

## RESEARCH ARTICLE

## CHIBOK RIFTO-MAGNETICS AND GEOLOGY

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## ABSTRACT

On sheet 134 of the aeromagnetic map of Nigeria is a prominent northeast (NE) trending negative anomaly that extends for >20 km. This work reinterprets the anomaly using *oasis montage™ 7.0* software, by inverse geological modelling of magnetic profiles. The aim of this work is to identify the Chibok magnetic anomaly as a plate tectonic feature, and as part of the West African Rift System. Three profiles were modelled across the residual magnetic anomaly, which yielded a depth range of 1 to 2 km. The result furnished a subsurface picture of 'horst and graben' which are characteristic of rifts. The sedimentary infill of the interpreted rift is considered to be sands/or sandstone due to the low magnetic anomaly. Sandstone has very low magnetic susceptibility [ $30 \times 10^6$  emu (S.I.)] compared to granite and basalt. Geological data showed NW, NE, N-S, and E-W structural trends on the granitic basement. These manifest as faults, shear zones, joints and foliations. Emplacement of the Tertiary basalt in the NW of the area of study area showed planes of crustal weakness in the Precambrian basement. A palinspatic map of the area identified the pre-Tertiary geology. The sediment infill of the interpreted rift may serve as very rich aquifer for groundwater abstraction for irrigation in this semi-arid zone. The evidence of the plate tectonic nature of the interpreted rift indicated its alignment with offshore transform faults like Chain and Charcot as well as the Cameroun Volcanic Line.

## KEYWORDS

Aeromagnetic, rift, sedimentary, low magnetic, semi-arid zone

## 1. INTRODUCTION

This work is a further attempt to study in a greater detail a remarkable NE trending linear magnetic anomaly on sheet 134 of Nigeria's aeromagnetic map published by the Nigeria Geological Survey Agency (NGSA). The anomaly extends over 20 km with a width through the centre of about 6 km. This magnetic anomaly was first interpreted by the first author in 2006, using Stanley 'Contact and Dyke Model' of interpreting gravity and magnetic profile data (Bassey, 2006; Stanley, 1977). In that interpretation, the depth to the causative body was computed to be 2.65 km. Based on satellite, topographic and field geological data. The Chibok magnetic anomaly was interpreted to be an extension of a major Benue Rift fracture zone, whose origin was linked to some oceanic fracture zones, namely *Romanche*, *Chain* and *Chacort*.

Bala on his investigation of magnetic anomalies over Chibok and Damboa areas (the latter being part of the Chad Basin) used derivative, upward continuation, source parameter imaging, Euler deconvolution and spectral techniques as analytical tools to map the area (Bala, 2016). The author computed depth to magnetic source using magnetic profile over Chibok to be 2.20 km. With security challenges in northeast Nigeria, which seriously affected the town of Chibok in 2014, field geological studies in the area, has not been possible. The only detailed geological mapping of Chibok was done by the first author as part of a doctoral research in the Hawal Basement Complex (Bassey, 2006a). This work aimed at giving more evidence on Chibok magnetic anomaly as a plate tectonic feature, and as part of the West African Rift System.

## 2. REGIONAL TECTONIC SETTING AND GEOLOGY

Chibok is a town in Borno State of Nigeria, located towards the northern boundary of Nigeria's north-eastern Basement Complex, otherwise called Hawal Massif, after the River Hawal, a major drainage feature of the Massif (see Figure 1) (Bassey, 2006a). The town lies few kilometres to the Basement – Chad Basin boundary. The Hawal basement has been intruded by Tertiary rocks (basalt flows) to the north-western region of the area. It is bounded to the west by Cretaceous Upper Benue Trough (Gongola Basin), to the south by an arm of the Trough, the Yola Rift. To the north of the Massif is the Borno sector of the Quaternary Chad Basin. The Massif extends across the Nigeria's national boundary into Cameroun.

Bassey, (2006a) presented detailed accounts of the geology of Chibok area. It is represented here as an aid to analysis of magnetic data (Bassey, 2006b). The survey covers longitude  $12^{\circ} 50'$  to  $10^{\circ} 52'$  E, and latitude  $12^{\circ} 50'$  to  $12^{\circ} 53'$  N. The area is composed migmatite-gneiss intruded by granites which form residual hills or inselbergs. Major rock outcrops of the granites are *Dutse Ligama*, *Chibuk*, *Vakriva hills*, and *Dutse Koglak* (Figure 2). The minor ones are *Payagima* and *Kanzu*. From aerial view; they form a ring structure typical of some granitic terrains. The geological map is shown in Figure 3. The granites are generally medium grained (0.2-0.5 cm) and their colours are pinkish or whitish depending on the dominant feldspar content. Other minerals are quartz, biotite and muscovite.

The coarse-grained granite was found on the Shiki hill to the east. Rock foliation is generally weak and is of magmatic type since the igneous minerals are aligned (Paterson et al., 1989). The authors also posited that

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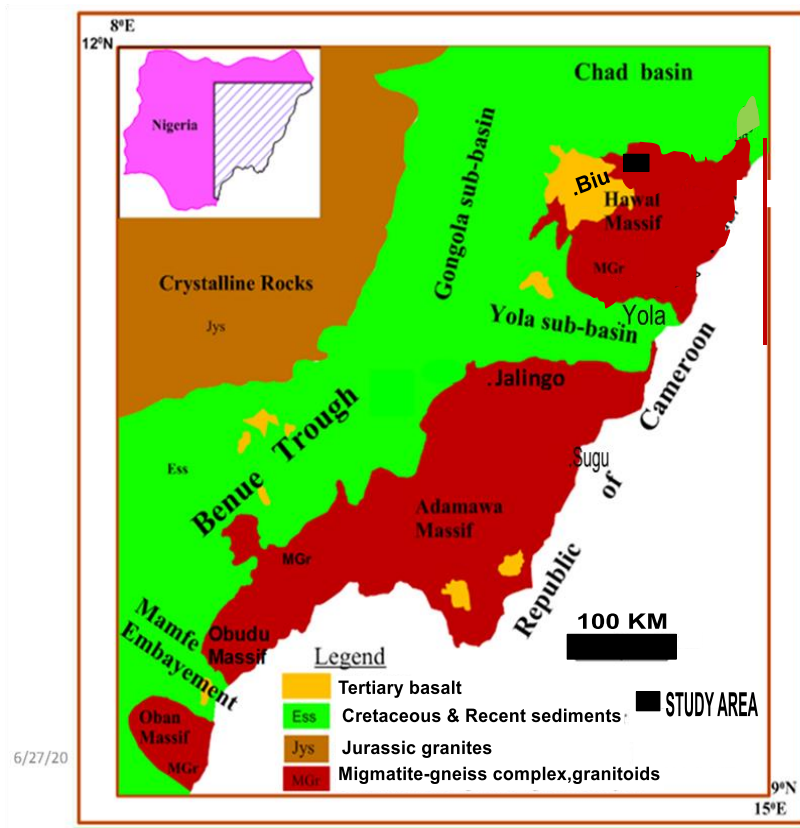
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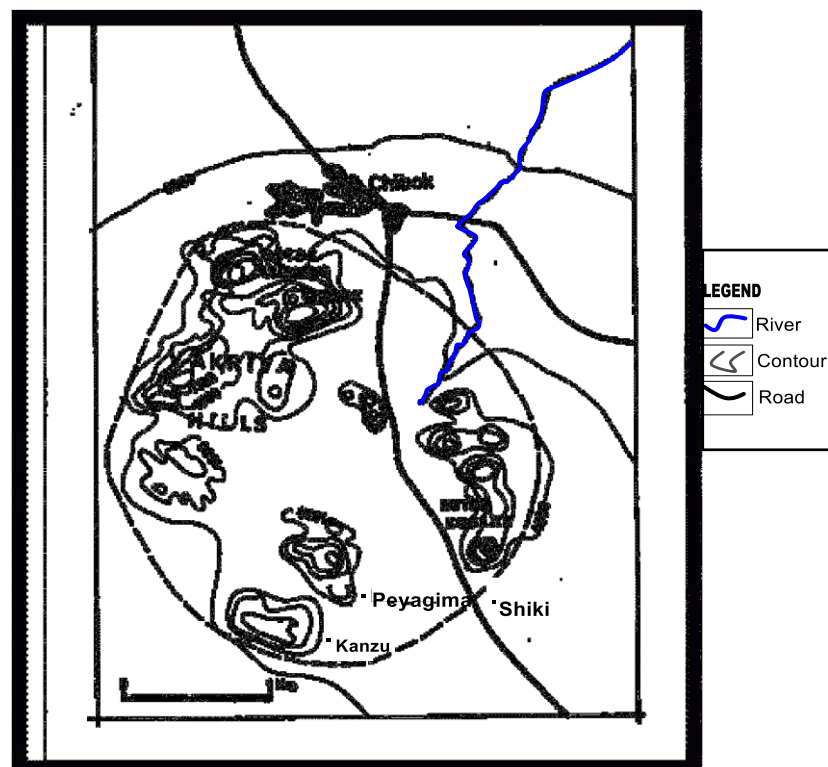
weak foliation in magmatic rocks also suggest the plutons were probably emplaced by magmatic flow. Shear zones are the commonest structural deformation observed. About 87 shear zones were observed and their strikes measured. The rosette plot of these shear zones is presented in Figure 4. The major shear directions are NW-SE, N-S and E-W. Evidences of faulting in the area occur as rock brecciation, example at Vakriva hills in the NW. At Peyagima hill, a plunging lineation ( $65^{\circ}\text{NW}$ ) on a steeply dipping NW-SE fault plane occurs (Figure 4).

This is evidence of NW striking fault in Payegima hill. Few dykes and veins

were observed. At Payagima hills, a NW – SE shear zone crosscuts a  $\text{N}50^{\circ}$  Pegmatite dyke. The dyke is 4 m by 2 m in dimension. At Limana Dutse hill, polyphase shearing are found (N-S, NE-SW, and NW-SE). The intersections of these shear zones produce rock fragmentation and brecciation, which are also observed at Vakriva hills (Figure 4). Joints are common features on the eastern and southern hills and they influence the evolution of the hills. The joints, which are of tectonic origin, are at Dutse Koglak hill (Figure 4). Some of the joints strike E-W. The major deformational directions in Chibok are NW, NE, N-S, and E-W.



**Figure 1:** Location map of the study area within the tectonic setting of Benue Trough and Hawal Massif in northeast Nigeria, (adapted from Haruna et al, 2011).



**Figure 2:** Postulated emplacement pattern of Chibok granitic hills from topographic map to form ring structure as shown by broken lines, (contour interval are in feet, names in capital letters represent hills).

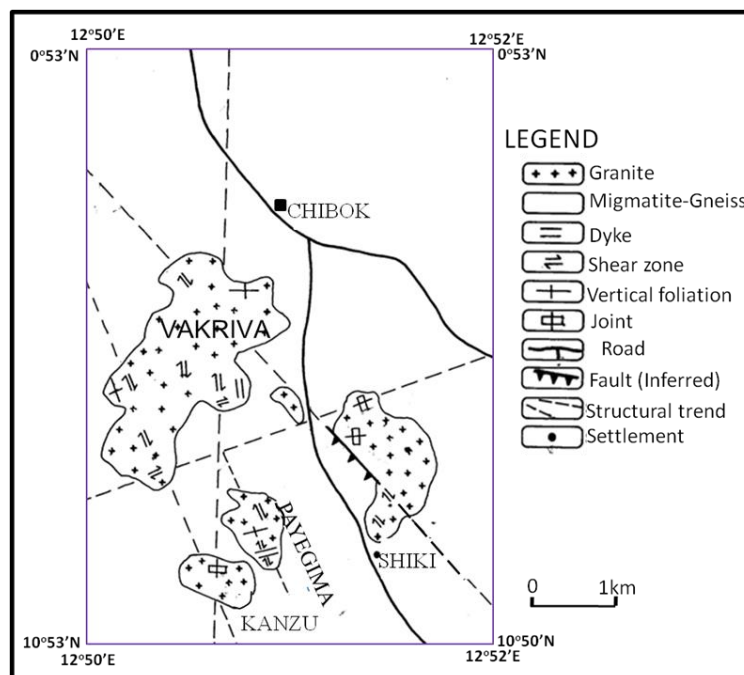


Figure 3: Geological map of Chibok.

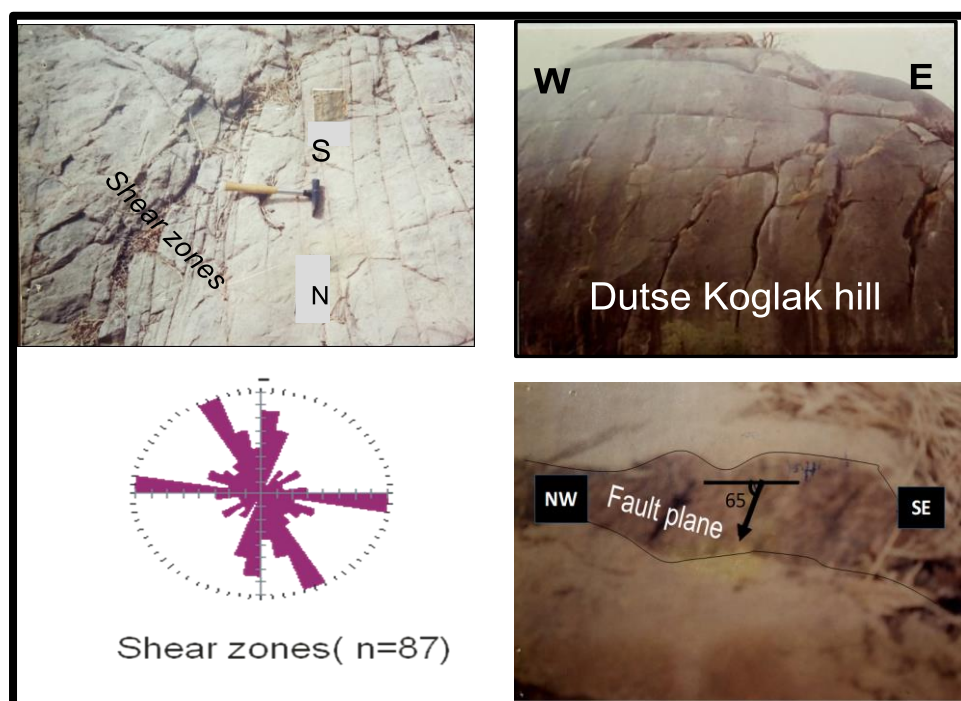


Figure 4: Structural features at Chibok from geological mapping.

### 3. METHODOLOGY

The present work re-interprets Chibok magnetic anomaly across several profiles using *oasis montage*<sup>TM</sup> software version 7.0 with the objectives of determining depth to the magnetic basement and to give more evidence that the area of survey is an intra-basement rift zone. The total magnetic intensity (TMI) map was digitized at the scale of the published map (1 km) to minimize errors. The digitized data were re-contoured using *surfer 11* surface mapping software programme. The digitized data compares favourably with the published equivalent (Figure 5). The sampling interval of 1 km was considered adequate as all significant features of the original data are retained in the digitized data. For modelling purpose, *oasis montage* was used on the digitized data. The digitized data were subjected to regional-residual separation using 1<sup>st</sup> order polynomial fitting processing technique to generate a residual map.

#### 3.1 Polynomial Fitting

Polynomial fitting is a numerical technique developed for regional-residual separation of potential field data (Lowrie, 1997). It is here adapted to magnetic data. The regional trend can be represented by a

straight line, or more generally by a smooth polynomial curve. If  $\Delta H$  is the magnetic field and  $x$  denotes the horizontal position on a magnetic profile, the regional field  $\Delta H_R$  may be written as shown in equation 1:

$$\Delta H_R = \Delta H_0 + \Delta H_1x + \Delta H_2x^2 + \Delta H_3x^3 + \dots \Delta H_nx^n \quad (1)$$

Where 0, 1, 2...n are constants.

The polynomial is fitted by method of least squares to the observed anomaly. This gives optimum values for the coefficients  $\Delta H_n$ . The higher the order of polynomial, the better it fits the observations. The interpreter's judgement comes to play in choosing the order of the polynomial, which is usually chosen to be the lowest possible order that represents most of the regional trends. The residual map is shown in Figure 6. Thereafter, the residual data were subjected to inverse 2-D modelling across three profiles: A, B and C for depth computation.

In this study, more evidence is added by the authors in favour of Chibok magnetic anomaly existing over a rift structure. Field geological data are integrated with the magnetic data to further demonstrate the rift genesis at Chibok.



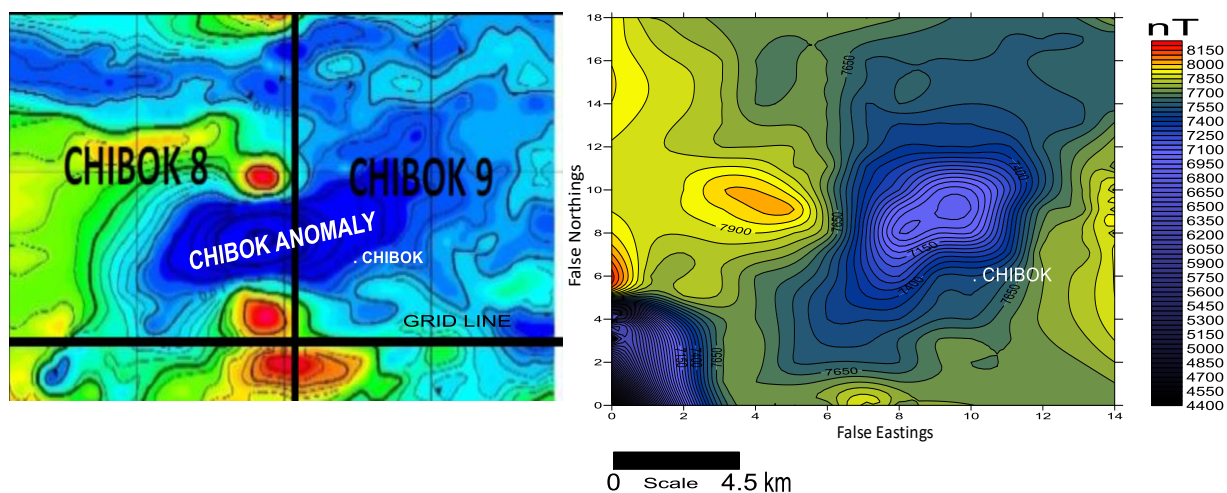


Figure 5: Left: published magnetic map of Chibok; right: digitized and recontoured map used in this study.

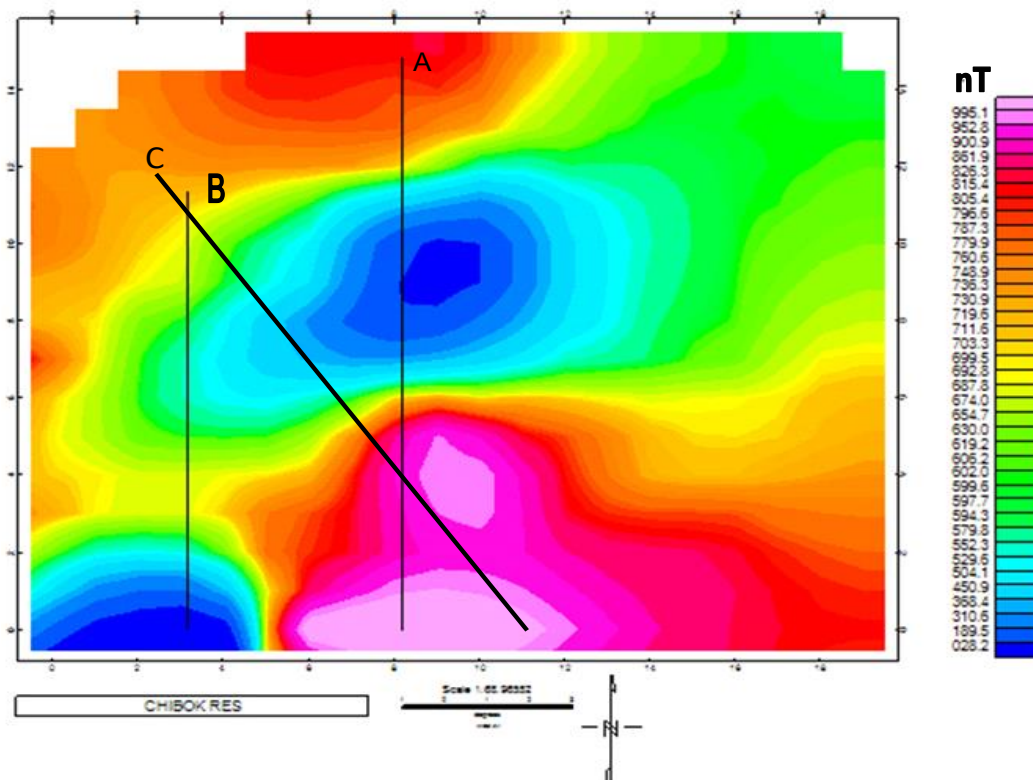


Figure 6: Residual magnetic anomaly map of Chibok. A, B, and C are profiles used in inverse modelling.

## 4. RESULTS AND DISCUSSION

### 4.1 Results

#### 4.1.1 Magnetic Data

Both the total magnetic intensity (TMI) and residual magnetic maps show a prominent NE trending magnetic low zone surrounded by high amplitude zones (Figure 5 and 6 respectively). Cross sections through the TMI map also illustrate this point (Figure 7).

#### 4.2 Discussion of Results

According to Quennell continental rifts are primarily tectonic landforms (Quennell, 1987). They are depressions that are elongated in shape, which are formed by subsidence of crustal blocks lying between sub-parallel as opposed to normal faults. Once formed, the rift gets modified by exogenous process. Horst and grabens are products of normal faulting and extensional tectonics. The field geology of the study area has shown evidence of normal faulting at Vakriva hills and Payegima hill. The interpretation of the geologic subsurface models can be followed from the profiles A, B, and C.

In Figure 8, the profile B passes across the study area in the N-S direction almost along the central region of the study area. It shows a good fit

between the observed and computed magnetic profiles with a root mean square error (RMSE) of approximately 2.7%. The profile was modelled as seven (7) basement blocks i.e. rock 1-7. Relative subsidence of these blocks are considered to be responsible for the uplifted blocks (horst) and down faulted blocks (graben) giving rise to undulations of the basement topography. The green line that separates rocks 1-7 are lithological or structural contacts. The structural contacts are possible faults or tectonic joints as observed on surface geology. The entire profile has a depth of approximately 42 km with sediment thickness of less than 2 km. Blocks 2, 5 and 7 constitute the grabens while the rest are horsts. Some parts of block 1 are exposed to the surface as this portion coincides with the mapped hills of Chibok.

This profile B passes across the study area in the N-S direction towards the western region of the study area. It shows a good fit between the observed and computed magnetic profile with a root mean square error (RMSE) of approximately 1.2%. The profile was modelled as twelve (12) basement blocks i.e. rock 1-12 (Figure 9). Again, relative subsidence between these blocks may be responsible for the uplifted blocks (horst) and down thrown blocks (grabens) giving rise to undulations of the basement topography. The green line that separates rocks 1-12 are lithological or structural contacts. The entire profile extends to a depth of 30 kilometres with sediment thickness of less than 1.4 km. Two broad grabens are seen at the centre (blocks 4 and 5) and they appear to contain the largest amount of sediments.

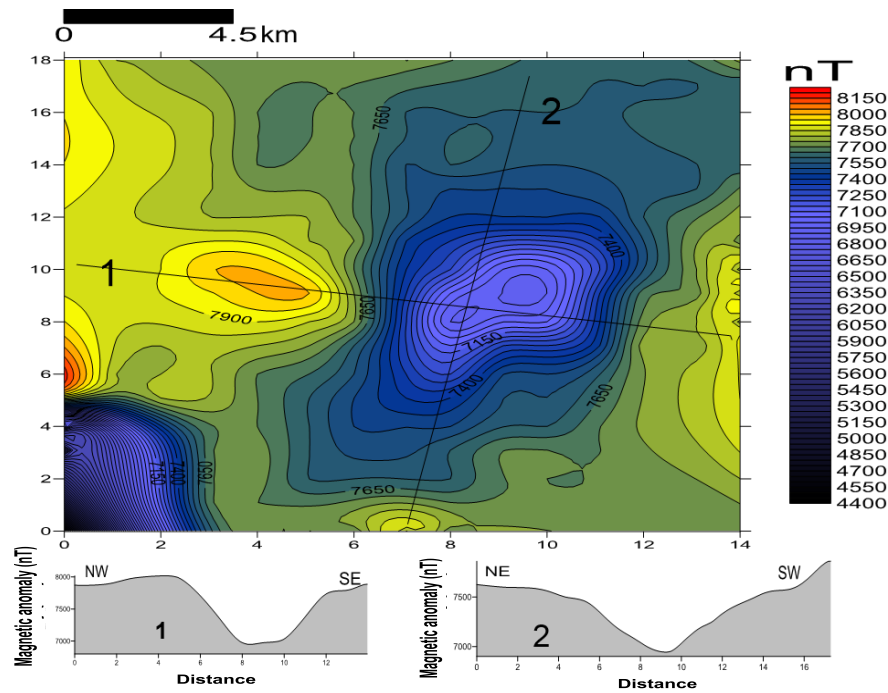


Figure 7: Magnetic map illustrating the prominent negative magnetic anomaly across the study area.

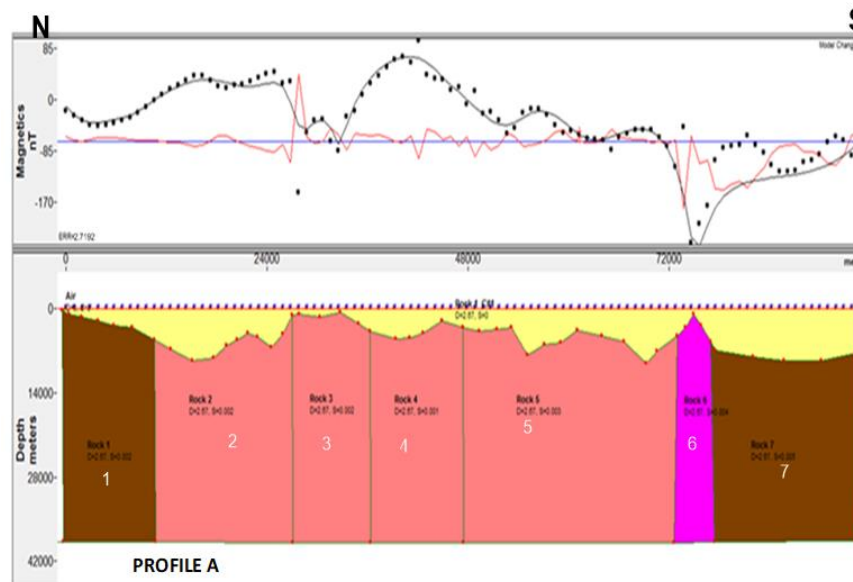


Figure 8: Model magnetic profile along A, top panel is the magnetic anomaly; bottom panel is the depth section. (Red line indicates error deviation).

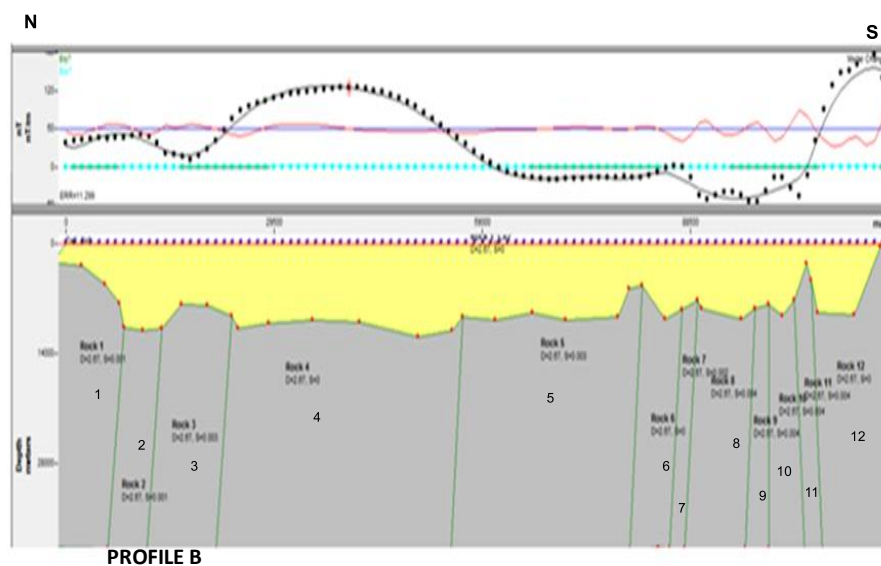
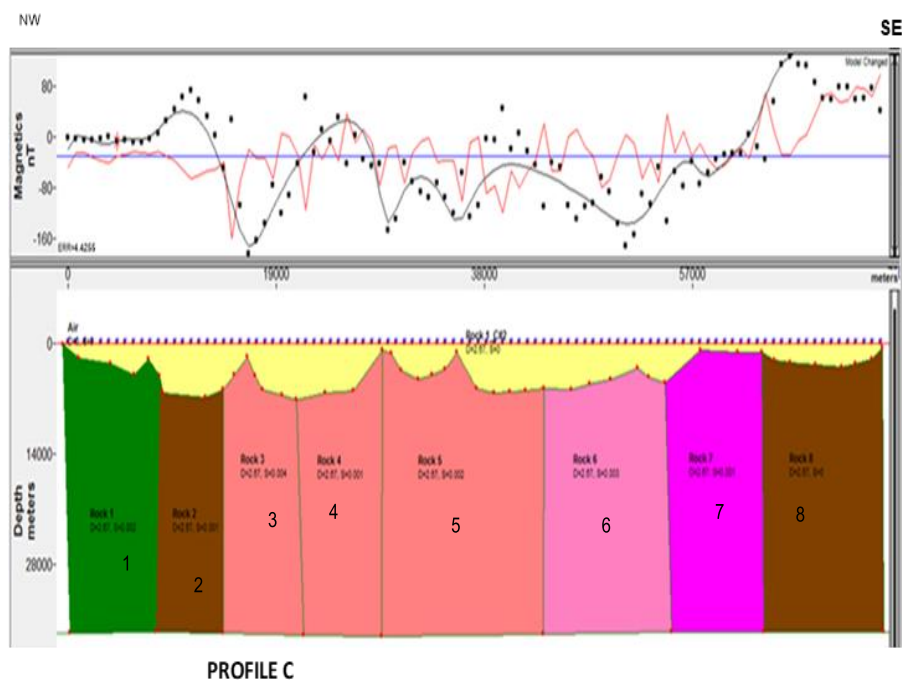


Figure 9: Model magnetic profile along B, top panel shows magnetic anomaly, bottom panel is depth section. (Red line indicates error deviation).



**Figure 10:** Model magnetic profile along C, top panel is the magnetic anomaly, bottom panel is depth section. (Red line indicates error deviation).

This profile C passes across the study area in the NW-SE direction. It shows a good fit between the observed and computed magnetic profile with a RMSE of approximately 2.7%. The profile was modelled as eight (8) basement blocks i.e. 1-8 (Figure 10). Relative subsidence between these blocks may be responsible for the uplifted blocks (horsts) and down faulted blocks (grabens) giving rise to undulation of the basement topography. The green line that demarcates rocks 1-8 are lithological or structural contacts. The entire profile extends to depth >28 km with sediment thickness of about 1km at the deepest section, which is at the centre. The subsurface geologic models above present more evidence of Chibok as a rift zone. From sediment thickness computed, the values lie between 1 to 2 km. Bassey (2006b) computed a depth to magnetic basement (sediment thickness) of 2.65 km on a single profile through the centre of the anomaly.

Bala got a depth range of 1.7 to 2.2 km (Bala, 2016). The average sediment thickness from these results is 2.28 km. The sediments infill in the rift could be attributed denudational process on the horst and depositions on the grabens. The sediments are considered responsible for the low amplitude magnetic anomaly of the study area (29,400 to 31,700 nT), compared to 33,150 nT at the flanks. The sediments are likely to be of fluvial origin as it is always the case at the initial stage in rifting. They may also have been from the granitic rocks, which weathering has caused it to become as residual hills. With this, the sediments are considered to be sands or sandstones, which have low magnetic susceptibility because of low magnetite content. A group of researchers gave magnetic susceptibility value for sandstones to be an average of  $30 \times 10^6$  emu (S.I.), whereas granite has an average of  $200 \times 10^6$  emu (S.I.), and basalt  $6000 \times 10^6$  emu (S.I.) (Telford et al., 1976). The computed magnetic anomaly gradient across the centre of the survey area is 300 nT/km, which is high compared to the magnetic gradient at the northern flank of 100 nT/km.

In geophysical phenomena, high amplitude/high gradient is caused by shallow sources. This buttresses the interpreted shallow average depth to basement of 2.28 km. The long wavelength nature of the Chibok magnetic anomaly further gives credence that the anomaly is over a rift. Long wavelength anomalies have been reported by Ofoeghu, Ofoegbu and Onuoha over the Benue Rift (Ofoeghu, 1985; Ofoegbu and Onuoha, 1992). These authors also said that short and medium wavelength signatures are often observed as perturbations on long wavelength events and are attributable to changes in susceptibility of basement rocks or near surface intrusives within the basement or their combined effects. Hayatudeen in his work on magnetic and satellite data over the part of the Upper Benue Trough showed the dominance of long wavelength magnetic anomalies over the Trough (Hayatudeen, 2018). Also in their study of the structural architecture of the Middle Niger Basin in Nigeria the following authors observed long wavelength magnetic anomalies over the Basin (Salawu et al., 2021).

Nwajide stated that the Benue Trough formed by rifting of the central African basement at the start of the Cretaceous (Nwajide, 2006). It was

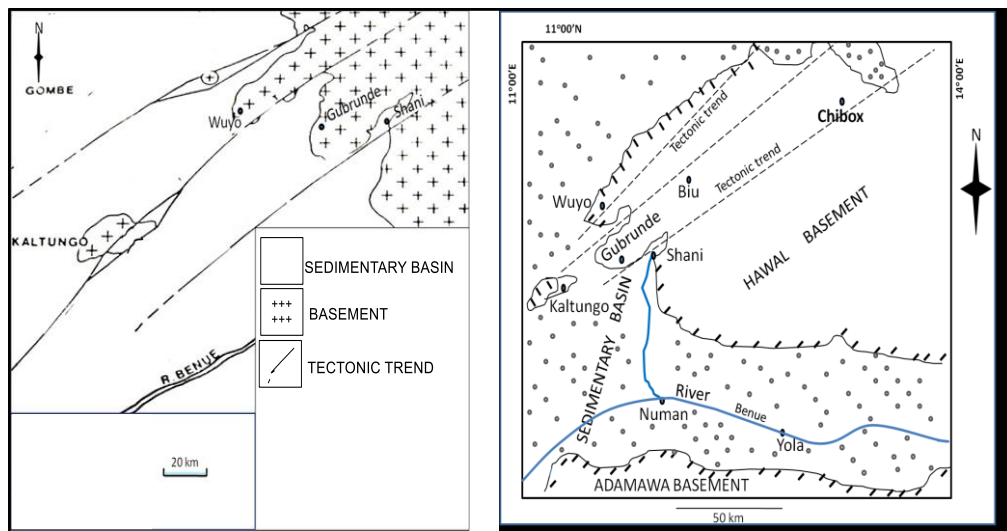
opined that its orientation must have been marked by earlier NE shear zones of late Pan African age (Precambrian), which were reactivated during the breakup of Gondwana land. The author further said that the shape and general structure are therefore determined and controlled by pre-existing ductile/brittle shear zones that were periodically reactivated. A group of researchers have given evidences that the Benue Trough is the product of sinistral structural dynamics along pre-existing NE-SW transcurrent faults (Benkhelil, 1982; 1986; Benkhelil and Robineau, 1883; Guiraud, 1990; Maurin et al., 1986). Chibok is geologically contiguous to the Upper Benue Trough and shares lithological and structural characteristics with the Pan African granitic (basement) inliers of the Trough namely the Wuro-Guburunde inlier and the Kaltungo inlier (Bassey, 2006b). Figure 11 is an illustration of these similarities.

The inliers are marked by N-S shear zones and faults, NE (50°) and N-S conjugate fractures (Benkhelil, 1987; Guiraud, 1990; Suh and Dada, 1997). Chibok inselbergs have N-S shear zones, and also NE (50°), NW-SE and E-W structural trends (Figure 4). Based on these relationships it is worthwhile to posit that Chibok area is an intra-basement rift zone, a zone of structural weakness and part of the West African Rift System (WARS) (Figure 12). The rift is among plate tectonic features of western Africa consisting of the Benue Trough, the Niger Delta, Cameroon Volcanic Line (CVL), Central African Shear Zone, and Oceanic Transform Faults of offshore Nigeria namely Chain and Chacort (Figure 12). This rift zone should be a good place to explore for groundwater, which is a problem in the area, since it is a depression with the adjoining hills serving as watersheds. This envisaged prolific source of groundwater can be exploited for agricultural irrigation in this semi-arid region.

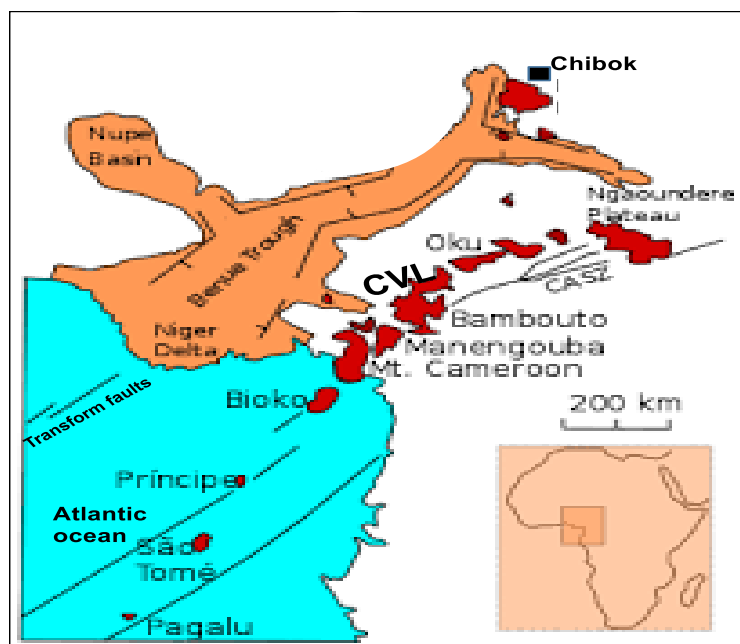
The Bui Plateau is Tertiary basalt plateau covering an area of about 5200 km<sup>2</sup> (Wikipedia). It has an average elevation of 700 m above sea level. Most of the basalts date between 7 and 2 Ma, and some are <1 Ma. The plateau has a number of well-preserved NNW-SSE trending volcanic cones. The emplacement of the Bui basalt would have exploited planes of crustal weakness of the basement along NE, NW, and N-S directions. These are the major deformational directions in the area. A palinspastic (pre-Tertiary) map of the area is presented in Figure 13. The map shows the geology of Chibok and the Upper Benue Trough before Bui plateau magmatism. During pre-Tertiary times it was probably only Precambrian basement fractures zones (NE trending), which later controlled the emplacement of the Bui basalt that are dominant in the area.

The authors have agreed to name Chibok rift as **NSIKAK RIFT VALLEY**, after its discoverer (the first author) in 2004 and the first geologist to map and publish geological work on Chibok in 2006. This follows other practices such as the naming of **CHARCOT FRACTURE** zone after R.V. JEAN CHARCOT, who collected geological data offshore Nigeria during the Geoginnee Cruise in 1968. Also the Maxwell fracture zone in the Mid-Atlantic Ridge, the Murray Fracture zone in the northeast Pacific Basin are all named after people. Mount Everest is named after Sir George Everest, a British surveyor for his studies of the mountain in India in the mid 1800.

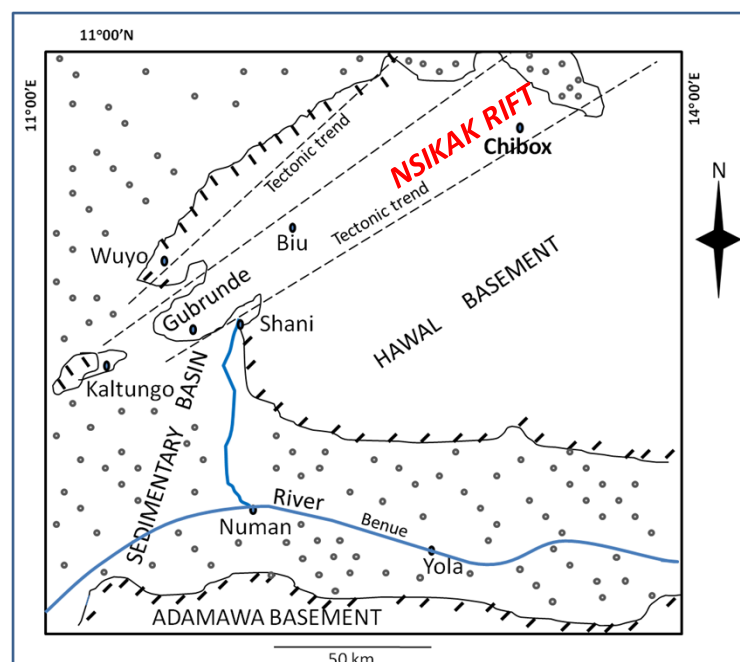




**Figure 11:** Structural trends of Pan African granitic (basement) inliers of Wuro-Guburunde and the Kaltungo inliers. These trends continue northeast wards to Chibok. Left map is after: (Maurin et al., 1986). Right map is modified from (Bassey, 2006).



**Figure 12:** Features of the West African Rift System (Adapted: Internet source <https://images.app.goo.gl/YK7ZNwMQWnsSUxN6A>).



**Figure 13:** Palinspastic (pre-Tertiary) map of Hawal Basement Complex and part of Upper Benue Trough. Note the absence of Tertiary Basalt extrusives.

## 5. CONCLUSION

Analysis of Chibok magnetic anomaly backed up with field geological data has given further credence that the anomaly is generated by an intra basement rift. Computed depth range to magnetic basement is 1 to 2 km. Plate tectonic evidences in support of our interpretation include horst-graben surface topography across study area, and similar structure as revealed from subsurface (inverse) geological modelling. The anomaly identified aligned with other regional plate tectonic features such as offshore fracture zones, the Benue Trough and Cameroun Volcanic Line. The identified rift is named '**Nsikak Rift**' after its discoverer (the first author), who conducted the first published geological field work in Chibok.

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