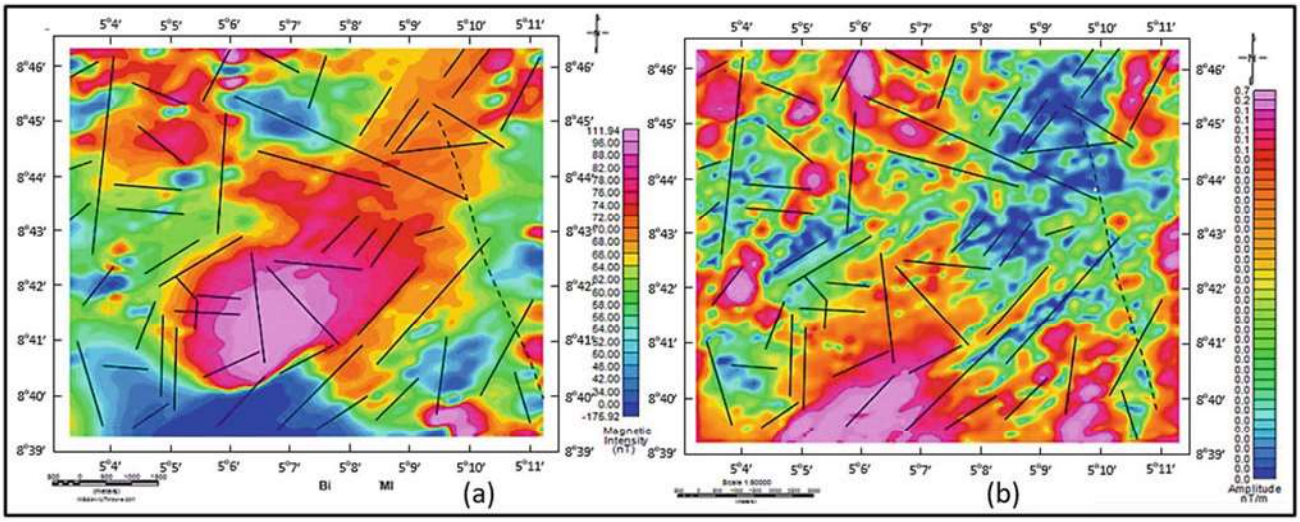


Fig. 3 **a** Reduced to equator residual magnetic anomaly and; **b** analytic signal amplitude maps of Bishewa

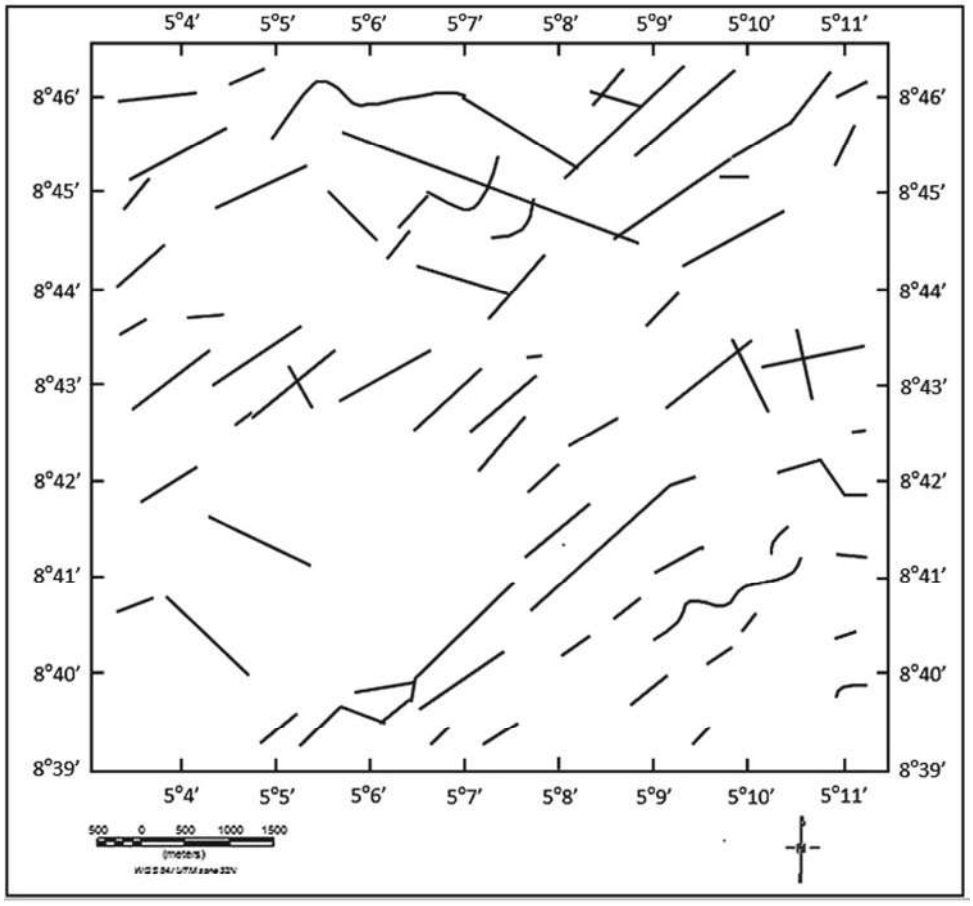


Fig. 4 Lineament extracted from normalized derivative of the reduced to equator magnetic anomalies of the area

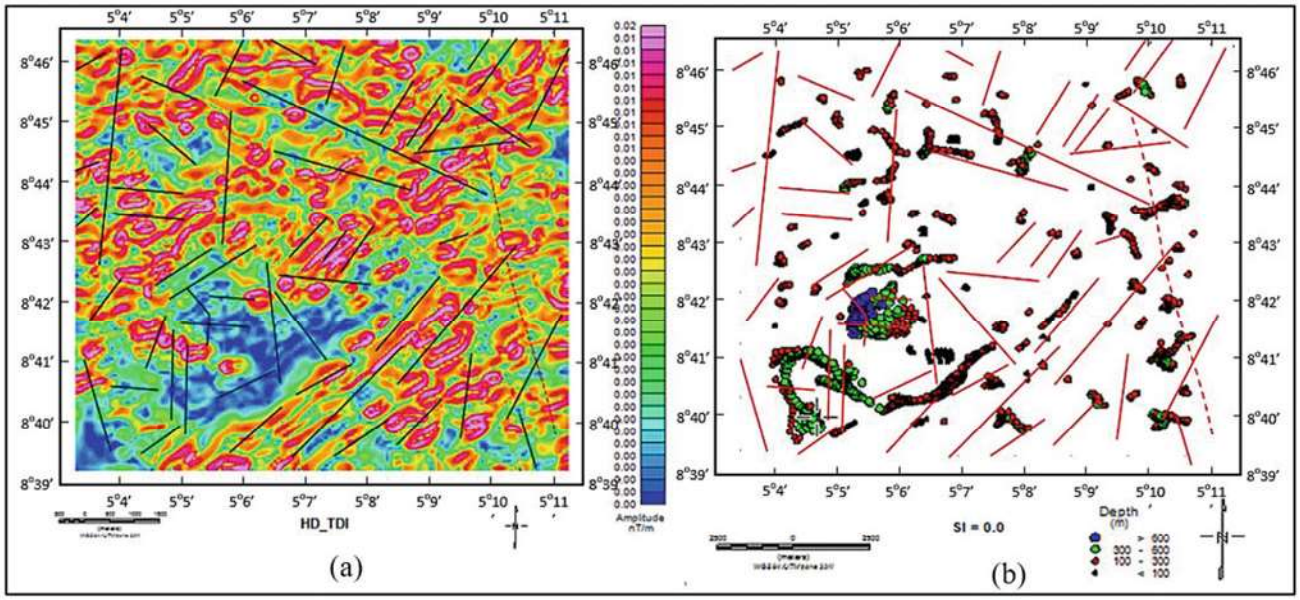


Fig. 5 **a** Total horizontal derivative and; **b** Euler deconvolution maps of Bishewa

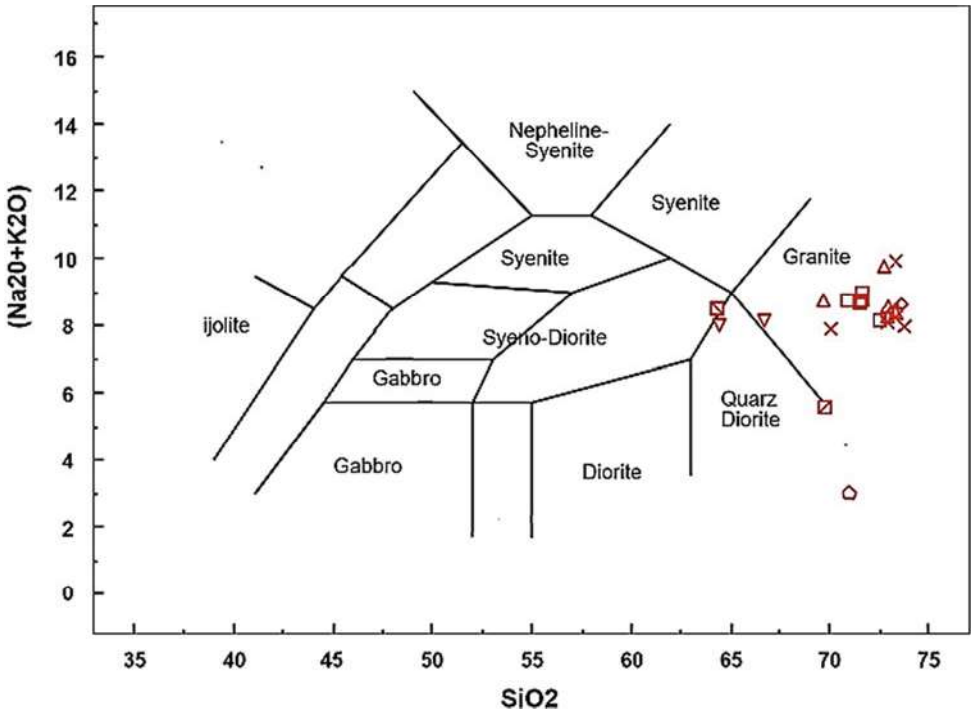


Fig. 6 TAS discriminatory plot for plutonic rocks in Bishewa area (Caby 1989)

4 Discussion

The residual magnetic anomalies (Figs. 3a and 4) obtained from reduction to magnetic equator through fast Fourier transform (FFT) of the TMI map range from −174.9 to 111.9 nT while the corresponding AS amplitude (Fig. 3b) range from 0 to 0.7 nT m^{-1}. The negative (low) anomalies in the southern region correspond to the high amplitude of analytic signal attributable to granitic intrusion (Mume 1964) comprising biotite hornblende granite and porphyritic granite (Neoproterozoic). The relatively high anomalies coincide with the presence of relict amphibolite lenses outcropping within the massive hornblende-bearing schist (Lower Proterozoic) in the southcentral and the sandstone in the northeastern areas while the intermediate anomalies

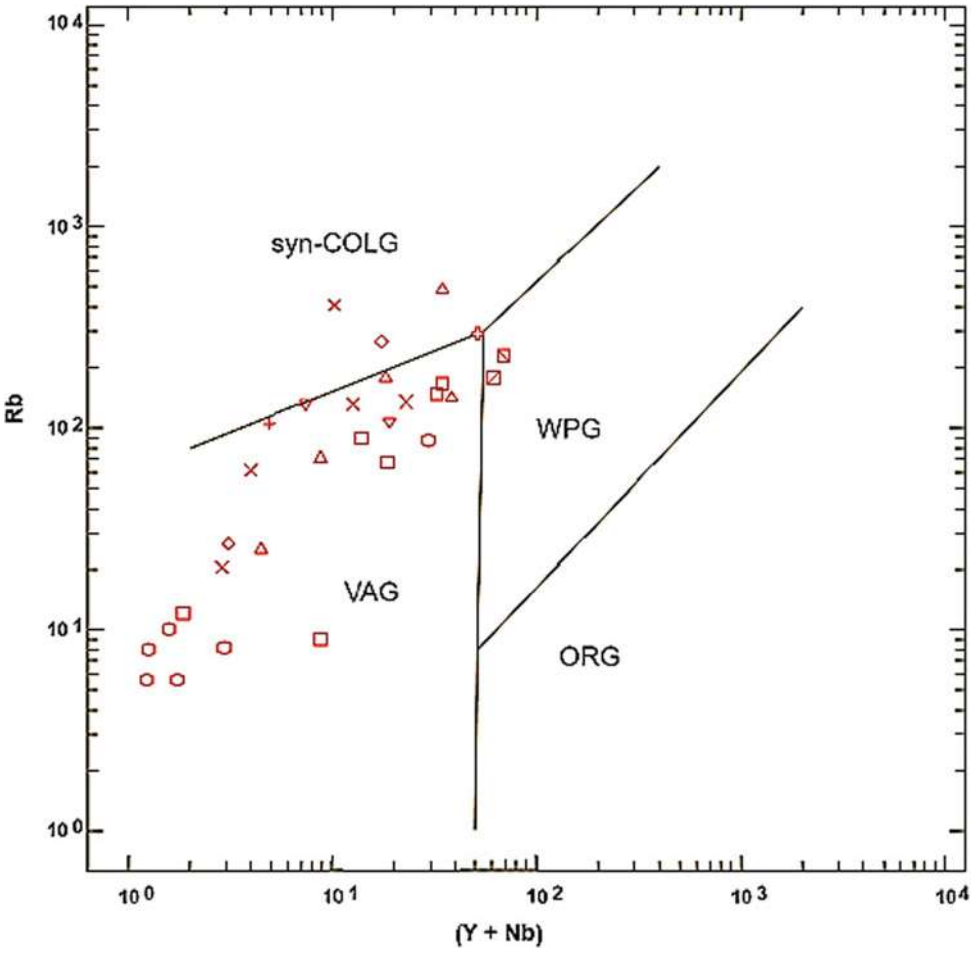


Fig. 7 Rb versus Y + Nb discrimination diagram for granitic rocks in Bishewa area (Cox et al. 1979)

depict the predominant migmatitic gneiss rocks. The THDR model (Fig. 5a) depicts the dominantly NE–SW structural grains of the Nigerian basement complex which lies between the Neoproterozoic Trans-Saharan Fold Belt (Ajadi 2017) formed between 750 and 500 Ma by accretion of terrains between the converging Archaean blocks of the West African Craton, the Congo Craton and the East Saharan Block (Caby 1989). The Euler deconvolution at SI = 0 for a contact (Foss 2011) (Fig. 5b), corresponds to the linear trend revealed on THDR and estimated depth to magnetic source ranges from 100 to 600 m. Total alkali versus silica discriminatory plot for the plutonic rocks (Cox et al. 1979) in the study area (Fig. 6) shows granitic affinity with few being dioritic while the trace element tectonic discrimination plot of Rb versus Y + Nb for the granitic rocks in the area (Pearce et al. 1984) (Fig. 7) suggests an intra-continental volcanic arc origin that is spatially related to the established easterly dipping subduction zone in the eastern part of West African craton (see Fig. 1 inset) (Caby 1989).

5 Conclusions

Interpretation of the high resolution aeromagnetic data of Bishewa area has revealed the contrasting lithologic units with associated structural grains. Structural relationships between the granites and metasedimentary host rocks suggest that the emplacement of the granitoids are associated with early, large-scale thermotectonic regional deformation associated with transpressional regime that is characterized by WNW-ESE shortening and a large-scale NE-SW trending fractures within the Nigerian basement complex. Structural relationships between the metasedimentary host rocks and the intruding granites suggest an emplacement within early, large-scale thermotectonic regional deformation of the Nigerian basement complex. Geochemical plots revealed that the granitic rocks of the study area are structurally emplaced within a subduction-related volcanic arc environment.

References

Ajadi, J.: Geochemistry and petrogenetic evolution of rocks around Bishewa-Ologomo area, part of Lafiagi Sheet 203, Northcentral Nigeria. Int. J. Sci. Eng. Res. **8**(4), 1333–1343 (2017)

Caby, R.: Precambrian terranes of Benin-Nigeria and Northeast Brazil and the late Proterozoic South Atlantic fit. Geol. Soc. Am. Spec. Pap. **230**, 145–158 (1989)

Cox, K.J., Bell, J.D., Pankhurst, R.J.: The Interpretation of Igneous Rocks, 450 pp. Allen and Unwin, St Leonards (1979)

Fairhead, J.D., Williams, S.E.: Evaluating normalized magnetic derivatives for structural mapping. SEG 2006 New Orleans Extended Abstract. SEG (2006)

Foss, C.: Magnetic data enhancement and depth estimation. In: Gupta, H.K. (ed.) Encyclopedia of Solid Earth Geophysics. Springer Science+Business Media B.V. (2011)

Garba, A.A., Adekeye, J.I.D., Akande, S.O., Ajadi, J.: Geochemistry and rare-metal bearing potentials of pegmatites of Gbugbu, Lema and Bishewa areas of North Central Nigeria. J. Environ. Earth Sci. **9** (3), 170–186 (2019)

Mume, W.G.: Negative total-intensity magnetic anomalies in the southeast of South Australia. J. Geophys. Res. **69**(2), 309–315 (1964)

Nabighian, M.N.: The analytic signal of two-dimensional magnetic bodies with polygonal cross-section: its properties and use for automated anomaly interpretation. Geophysics 507–517 (1972)

Paananen, M.: Completed lineament interpretation of the Oikiluoto region. Posiva (2013).

Pearce, J.A., Harris, N.B.W., Tindle, A.G.: Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. J. Petrol. **25**(4), 956–983 (1984)

Thompson, D.T.: EULDPH-new technique for making computer-assisted depth estimates from magnetic data. Geophysics, 31–37 (1982)

Thurston, J.B., Smith, R.S., Guillion, J.C.: A multi-model method for depth. Geophysics, 555–561 (2002)