NRIAG JOURNAL OF ASTRONOMY AND GEOPHYSICS
2020, VOL. 9, NO. 1, 539–547
https://doi.org/10.1080/20909977.2020.1797427

Taylor & Francis
Taylor & Francis Group

Seismotectonic lineament mapping over parts of Togo-Benin-Nigeria shield

Oluwaseyi A. Dasho [a,b], Emmanuel A. Ariyibi [b], Adebiyi S. Adebayo [c] and Sesan C. Falade [d]

[a]Department of Physical Sciences, Dominion University, Ibadan, Nigeria; [b]Physics and Engineering Physics Department, Obafemi Awolowo University, Ile-ife, Nigeria; [c]Department of Physics, University of Medical Science, Ondo, Nigeria; [d]Department of Physical Sciences, Landmark University, Omu- Aran, Nigeria

ABSTRACT

This study carried out a seismotectonic analysis of parts of Togo-Benin-Nigeria shield by delineating and characterising crustal discontinuities using gravity bouguer anomaly data. This was with a view to understand the significance of the discontinuities to the seismicity of the area. Three dimensional (3-D) Euler deconvolution and horizontal gradient magnitude (HGM) at varied upward continued layer were applied on the filtered bouguer gravity data to highlight crustal discontinuities and determine their dip directions. The result showed that 89 lineaments were mapped as faults/fractures from the gravity data. The lengths of the lineaments range from about 6.2 to 94.3 km. The prominent fault/fracture trends were in the N-S and NNE-SSW directions with less dominant trends in the NE-SW and NW-SE directions. The prominent N-S trend pattern aligns with the general N-S foliation strike emplacement across the shield. The Lagos-Ibadan-Ijebu-Ode fault line was identified in this map as having close proximity to locations of previous earth tremors and therefore might be associated to those events.

ARTICLE HISTORY
Received 10 October 2019
Revised 4 July 2020
Accepted 9 July 2020

KEYWORDS
Lineament; gravity; tectonics; 3D Euler; Togo-Benin-Nigeria shield

1. Introduction

Devastating earthquakes are known to occur along tectonic plate boundaries, although there have been intraplate earthquakes which have also resulted in devastations. In Africa, the East African Rift system and the North Africa Atlas thrust and fold belt are areas experiencing a lot of seismicity of earthquake magnitude (Yang and Chen 2010; Meghraoui and Pondrelli 2012). Other parts of the continent such as the Southern African plateau, the Congo basin, the Cameroon Volcanic Line and the West Africa region are also seismically active. In the West African region, major historic and recent earthquake events have occurred in the region. Examples are the M_w 6.5 earthquake that occurred in Accra, Ghana on the 22nd of June 1939 and the intraplate earthquake of 22 December 1983 (M_w 6.4) on the stable West African Craton (WAC) in Guinea (Ajakaiye et al. 1987). The Togo-Benin-Nigeria (TBN) shield, which lies southeast of the WAC, has also recorded cases of earth tremors especially in the southwestern part of Nigeria. The first reported event of earth tremor around the shield was in 1933 near Warri (Ajakaiye et al. 1987). Recently within and around the shield, events such as tremor of 6 June 2016 in Saki; 10 July 2016 in Bayelsa with attendant destruction of buildings; and the 2.6 M_L magnitude tremor of 12 September 2016 in Jaba Kaduna State have been witnessed. These occurrences establish the fact that the TBN shield is not aseismic as previously thought. The reoccurrence of tremor events within and around the shield suggests the need for identification of weakness zones in the region and their relationship with the tremor events. This will serve as a measure for earthquake preparedness in this region, necessitating this study.

Previous studies, though limited by paucity of instrumentally recorded seismic data, suggested that the tremors in the shield are as a result of the inland extension of the Atlantic fracture system in the NE-SW direction which is inferred to be associated with the Ifewara-Zungeru fracture systems (Adepelumi et al. 2008; Anifowose et al. 2010; Akpan et al. 2014). Eze et al. (2011) suggested that the zones of weakness resulting from magmatic intrusions and other tectonic activities in the sediments could be a possible mechanism for the intraplate tremors experienced in the shield. Onuoha and Ezeh (1992) in their examination of the association of fossil plate boundaries and seismotectonics events in West Africa observed that there exist a relationship between fossil plate boundaries/suture zones and seismic events in the region, indicating the importance of lineament mapping in the study of intraplate earthquake events in the region. This study therefore seeks to delineate the discontinuities within the study area to provide further insight into the tectonic setting of the region and its relation to the reoccurring seismic events within the shield.

CONTACT Oluwaseyi A. Dasho seyidasho@gmail.com Department of Physical Sciences, Dominion University, Ibadan, Nigeria

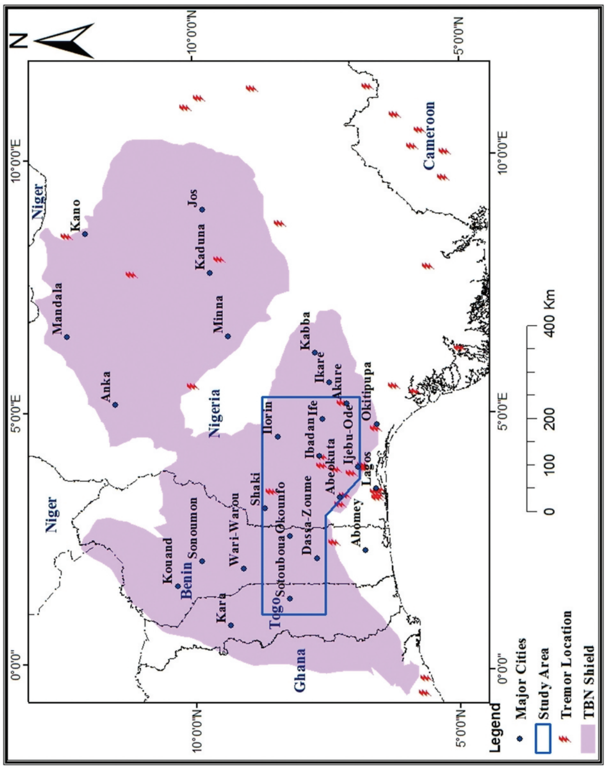

Figure 1. Map of the Study Area within the TBN Shield (Ajibade and Wright 1989).

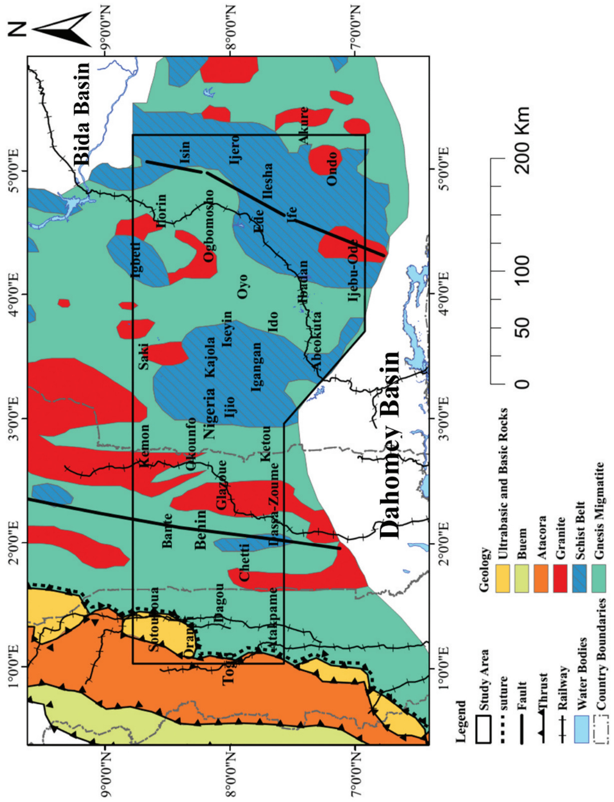

Figure 2. The Geologic Map of the Study Area (Affaton et al. 1991).

2. Study area

The study area is situated within the TBN shield from longitude 1°02′ E to 5°16′ E and from latitude 6°56′ N to 8°47′ N (Figure 1). It spans through Togo, Benin Republic and southwestern Nigeria.

3. Geological setting of the TBN shield

The TBN shield is the southward elongation of the Pan-African mobile belt situated in-between the West African and the Congo cratons (Black 1980). The shield is understood to have emerged from plate tectonics processes (Ajibade et al. 1989). It is bounded to the west by a suture zone which emanated from the collision of the passive continental margin of the WAC and the active margin of the shield. This collision at the suture zone is thought to have resulted in the reactivation of existing rocks and the emplacement of large volume of granites in the internal region of the shield (Ajibade and Fitches 1988; Ajibade et al. 1989). Geochronological studies revealed that the shield is made up of rocks of varying age which include Liberian (Archaean), Eburnean (early Proterozoic), Kibaran (middle Proterozoic) and Pan-African (late Proterozoic) (Ajibade and Fitches 1988). The geology of the TBN shield is subdivided into three structural units as suggested by Affaton (1990), namely, the external structural units, the suture zone and the internal structural units. The external units consist of the Buem and Atacora groups. The suture zone is a narrow area that cut-across south-east Ghana, Togo and north-west Benin Republic consisting of ultrabasic and basic rocks. The internal units, also known as the Benino-Nigeria basement, consist of the Migmatite–Gneiss Complex (MGC), the Schist Belt, the Older Granites and the undeformed acid and basic dykes (Obaje 2009).

The study area is underlain by the atacora unit (quartzites and mica schists), the ultrabasic and basic rocks, the older granite, the schist belt and the MGC (Figure 2).

4. Methodology

The Bouguer gravity anomaly data from Earth Gravitational Model 2008 (EGM2008) was used for this study. The spatial resolution of the EGM2008 model is $2.5' \times 2.5'$. It was gridded using the minimum curvature algorithm. High-pass filter using a 1000 km cut-off wavelength was applied on the gravity data to remove deep mantle sources. Upward continuation filter at 10, 20, 30, 40, 50 and 60 km were also applied to the filtered Bouguer anomaly data. The horizontal gradient magnitude (HGM) of the filtered Bouguer gravity anomaly was computed, at the varied upward continued layers, to amplify lateral boundaries of density contrast in the gravity data at those layers. In order to obtain depth estimates to geological lineaments, 3-D standard Euler deconvolution technique (Reid et al. 1990) was also carried out on the filtered Bouguer anomaly data. The Euler deconvolution parameters used window sizes of 10 and 20 and structural index of 0.

5. Result and discussion

5.1. Qualitative interpretation of the gravity Bouguer anomaly map

The gridded map generated using the minimum curvature interpolation on EGM2008 Bouguer gravity data is presented in Figure 3. The values of the data ranged between −36 and +28 mGal. The map indicates an area covering a continental crustal region. It shows the gravity anomalies arising from the lateral variations in density of underlying rocks within the crust. From the extreme west of the study area, a broad elongated gravity low oriented in the N-S direction is observed at Sotouboua, Oranyi and west of Atakpame. These gravity lows correspond to the external structural unit domain of the Dahomeyide range, coinciding with the Atacora rock unit (Figure 2). The negative gravity value is likely related to the tectonic overload (crustal thickening) during the Pan-African Orogeny in this area (Tidjani et al. 1993). Tending towards the east from Oranyi, a gradient zone in which the gravity anomaly value increases until Bante is observed. The gradient zone confirms the presence of dense basic rock massifs along the suture zone that passes in-between Oranyi and Bante. At Bante, a north-south trending positive gravity anomaly extends south to Chetti. This high gravity anomaly value is connected to the severe magmatic and high-temperature metamorphism that developed east of the suture zone indicated by the presence of granulitic formations or of syn- to post-tectonic granites along this line (Caby 1989; Tidjani et al. 1997). It suggests the existence of subjacent dense bodies or rise of the upper mantle (Tidjani et al. 1993). East of this positive gravity anomaly lies the N-S trending Kandi fault (Figure 2). At Kemon and Saki, an east-west trending gravity low is observed. Trending southward, the anomaly value gradually increases and peaks at Ketou, Abeokuta and Ijebu-Ode. The positive gravity anomalies noticed at locations such as Abeokuta, Ibadan, Igangan, Ife and Ilesha are due to the presence of mafic/ultramafic bodies in the schist belt of southwestern Nigeria. Zero gravity anomaly value is observed to run east beginning from Bante through Glazoue, Ijio, Iseyin, Oyo and Ede dividing the study area east of Bante to negative gravity anomaly in the north and positive anomaly in the south. This trend is likely due to the gradual mantle rise going from north to south (Tidjani et al. 1997).

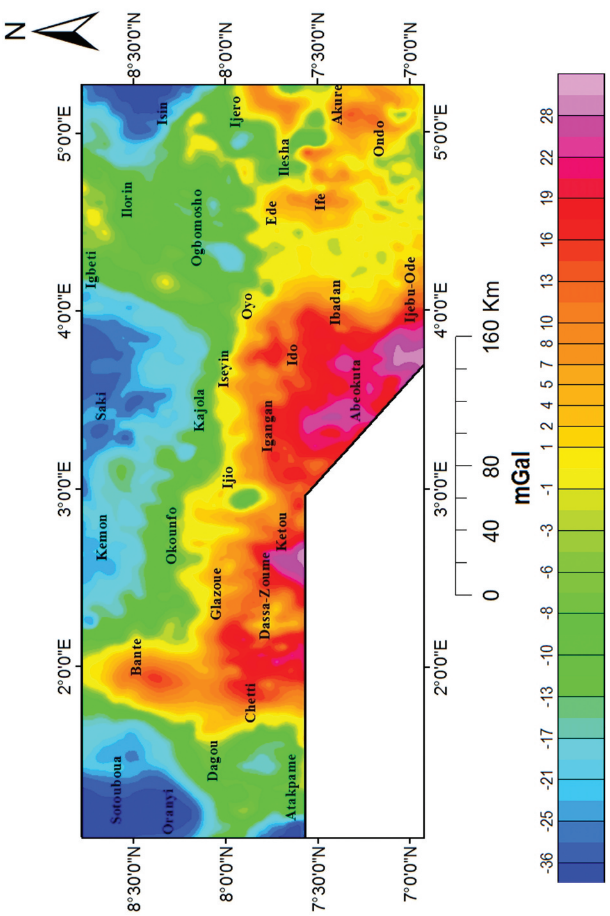

Figure 3. Bouguer Gravity Anomaly over the Study Area.

Figure 4 shows the bouguer map after the removal of deep mantle effect using high-pass filter at 1000 km cut-off wavelength. The filter enhanced short-wavelength signal which corresponds to sources from within the lithosphere. The filtered Bouguer anomaly map has gravity anomaly values ranging between −21 and +24 mGal. The map can be subdivided into three principal divisions of gravity anomaly values, namely – high, intermediate and low. The high gravity anomalies, 5 to 24 mGal, occupy a large part of the study area underlying locations such as Bante, Glazoue, Ido, Abeokuta, Igbeti and Ife. The intermediate value gravity anomalies (values ranging from −4 to 4 mGal) are noticed across the study area in between the high and low gravity anomalies; they are present at Kemon, Dagou Kajola and Ogbomosho. A number of gravity lows are noticed at Sotouboua, Oranyi, Atahpame, Ondo, Isin and Saki. The gravity low at Sotoubona is elongated in the N-S direction while those at other locations are diffused in no particular main direction.

5.2. HGM of the Bouguer anomaly

Figure 5 presents the amplitudes of the HGM of the Bouguer anomaly. The horizontal gradient values range from 0.095 to 1.205 mGal/km. The magenta to red colour show areas of high horizontal gradient, the greenish colour indicates moderate gradient, while the blue clour shows low horizontal gradient. The high

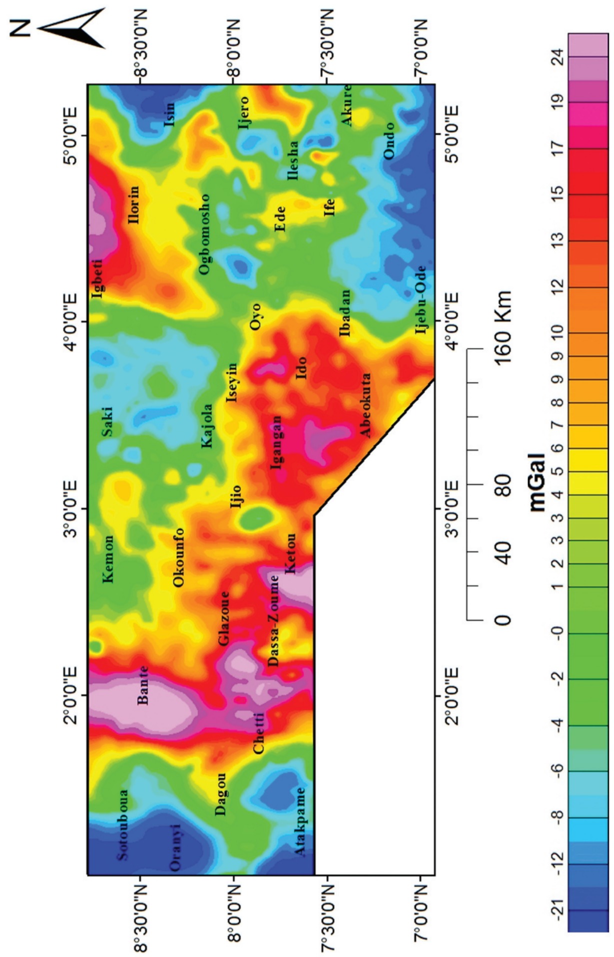

Figure 4. Filtered Bouguer Gravity Data over the Study Area.

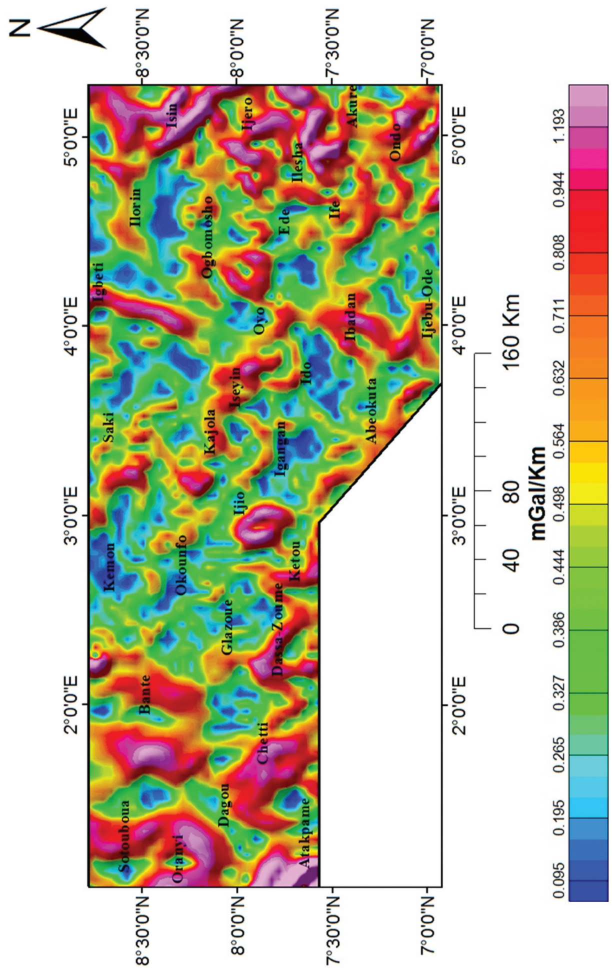

Figure 5. Horizontal Gradient Magnitude Map from Gravity Data over the Study Area.

amplitude HGM trend in varied directions ranging from the NW-SE, NNE-SSW to N-S. The low gradient anomalies are mostly closed and elongated trending in the NE-SW and E-W directions.

The HGM map highlights gradient amplitudes of various shapes in the study area. The elongated high amplitude gradients indicate the presence of fault/fractures while intrusions are indicated by circular high amplitude gradients. The HGM map suggests areas that have undergone varied geotectonic events. These areas are indicated by the amount of faults, fractures and intrusions of varying attributes represented by elongated and close-contoured high gradients. West of the study area, at Oranyi, the circular high gradient zone, centred on the suture zone, is due to the presence of dense mantle materials which are displayed in nappes basic rock massifs (Tidjani et al. 1993). Similarly, the circular high gravity gradients at Bante and Chetti confirm magmatic intrusives. In like manner, the circular high gravity gradients at Ijio, Ife, Ilesha, Ibadan and Ogbomosho indicate the presence of magmatic intrusives (mafic and ultramafic rock), especially in the schist belt, of the Precambrian basement of southwest Nigeria (Rahaman et al. 1988; Caby and Boesse 2001; Ariyibi 2011). The elongated high gradients at locations such as Igbeti, Isin, Ijero, Ibadan, Dassa-Zoume, Bante and Chetti are indicative of intrabasement faults/fractures and contacts. Ajibade and Wright (1989) proposed that the TBN shield is an aggregation of continental fragments and that shears/fractures with close proximity to ultramafic/mafic bodies of ophiolitic origin might be crustal sutures along continental collisions zone. These crustal sutures are important in understanding the seismicity of this shield as they provide zones of weakness along which transcurrent movements might occur (Sengor 1985). The eastern part of the study area is dominated by brittle tectonics indicated by short wave high gravity gradients.

5.3. 3-D Euler deconvolution

The result of 3-D Euler deconvolution applied on the Bouguer map of the study area is presented in Figure 6. In this study, the structural index of zero and window size of 10 gave the best clustering solution representative of fault, contact and dykes. The clustered Euler solutions revealed both linear and curved elements which correspond to faults/fractures and probable deep contacts, respectively. The result obtained from the Euler deconvolution mirrors many of the structures that were highlighted using the HGM technique in Figure 5. By reason of the structural index used, locations with linear clustering solution were assumed to be faults/fractures. Therefore, the lineaments derived from HGM map which do not indicate association to the Euler linear clustering solutions were not considered as fault or fracture. Significant lineaments highlighted by the Euler plot (Figure 6) are noted by rectangles labelled L1 – L7. L1 is a N-S trending lineament along Ibadan and Ijebu-Ode. L2, which extends through the south of Igbeti, is a major lineament oriented in approximately NNE-SSW direction. L3 marks a fault/fracture system which extends across L2 in the NW-SE direction. L4 marks a lineament in the northeastern part of the study area. The lineament trends ENE-WSW across Ilorin. L5 and L7 indicate lineaments oriented in the NE-SW direction with L7 coinciding with the well-known Ifewara fault. L6 trends in the N-S direction and coincides with the Kandi fault. The circular solutions C1 and C2 correspond to contacts or magmatic intrusive bodies. C3 maps the intrusive bodies at the suture zone while C4 reveals those close to the Kandi fault.

The Euler plot result (Figure 6) shows that the depths obtained range from about 2 km to greater than 6 km. The plot reveals the non-uniform depth distribution of the faults/fractures from shallow to deep subsurface layers. Larger portion of L4 and parts of L2 are either buried or deep faults as solutions less than 2000 m are missing along these lineaments. L5 and L7 are of relative shallower depth. L1, L2, C1 and C2 are deeper bodies than L5 and L7 though lesser in depth compared to C3 and C4. C3 and C4 have extension into deep depth suggesting the source of the intrusive to be from the mantle. Generally structures in the western part of the study area have deeper depth in comparison to those in other areas.

Figure 7 is the 3D Euler solution plot obtained using zero structural index and window size of 20. The map gives additional details on the features and was considered in delineating these structures. It reveals that L1 and L2 from Figure 6 are interconnected forming a NNE-SSW trending mega-structure (hereafter referred to as Lagos-Ibadan-Ijebu-Ode fault system). It can also be seen that L1 forms a part of a ring structure running through Abeokuta, Ibadan, Iseyin and Kajola. At Sotouboua, it is observed that C3 and C4 in Figure 6 are interconnected at deep depth and might have the same origin from the collision of the WAC with the TBN.

5.4. Multilayer horizontal gradient maxima analysis

Figure 8 is the superimposed map of HGM solutions at continuation heights 10, 20, 30, 40, 50 and 60 km. The progressive migration of the lines of maxima indicates the orientation of the dip of each lineament and the depth extent of the lineaments in the study area. Some of the significant structures within the study area are labelled M1 to M10. M1, M2, M3, M5 and M6 indicate deep structures with noticeable presence at continuation height of above 50 km. Intermediate depth structures are observed at M4, M8, M9 and M10 indicated by their presence of 30 to 40 km maxima and not beyond. M7, whose location and orientation suggest the well-known Ifewara fault, is of relative shallow depth as no maxima solution is noticed beyond the 20 km continuation height.

As observed from Figure 8, structures M4, M7, M8, M9 and M10 have vertical dip as the maxima lay on each other with little or no offset. M1 and M2 dips east, M3 dips west and M5 dips in south-west direction. M6 which trends NE-SW dips south-east at one end and dips NW at the other end. Most of the maxima solutions show linear or curvy-linear structures

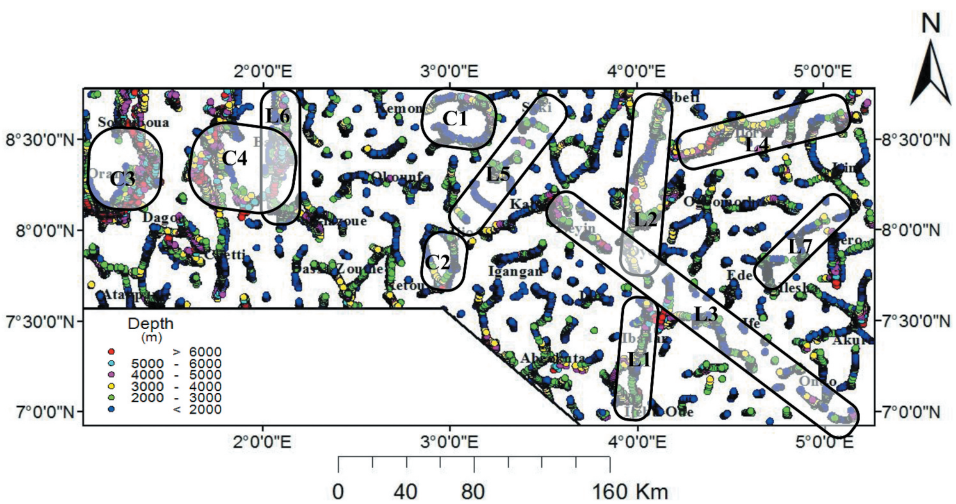

Figure 6. Gravity Derived 3-D Euler Solution Map of the Study Area (Window Size = 10, SI = 0).

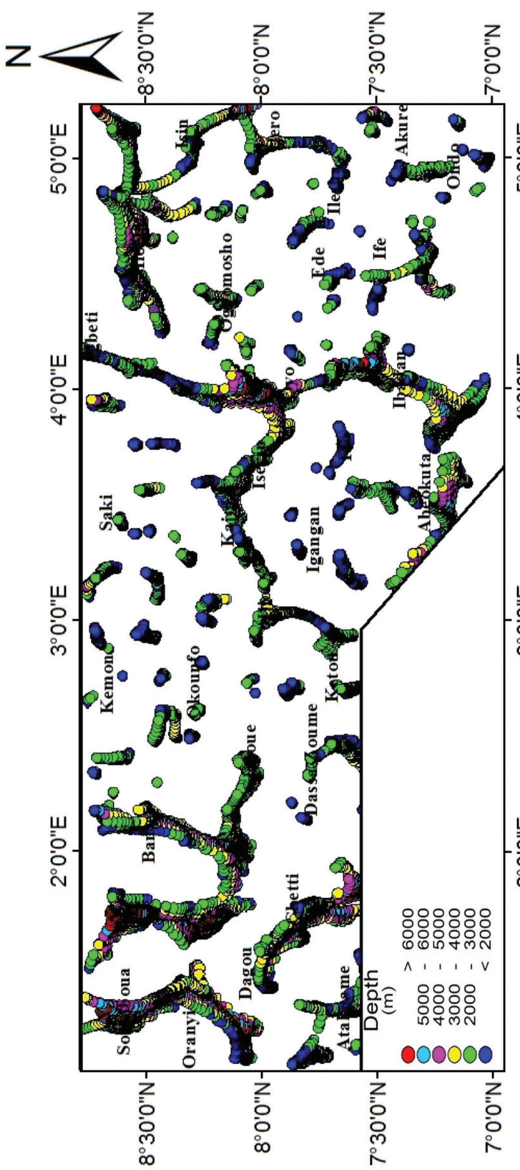

Figure 7. Gravity Derived 3-D Euler Solution Map of the Study Area (Window Size = 20, SI = 0).

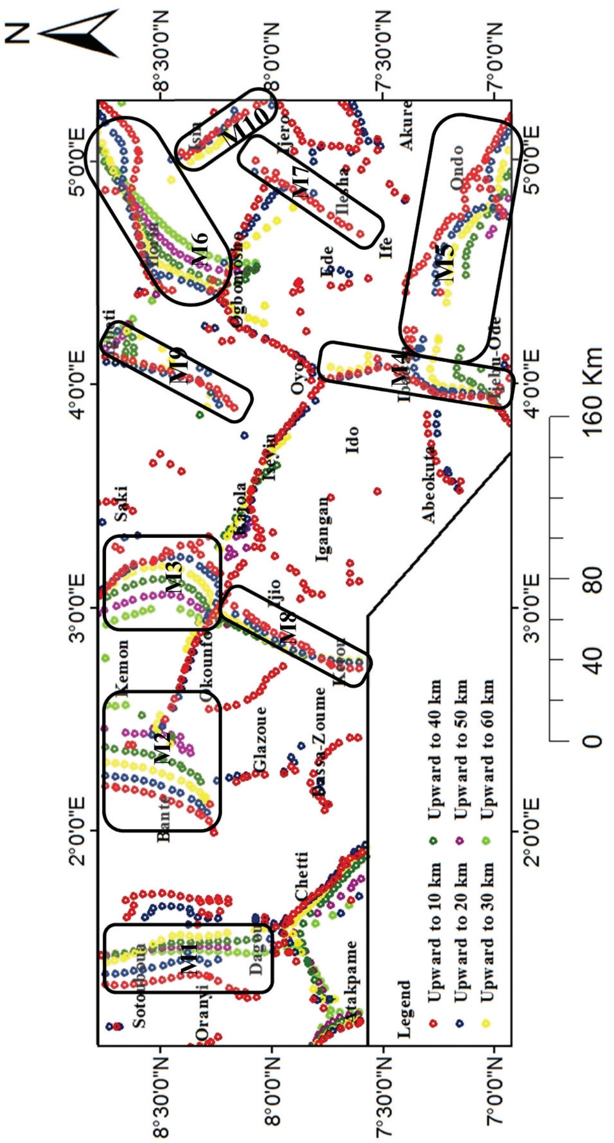

Figure 8. Horizontal Gradient Maxima Solution Plot at Continuation Height of 10, 20, 30, 40, 50 and 60 km.

indicating fault or fractures. M3 however appears to be part of a larger circle suggesting deep circular contact or intrusive.

5.5. Inferred contacts from Bouguer anomaly

Figure 9 is the derived contact maps of the study area. A total number of 149 lineaments were mapped with lengths ranging between about 4.4 km and 64.8 km. Each of these linear features can be considered to be structurally significant as they extend beyond 4 km. The sum and mean of the lineament length are 3056.2 km and 20.5 km, respectively. The rose diagram prepared using the lineament length at 10° interval (Figure 9) shows prominent lineament trends in the NNE-SSW and NW-SE directions.

5.6. Inferred faults/fractures from gravity data

Figure 10 is the inferred fault/fracture map of the study area, its rose diagram and superimposed previous tremor locations. The map was generated from the examination of the HGM and the 3D Euler techniques. A total number of 89 lineaments were mapped with lengths ranging from about 6.2 to 94.3 km. The sum and mean of the lineament lengths are 2945.8 km and 33.1 km, respectively. The rose diagram prepared using the fault length at 10° interval shows prominent lineament trends in the N-S and NNE-SSW directions. The N-S and the NNE-SSW trend patterns align with the general N-S foliation strike emplacement and the transcurrent faults system across the region, suggesting that this region has been intensively affected by the reactivated Pan-African shear zones and transcurrent

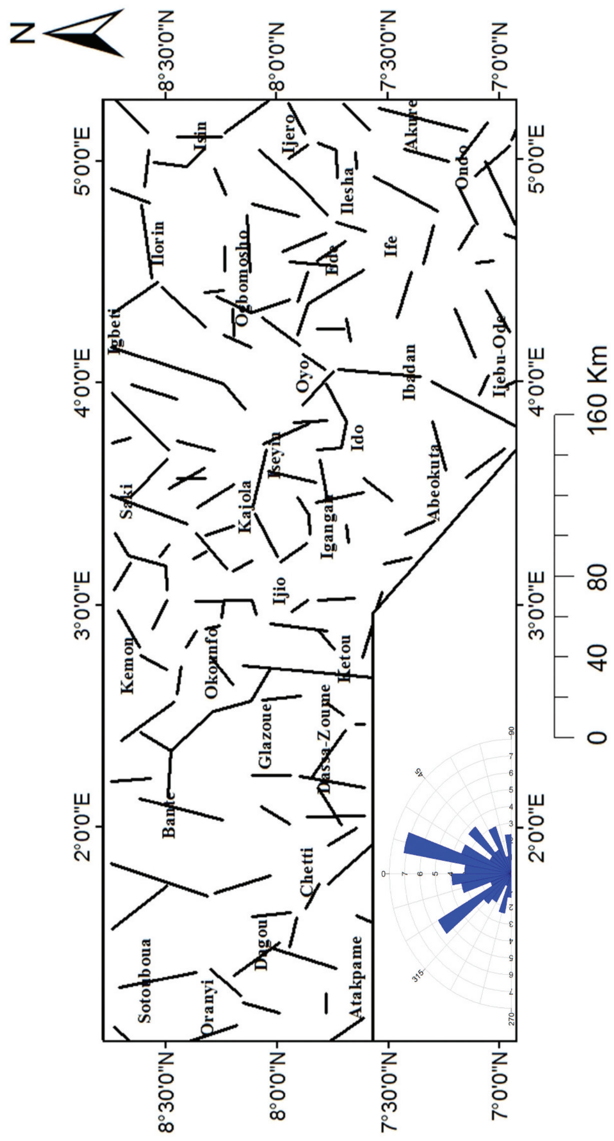

Figure 9. Inferred Contact Map over the Study Area. Insert: Rose Diagram.

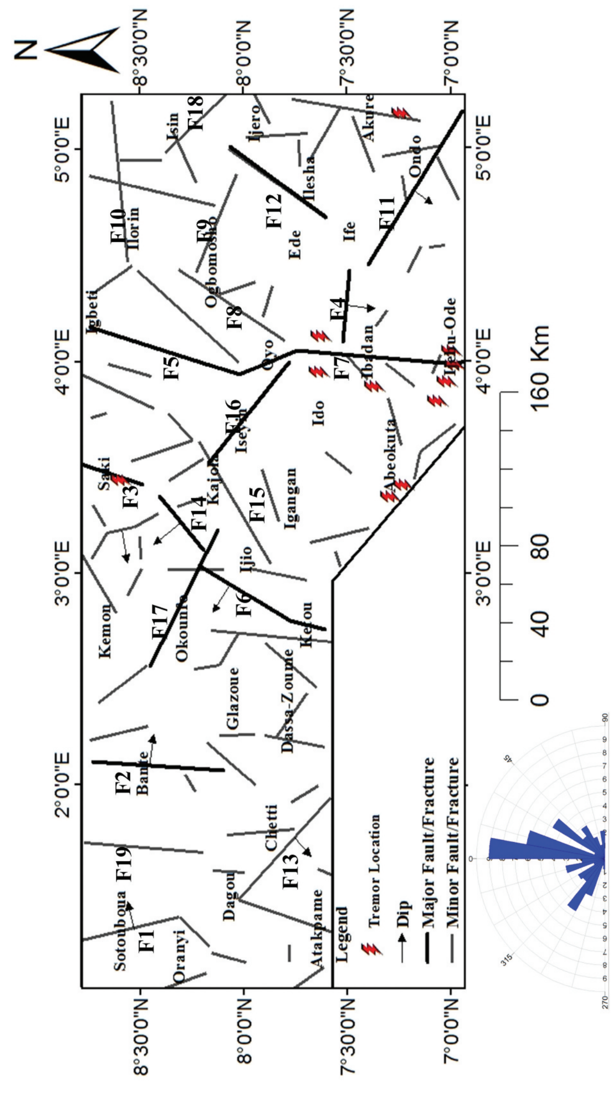

Figure 10. Inferred Faults/Fractures Map over the Study Area.

faults (Oluyide 1988; Dasho et al. 2017). Less dominant trends, from the rose diagram, are the NE-SW and NW-SE directions, the twin conjugate produced by transcurrent movements (Oluyide 1988). The wide spread in the lineaments' azimuths confirms the polycyclic history of the region (Rahaman et al. 1988). At regional scale, the prominent trends align with Pan-African – Brasiliano trends which are associated with the Pan-African-Brasiliano orogeny (Caby 1989; de Wit et al. 2008; Ganade et al. 2016).

The major faults/fractures were mapped as continuous lines of the minor faults/fractures. The superposition of the previous tremor locations on this structural map reveals existing relationship between the fault systems and the previous seismic events. The proximity of most of the felt seismic events to the N-S trending F7 fault, which runs through Ibadan and extends south beyond the study area towards the Atlantic, indicates that this fault/fracture zone could be associated to the tremors felt in Lagos, Ibadan and Ile-Ife in 1939; Ibadan in 1948; Ijebu-Ode in 1963; Ijebu-Ode, Ibadan, Shagamu, Abeokuta, Ijebu Remo in 1984; Lagos in 1988; Ibadan in 1990; Ijebu-Ode in 1994; Ibadan, Akure, Abeokuta, Ijebu-Ode and Oyo in 2000; Abeokuta, Ago-Iwoye, Ajambata, Ajegunle, Imeko, Ijebu-Ode, Ilaro and Ibadan in 2009; and Abeokuta in 2011. Most of these events were previously linked to the NE-SW trending Ifewara fault system (F12) by various authors (Afegbua et al. 2011; Akpan et al. 2014; Tsalha et al. 2015). The Ifewara fault system though believed to be an inland incursion of the Atlantic fracture zone cannot be assumed to be more associated to these tremor events than F7. It may be difficult to confirm whether or not F7 is an active or reactivated fault, due to the paucity of data, it is however by no means mere coincidence that the tremor events had such proximity to the fault. The 1984, 1990, 2000 and 2009 tremors are the only events that were instrumentally recorded. The 1984 and 1990 events had their epicentres at Ijebu-Ode (Ajakaiye et al. 1987; Osagie 2008). These events could be due to crustal adjustment along F7. The 2000 and 2009 events had their epicentres at Okitipupa and at Allada Benin Republic, 129 km and 190 km from Ibadan, respectively (Akpan and Yakubu 2010; Akpan et al. 2014). Although these events had their epicentres far from F7, the shocks were still particularly felt along this fault system. In these events, the F7 might have served as a zone of weakness thereby amplifying propagated seismic waves along it. Shocks from distant plate boundaries, such as the Mid-Atlantic ridge, could in like manner, may have been propagated by the F7 in some other events.

F11 can be observed to be a part of an extended NW-SE trending fault system comprising F17, F16 and F4 underlying Iseyin and Okounfo (Figures 8 and 10). The dislocations along this fault system at Kajola, Oyo and at the location south of Ife are indication of past tectonic movements along F15, F7 and F12, respectively. Similar tectonic movement is also indicated, north of Ijio, by the dislocation of F14 – F6 NE-SW trending fault system along F17. Movements (crustal adjustments) along this fault lines could be trigger mechanism for some of the previous and possibly future seismic events within the study area.

The NNE-SSW trending F5 is observed to be linked to the N-S trending F7 (Figures 7 and 10) forming a megastructure across the study area. In like manner, the NE-SW trending F8 is also connected to the F7. Faults F8 and F12 trending in the same direction may have emanated from the same tectonic process or processes. The interconnection between these faults/fractures could further be tremor trigger mechanism within the study area. The NW-SE trending F11, which dips in the SW direction, is connected to the F7 through F4. It could be associated to the year 2000 tremor that occurred near Akure. F16 which is directly connected to F11 across F7 may also be associated to the 2016 tremor felt in Saki and Iseyin areas. The structural attributes, in terms of strike and dip, of some of the inferred faults/fractures are detailed in Table 1.

Table 1. Structural Attributes of some Inferred Faults.

Inferred Fault Segment	Strike	Dip
F1	NNW-SSE	NE
F2	N-S	E
F3	NNW-SSE	WSW
F4	WNW-ESE	S
F5	NNE-SSW	VERTICAL
F6	NNE-SSW	NE
F7	N-S	VERTICAL
F8	NE-SW	VERTICAL
F9	NW-SE	VERTICAL
F10	ENE-WSW	VERTICAL
F11	NW-SE	SW
F12	NE-SW	VERTICAL
F13	NW-SE	VERTICAL
F14	NE-SW	NW
F15	NE-SW	VERTICAL
F16	NW-SE	VERTICAL
F17	NW-SE	VERTICAL
F18	NW-SE	VERTICAL
F19	NNE-SSW	W

6. Conclusion

This study deals with the mapping of the crustal discontinuities in order to understand their significance to seismic events within the study area using bouguer gravity data. The inferred faults/fractures map revealed footprints of major tectonic activities within the study area. The rose diagram of the inferred faults/fractures within the study area showed dominant lineament trends in the N-S and NNE-SSW directions. Major discontinuities were mapped at locations such as Ijebu-ode, Ibadan, Igbeti, Saki, Ondo, Ilesha, Iseyin, Kajola, Ketou, Okounfo and Bante. Footprints of tectonic movements/dislocations were identified at Kajola, Oyo, south of Ife and north of Ijio. Further crustal adjustment along these fault systems could be trigger mechanism for future seismic events. This study concludes that the Togo-Benin-Nigeria Shield contains footprints of past tectonic activities and that the Lagos-Ibadan-Ijebu-Ode fault system is more associated with the tremor events within the study area than previously reported.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Oluwaseyi A. Dasho http://orcid.org/0000-0001-8514-0181
Emmanuel A. Ariyibi http://orcid.org/0000-0002-8864-8105
Adebiyi S. Adebayo http://orcid.org/0000-0001-6152-0569
Sesan C. Falade http://orcid.org/0000-0001-9479-2683

References

Adepelumi AA, Ako BD, Ajayi TR, Olorunfemi AO, Awoyemi MO, Falebita DE. 2008. Integrated geophysical mapping of the Ifewara transcurrent fault system, Nigeria. J Afr Earth Sci. 52(4–5):161–166. doi:10.1016/j.jafrearsci.2008.07.002.

Afegbua KU, Abubakar YT, Umo AO, Dauda D, Saturday UE. 2011. Towards an integrated seismic hazard monitoring in Nigeria using geophysical and geodetic techniques. Int J Phys Sci. 6(28):6385–6393. doi:10.5897/IJPS10.375.

Affaton P. 1990. Le Bassin des Volta (Afrique de l' Quest): une marge passive, du protérozoique supérieur, tectonisé au Pan-Africain (600 +50Ma) [Thèse Doctorat d'Etat, Collections Etude et Thèses]. Paris: ORSTOMS.

Affaton P, Rahaman MA, Trompette R, Sougy J. 1991. The Dahomeyide orogen: tectonothermal evolution and relationships with the Volta basin. In: Dallmeyer RD, Lecorche JP, editors. The West African orogens and circum-Atlantic correlatives. Berlin: Springer Verlag; p. 107–122.

Ajakaiye DE, Daniyan MA, Ojo SB. 1987. The July 28, 1984 southwestern Nigeria earthquake and its implications for

the understanding of the tectonic structure of Nigeria. J Geodyn. 7:205–214.
Ajibade AC, Fitches WR. 1988. The Nigerian precambrian and the Pan-African orogeny. In: Oluyide PO, Mbonu WC, Ogezi AE, Egbuniwe IG, Ajibade AC, Umeji AC, editors. Precambrian geology of Nigeria. Kaduna: Geological Survey of Nigeria; p. 45–53.
Ajibade AC, Woakes M, Rahaman MA. 1989. Proterozoic crustal development in the Pan-African Regime of Nigeria. In: Kogbe CA, editor. Geology of Nigeria. Jos (Nigeria): Rock View Limited; p. 57–69.
Ajibade AC, Wright JB. 1989. The Togo-Benin-Nigeria shield: evidence of crustal aggregation in the Pan-African belt. Tectonophysics. 165(1–4):125–129. doi:10.1016/0040-1951(89)90041-3.
Akpan OU, Isogun MA, Yakubu TA, Adepelumi AA, Okereke CS, Oniku AS, Oden MI. 2014. An evaluation of the 11 th September. 2009 Earthquake and Its Implication for Understanding the Seismotectonics of South Western Nigeria. Open J geol. (4):542–550.
Akpan OU, Yakubu TA. 2010. A review of earthquake occurrences and observations in Nigeria. Earthquake Sci. 23(3):289–294. doi:10.1007/s11589-010-0725-7.
Anifowose AYB, Oladapo MI, Akpan OU, Ologun CO, Adeoye-Oladapo OO, Tsebeje SY, Yabuku TA. 2010. Systematic multi-technique mapping of the southern flank of Iwaraja fault, Nigeria. J Appl Sci Tech. 15(1–2):70–76. doi:10.4314/jast.v15i1-2.54829.
Ariyibi EA. 2011. Integrated geochemical and geophysical approach to mineral prospecting – a case study on the basement complex of Ilesa Area, Nigeria. In: Chen D, editor. Advances in data, methods, models and their applications in geoscience. Rijeka: InTech; p. 71–92.
Black R. 1980. Precambrian of West Africa. Episodes. 4:3–8. doi:10.18814/epiiugs/1980/v3i4/001.
Caby R. 1989. Precambrian terranes of Benin–Nigeria and northeast Brazil and the late proterozoic south Atlantic fit. In: Dallmeyer RD, editor. Terranes in the circum-Atlantic paleozoic orogens. Geological Society of America. Special Papers, 230; p. 145–158. doi: 10.1130/SPE230-p145.
Caby R, Boesse JM. 2001. Pan-African nappe system in southwest Nigeria: the Ife-Ilesha schist belt. J Afr Earth Sci. 33(2):211–225. doi:10.1016/S0899-5362(01)80060-9.
Dasho OA, Ariyibi A, Akinluyi FO, Awoyemi O, Adebayo AS. 2017. Application of satellite remote sensing to groundwater potential modeling in Ejigbo area, Southwestern Nigeria. Model Earth Syst Environ. 3 (2):615–633. doi:10.1007/s40808-017-0322-z.
de Wit MJ, Stankiewicz J, Reeves C. 2008. Restoring Pan-African-Brasiliano connections: more Gondwana control, less Trans-Atlantic corruption. Geol Soc London, Special Publications. 294(1):399–412. doi: 10.1144/SP294.20.
Eze CL, Sunday VN, Ugwu SA, Uko ED, Ngah SA. 2011. Mechanical model for Nigerian inter -plate earth tremors. Earthzine. [Accessed 2017 January 31]. http://www.earthzine.org/2011/05/17/mechanical-model-for-nigerian-intraplate-earth-tremors
Ganade CE, Cordani UG, Agbossoumounde Y, Caby R, Basei MAS, Weinberg RF, Sato K. 2016. Tightening-up NE Brazil and NW Africa connections : new U – pb/Lu – hf zircon data of a complete plate tectonic cycle in the Dahomey belt of the West Gondwana Orogen in Togo and Benin. Precambrian Res. 276:24–42. doi:10.1016/j.precamres.2016.01.032
Meghraoui M, Pondrelli S. 2012. Active faulting and transpression tectonics along the plate boundary in North Africa. Annals Geophys. 55:5. doi:10.4401/ag-4970
Obaje NG. 2009. Geology and mineral resources of Nigeria. In: Bhattacharji S, Neugebauer HJ, Reitner J, Friedman GM, Seilacher A, editors. Lecture notes in Earth sciences. Berlin: Springer-Verlag; p. 120. doi:10.1007/978-3-540-92685-6.
Oluyide PO. 1988. Structural trends in the Nigerian basement complex. In: Oluyide PO, Mbonu WC, Ogezi AE, Egbuniwe IG, Ajibade AC, Umeji AC, editors. Precambrian Geology of Nigeria. Kaduna: Geology Survey of Nigeria; p. 93–98.
Onuoha KM, Ezeh CC. 1992. Fossil Plate Boundaries in West Africa and their Bearing on Seismotectonic. In: Freeth SJ, Onuoha KM, Ofoegbu CO, editors. Natural hazards in West and Cenral Africa, Earth Evolution Sci. Monogr. Series, Friedr. Wiesbaden: Vieweg & Sohn; p. 13–30.
Osagie EO. 2008. Seismic activity in Nigeria. Pac J Sci Technol. 9(2):546–551.
Rahaman MA, Ajayi TR, Oshin IO, Asubiojo FOI. 1988. Trace element geochemistry and geotectonic of Ife-Ilesha belt setting. In: Oluyide PO, Mbonu WC, Ogezi AE, Egbuniwe IG, Ajibade AC, Umeji AC, editors. Precambrian geology of Nigeria. Kaduna: Geological Survey Nigeria; p. 241–256.
Reid AB, Allsop JM, Granser H, Millet AJ, Somerton IW. 1990. Magnetic interpretation in three dimensions using Euler deconvolution. Geophysics. 55(1):80–91. doi:10.1190/1.1442774.
Sengor AMC. 1985. East Asian tectonic collage. Natureture. 318:16–17. doi:10.1038/318016a0.
Tidjani ME, Affaton P, Louis P, Socohou A. 1993. Gravity characteristics of the Pan-African Orogen in Ghana, Togo and Benin (West Africa). Miramare-Trieste. Internal report: International Centre for Theoretical Physics, Miramare-Trieste. IC/93/142:1–17.
Tidjani ME, Affaton P, Louis P, Socohou A. 1997. Gravity characteristics of the Pan-African Orogen in Ghana, Togo and Benin (West Africa). J Afr Earth Sci. 24 (3):241–258. doi:10.1016/S0899-5362(97)00041-9.
Tsalha MS, Lar UA, Yakubu TA, Kadiri UA, Duncan D. 2015. The review of the historical and recent seismic activity in Nigeria. IOSR J Appl Geol Geophys. 3 (1):48–56. doi:10.9790/0990-03114856.
Yang J, Chen WP. 2010. Earthquakes along the East African Rift system: a mul- tiscale, system-wide perspective. J Geophys Res. 115. doi:10.1029/2009JB006779.