*Earthquake* (2024) Volume 2 Issue 1
doi: 10.59429/ear.v2i1.1883

RESEARCH ARTICLE

# Tectonic activity in Gulf of Guinea and Sub-Sahara West Africa: A validation of Freeth (1977) using focal mechanism solutions

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## ABSTRACT

Fault plane solutions for a group of 104; 4.0 ≤ Mw ≤ 7.1 earthquakes between January 1979 and December 2016, extracted from the Global Centroid Moment Tensor Project catalog. Were used to investigate the regional tectonic stress regime of the Gulf of Guinea region. The idea is to validate the theory of membrane tectonics put forward by Freeth (1977)[1] in which the tectonic of the Gulf of Guinea and the sub-Sahara West Africa region were described based on Freeth (1977)[1]. The tectonic of the Gulf of Guinea and the sub-Sahara West Africa region are based on the movement of the African plate, we emphasized the use of rigorous statistical tests to decide on the quality and variability of the earthquake focal mechanisms (FMSs) utilized for the stress tensor inversion analysis. To constrain our analysis, we have applied both the Algorithm of Michael and Gauss technique in our stress tensor inversion analysis of FMS obtained from the region, and the results are found to be coherent and in good agreement with each other. Both Michael (1984)[2] and Zalohar and Vrabec (2007)[3] techniques show that the regional tectonic stress regime of the Gulf of Guinea and the sub-Sahara West Africa is extensional, which is in good agreement with the work of Freeth (1977)[1]. However, our investigation concluded that the orientation of the extensional stress regime is the same as the orientation of the movement of the African plate, which is towards the Euro-Asia plate.

Keywords: membrane tectonic; regional stress regime; gulf of Guinea

## 1. Introduction

The tectonic of Gulf of Guinea and West Africa has been studied by many scientists since the early 1970s.

**ARTICLE INFO**
Received: 13 December 2023 | Accepted: 28 March 2024 | Available online: 7 May 2024

**CITATION**
Eluyemi AA, Adeoti FO, Awosika, D.D, et al. Tectonic activity in Gulf of Guinea and Sub-Sahara West Africa: A validation of Freeth (1977) using focal mechanism solutions. *Earthquake* 2024; 2(1): 1883. doi: 10.59429/ear.v2i1.1883

All other available methods have been applied to postulate theory and explain the tectonics of the Gulf of Guinea and the sub-Sahara West Africa. Despite somewhat uneven coverage, a fairly coherent theory has been postulated. The period of episodes of deformation has been well established coupled with the identification of several episodes of Phanerozoic igneous activity, the characteristics of which each are now reasonably well defined[1]. Freeth (1977) remarked that the major geological issue at the moment is therefore not what happened during Phanerozoic times but why it happened, this led to the concept of membrane tectonics which provides one further step on the road to understanding why certain geological episodes occurred. The concept of membrane tectonics allows episodes of deformation and igneous activity in West Africa and the Gulf of Guinea during the last 90 million years to be related to movements of the African plate.

Turcotte and Oxburgh (1978)[4] put forward the concept of membrane tectonics, this was derived from the fact that the earth is not a perfect sphere but an oblate spheroid. Therefore, as a plate moves from one latitude to another, it must change in shape. Suggestions of some interesting possibilities from the work of Turcotte (1974)[5] which relates membrane stresses induced by the deformation of a thin shell to the deformation of a plate. This made some facts known; a plate moving from one equator towards another equator must increase its radius of curvature which in the process must have been subjected to peripheral tension, while a plate approaching an equator will have its radius of curvature decreased, therefore be subjected to peripheral compression. The lithospheric properties of the earth are such that an elastic deformation can only accommodate small stress while larger stress results in a brittle deformation in the surface layers and plastic yielding beneath the subsurface (under the surface of the earth).

However, the mathematical calculations of Turcotte and Oxburgh (1973)[4] were an illustration of medium or large plates migrating at the expected geological rate, relative to the poles. Stress generated in such a medium or large plate will be enough to cause a peripheral deformation. A geologic examination of a surface layer of such medium or large plate would presume evidence of brittle deformation of a compression nature in plates approaching an equator and tensional nature of brittle deformation in a plate moving away from the equator, geological examples of this have been illustrated in Turcotte (1974)[5] and Oxburgh and Turcotte (1974)[6]. In summary, the tectonics of the sub-Sahara West African countries including the Gulf of Guinea mainly an extensional stress regime during the breakup of Gondwanaland around 90 m.y. which was accompanied by the spreading of the West African rift systems. The palaeocontinental location of the African continent remains the same. Since 90 m.y. ago, the African continent has steadily migrated towards the north direction Freeth (1977)[1] and rotated faintly in an anticlockwise direction. Between 90 m.y. to 40 m.y. the tectonics of West Africa and the Gulf of Guinea were compressional but from 40 m.y. up till now, it has become extensional. However, the transformation of the tectonic regime of West Africa and the Gulf of Guinea from peripheral compression to peripheral extension occurred at the same time at which the effective mechanical center of Africa (around Jebel Marra) crossed the equator (Freeth, 1977)[1]. For as long as the effective center of the African plate is moving away from the equator, the current tectonic activities of the Gulf of Guinea and West Africa region are expected to be characterized by extensional stress regimes with extension of the West

African rift system,

In this work, we intend to investigate the regional tectonic stress regime of the Gulf of Guinea and the sub-Sahara West Africa region, from a seismological approach via stress tensor invasion of focal mechanism solutions (FMS). This is of huge importance to be able to predict the stability of the region, in terms of strategic constructions, as it was discussed by the earlier scientists Eluyemi et al. (2020a)[7], Eluyemi et al. (2020b) [8], Eluyemi et al. (2022b) [9] which is also in tandem with the preparedness of most of the countries of the region notably among them are Nigeria and Ghana aspiring for inclusion of nuclear power plants (NPPs) in their energy mix (Eluyemi et al., 2020a; Eluyemi et al., 2020b)[7,8]. Also, the knowledge of the regional tectonic stress regime of an area or a region is utilized in coulomb stress study, via stress transfer investigation. Hence the need to validate the work of Freeth (1977) [1] using Focal Mechanism Solutions. Delvaux and Barth (2010)[10] investigated the stress regimes of the African rift systems.

This work is different from the earlier study conducted by Eluyemi *et al*. (2019a)[11] because it takes into consideration the entire seismotectonic zones of the Gulf of Guinea as a single tectonic block to infer the regional tectonic stress regime of the stud area.

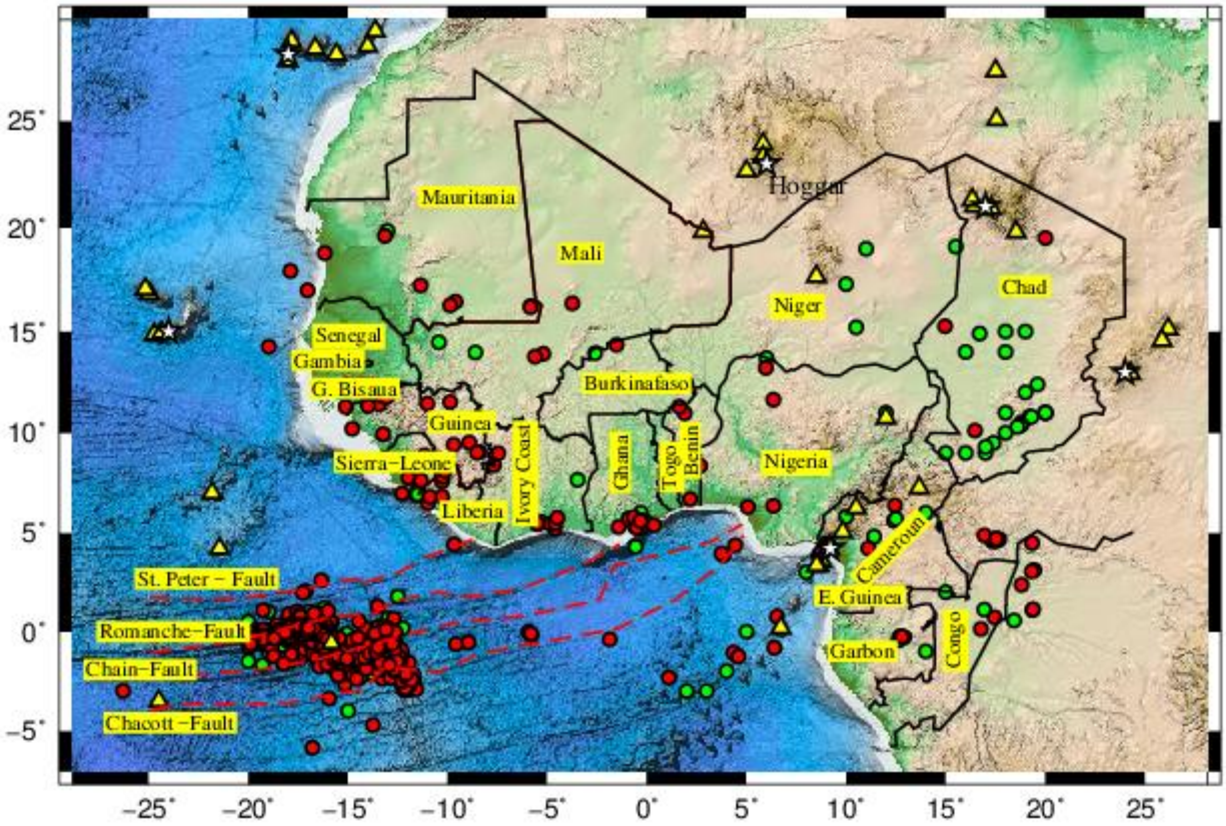

**Figure 1.** Tectonic setting and epicentral plot of the gulf of Guinea and the adjoining continental crust of the countries of Sub-Sahara west Africa. Seismic data during the period 1900-2015 are utilized. The epicentral are shown in green (deeper depth events: 33-70km) and red color (shallow depth events: 0-33km). ; dashed-red lines are the fault zones, volcanic zones in yellow triangle while the hot spot is represented in white stars.

Both the Gulf of Guinea and the sub-Sahara west-African region belong to the same tectonic and geologic unit before and after the separation of the Gondwanaland. We propose to achieve the goal of this work utilizing a set of well-determined fault plane solutions to determine the current tectonic or stress regime of the aforementioned region as it is contained in the work of Freeth (1977)[1], we used the focal mechanism solutions (FMSs) reported by Centroid Moment Tensor (CMT) in the study region around the Gulf of Guinea, applying geometrical and statistical tests to select a reduced sub-set of better-determined FMSs and to quantitatively assess their variability[12,13], This technique has been tested and utilized not only for tectonically active regions[14] but also near volcanoes[15,16].

## 2. Data and methods

The International Seismological Centre (ISC) data catalog was queried for earthquakes within a box with the following coordinates quadrangle of: -7.0° N to 20.0° N and -28.0° E to 20.0° E. The database contains 1100 records for earthquakes that occurred between January 1900 and December 2016 with $M_w$ magnitudes ranging between 4.0 and 7.1. The epicenters reported small to large earth-quakes which are distributed widthwise but are located mostly around the Gulf of Guinea within -25.0° E to -11.0°E and -7.0°N to 4.0°N. The ISC catalog includes information on the depths of earthquakes, magnitudes, and date of occurrence but usually, this parameter is constrained to a specific value by different location procedures. In the case of the location of the moment centroid, we have found FMS data useful for this study within the aforementioned coordinates above by selection of 104 better-determined FMS utilizing rigorous statistical criteria.

## 3. Fault plane solution data

The focal mechanism solutions (FMSs) data reported by the Centroid Moment Tensor (CMT) mentioned the orientation of the two conjugate planes that make up the double-couple part of each earthquake source mechanism. We take into consideration the fact that fault rupture is completely explained by a double-couple system of forces, and the isotropic components of the earthquake sources are not utilized for inversion of stress tensor analysis. A thorough inspection of focal mechanisms solutions reveals that earthquakes occur mostly on strike-slip and normal fault systems in the Gulf of Guinea region. For the quantitative assessment of the quality and variability of the fault plane solutions utilized in this work, we follow the approach of Davis and Frohlich (1995); Frohlich et al. (1997); Sanchez et al. (2009) and Eluyemi et al. (2019) [13,17,18].

The first parameter considered is the $f_{\mathrm{CLVD}}$. This is the sign ratio of the amplitudes of the intermediate and largest principal moments, an indicator utilized to determine the similarity of a particular focal mechanism solution (FMSs) to a compensated linear vector dipole (CLVD) mathematically expressed as:

$$f_{\mathrm{CLVD}} = \frac{-\lambda_B}{\max(|\lambda_T|.|\lambda_P|} \quad \textbf{(Eq.1)}$$

We consider evaluating a relative error ($E_{\mathrm{rel}}$), The $E_{\mathrm{rel}}$ compares the relative size of moment tensor M and its standard error tensor U.

$$(E_{\mathrm{rel}}) = \sqrt{\frac{U:U}{M:M}} = \sqrt{\frac{u_{11}^2 + u_{22}^2 + u_{33}^2 + 2u_{12}^2 + 2u_{13}^2 + 2u_{23}^2}{m_{11}^2 + m_{22}^2 + m_{33}^2 + 2m_{12}^2 + 2m_{13}^2 + 2m_{23}^2}} \quad \textbf{(Eq.2)}$$

The third parameter we examined for the quality assessment of the employed FMS is the $n_{free}$. which refers to the numbers of moment tensor components of an earthquake source that is not equal to zero. Therefore 104 FMS was selected from the numerous available FMS recorded for the region between the periods of January 1977 to December 2016.

## 4. Methodology

The regional stress regime of the Gulf of Guinea is determined from the stress tensor inversion of better determined 104 numbers of focal mechanisms solutions (FMS) obtained from the global centroid moment tensor (GCMT) catalog Dziewonski et al. (1981) and Ekstrom et al. (2012) [19,20] table 1(A). The orientation of the stress tensor is determined using two approaches with different concepts and different computational procedures. First, we utilize Michael (1984, 1987) [2,21], which works on the assumption that earthquakes are shear dislocated on pre-existing faults with slip occurrence in the direction of resolved shear stress on fault plane [22,23]. The second approach we follow is the Gauss method [3], the operational principle of Gauss method is based upon best fit of stress tensor taking into consideration of angular misfit between resolved shear stress and actual direction of fault plane movement. while the operational principle of Gauss method is based upon best fit of stress tensor taking into consideration of angular misfit between resolved shear stress and the actual direction of fault plane movement[3]. The inversion result is tabulated in table 1(B). Orientation of the stress tensor inversion results for the principal stresses $\sigma_1$ and $\sigma_3$ obtained from Michael and Gauss methods are illustrated in F**igure 2**.

| | **Physical characteristics of earthquake focal mechanism solutions (FMS)** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(A)** | **Zone** | **No of Events** | **Depth (Km)** | | | **Magnitude (Mw)** | | | **FMSs Type** | | | |
| | | | **Min** | **Max** | **Avge** | **Min** | **Max** | **Avge** | **NF** | **SS** | **TF** | **OB** |
| | **Gulf of Guinea** | 104 | 3.0 | 33.2 | 18.1 | 4.8 | 7.1 | 5.95 | 17 | 50 | 1 | 36 |

| | | **Stress Tensor Inversion Results** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(B)** | **Gulf of Guinea** | **Method Use** | **(σ1)** | | **(σ2)** | | **(σ3)** | | **ϕ** | **ϕ Avg** | **Variance** | **Std Dev.** |
| | | | **Azim (°)** | **Pln (°)** | **Azim(°)** | **Pln (°)** | **Azim (°)** | **Pln (°)** | | | | |
| | | Michael | 152.2 | 22.2 | -28.8 | 67.7 | 62.1 | 0.4 | 0.93 | 0.77 | 0.16 | 0.40 |
| | | Gauss | 151.0 | 75.0 | 325.0 | 14.0 | 56.0 | 1.0 | 0.60 | | - | - |

## 5. Stress tensor inversion results

Both results of the two methods utilized for the study are in good agreement with each other. The investigated zone reveals that the principal extensional axis $\sigma_3$ is along ENE-WSW direction. Michael method revealed azimuthal, plunge and phi measurement of this zone, for principal extensional axis ($\sigma_3$) as follows: $62.1^0$, $0.4^0$ and $\phi = 0.93$. The dominant principal extensional axis ($\sigma_3$) measurement, obtained from the result of Gauss method is as follows: azimuthal value of $56.0^0$, plunge of $1.0^0$ and $\phi = 0.60$, on the average, the value of $\phi$ is 0.77. Since the obtained results from our analysis shows mainly the dominant extensional axis ($\sigma_3$) and its orientation **Figure 2(b)**, we hereby infer that the present tectonic of the Gulf of Guinea and the entire sub-Sahara West Africa region is extensional. This conforms to the theory of membrane tectonics as proposed by Turcotte and Oxburgh (1973)[4] but put forward by Freeth (1977) [1]. Heidbach et al. (2016)[24] show the sub-tectonic domain characterized by the presence of three types of focal mechanisms solutions, within the study region F**igure 3**.

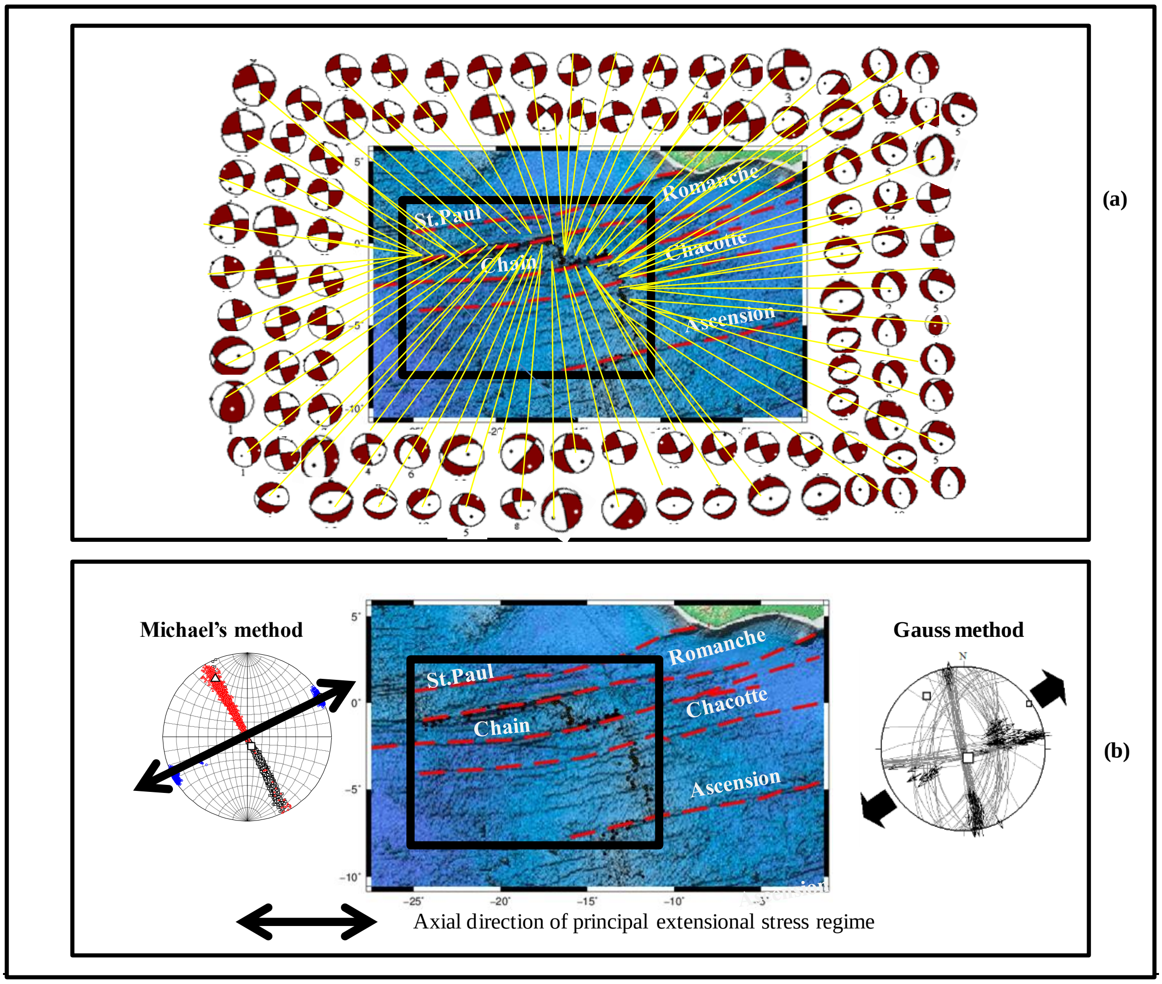

**Figure 2(a).** Illustrates a map showing the selected focal mechanism solutions (beach balls) utilized in this study while. **Figure 2(b)**. Illustrates the orientation of the stress tensor inversion results for the Gulf of Guinea region using Michael and Gauss methods. The black double-head arrow illustrates the orientation of the extensional stress direction in Michael's method.

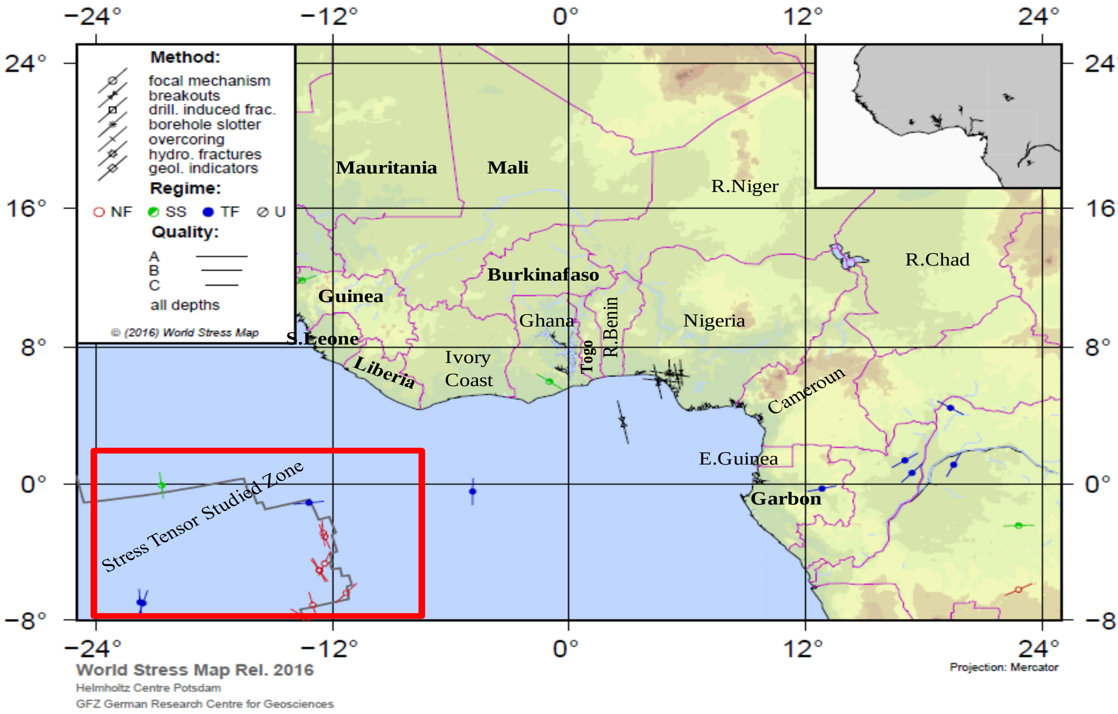

**Figure 3.** Illustrates the world stress map (WSM) release, of 2016 edition showing the studied region in rectangular red box with the dominant focal mechanisms solutions (FMS) positioned in its respective tectonic domain. Three (3) types of FMS have been identified within the studied region by WSM project: strike-slip (SS), normal (NF) and thrust (TF) [24].

## 6. Discussion

The Gulf of Guinea is indeed an interesting geologic environment influenced by complex tectonics since the earlier tectonic of the region was compression and later transformed into an extensional tectonic stress regime, thus it’s intuitive that the stress within the study region is in a cyclic state. The question we confront here is whether the current extensional stress regime will remain forever, or it will later transform to its initial tectonic regime (compression), if it will transform again, the length of time it will take, and the geologic implications on the adjoining region of the Gulf of Guinea. Freeth (1977) [1] illustrates that between 90 m.y. to 40 m.y. the tectonics of West Africa and the Gulf of Guinea were compressional but from 40 m.y. up till now, it became extensional. However, transformation of the tectonic regime of the West Africa and the gulf of Guinea from pheripheral compression to pheripheral extension occurred. An observation from our work gave a better explanation to the migration of the African plate as follows: The study region is located primarily around the plate boundary, between the South American and the African plates, it is intuitive to infer that the driving or splitting forces of the two continental plates begins from this zone. Furthermore, the inferred extensional stress regime from this work also coincides with the orientation of the movement of the African plate towards the Euroasia plate as contained in Kreemer et al. (2014)[25]. Hence the explanation contained in this study for the ENE-WSW movement of the African plate towards the Eurasia plate.

We therefore, applied a novel approach to explain the tectonic of the Gulf of Guinea from the perspective point of stress tensor inversion of the available earthquake focal mechanisms (FMSs) which is the inherent nature of the geologic condition of the region.

## 7. Conclusion

Epicenters and their computed focal mechanism solutions (FMSs) nearly suggest that the occurrences of the earthquake in the Gulf of Guinea relative to the adjoining region represent accommodation of deformation[18,26,27].

In this work, we have validated the work and the theory of Freeth (1977) [1] using stress tensor inversion of focal mechanism solutions (FMSs). Since 90 m.y. ago, the African continent has steadily migrated towards the north direction and rotated faintly in an anticlockwise direction, between 90 m.y. to 40 m.y. the tectonics of West Africa and the Gulf of Guinea were compressional but from 40 m.y. up till now, it has become extensional. However, the transformation of the tectonic regime of West Africa and the gulf of Guinea from pheripheral compression to pheripheral extension occurred at the same time at which the effective mechanical centre of Africa (around Jebel Marra) crossed the equator (Freeth, 1977) [1]. For as long as the effective centre of the Africa plate is moving away from the equator, the current tectonic activities of the gulf of Guinea and west Africa region is expected to be characterized by extensional stress regimes with the extension of the West African rift system,

Our results show that the present tectonic of the Gulf of Guinea and by proxy the sub-Sahara West African region is extensional which is oriented in ENE-WSW direction. This conforms also to the current direction of the movement of the African plate towards the Euro-Asia plate. Since the orientation of the stress tensor inversion result obtained from our work conforms to the direction of the movement of the African plate towards the Euro-Asian plate. We hereby propose a theory and explain it as follows; a Tectonic plate will remain stationary unless it's acted upon by stress, and the direction of movement of such a plate would conform exactly to the direction or orientation of the acting stress. The direction of movement of such a plate would change unless there is a change in the direction of acting stress, which will be experienced in terms of stress rotation.

## Data and resources

The International Seismological Centre catalogue was searched using http://www.isc.ac.uk/iscbulletin/search/catalogue/ (Accessed on October, 2nd, 2016).

## Acknowledgements

Eluyemi A.A. pays gratitude and appreciation to The World Academy for Sciences (TWAS) Italy and Council for Scientific and Industrial Research (CSIR) India, for a CSIR-TWAS sub UNESCO Ph.D fellowship. The Academy of Scientific and Innovative Research (AcSIR) India is acknowledged by EAA for availing the opportunity to carry-out Ph.D. The Nigeria Atomic Energy Agency (NAEC) and Centre for Energy Research and Development (CERD) are hereby appreciated and acknowledged for partial funding of this work. Authors also acknowledge the International Seismological Centre, On-line Bulletin, http://www.isc.ac.uk Internatl.

Seismol. Cent., Thatcham, United Kingdom, 2014 for enabling us access to recent and historic seismic data.

## Funding

This work was fully supported by The Council for Scientific and Industrial Research (CSIR) India and The World Academy for Sciences (TWAS), Italy [CSIR-TWAS, FR number: 3240275042].

## Conflict of interest

The authors declare no conflict of interest.

## References

1. Freeth, S. J. (1977). Tectonic Activity in West Africa and the Gulf of Guinea Since Jurassic Times-An Explanation Based On Membrane Tectonics. Earth and Planetary Sciences, Letter, pp. 298-300.
2. Michael, A. J. (1984). Determination of stress from slip data: Faults and folds, J. Geophys. Res. 89, 11,517–11,526.
3. Zalohar, J. and Vrabec, M. (2007). Paleostress Analysis of heterogeneous Fault-Slip Data: The Gauss Method. Journal of Structural Geology. 29, 1798-1810. doi:10.1016/j.jsg.2007.06.009
4. Turcotte , D.L, and Oxburgh, E.R. (1973). Mid-plate Tectonics. Nature, Vol.244.pp.337-339.
5. Turcotte, D. L. (1974). Membrane tectonics, Geophys J. R. Astron Soc., Vol.36 pp. 33-42
6. Oxburgh, E. R., and Turcotte, D. L. (1974). Membrane Tectonics and the East African rift.Earth and Planetary Science Letters, 22, pp.133-140.
7. Eluyemi, A.A., Sharma, S., Olotu, S.J., Falebita, D.E., Adepelumi, A.A., Tubosun, I.A., Ibitoye, F.I., and Baruah, S. (2020a). A GIS-based site investigation for Nuclear Power Plants (NPPs) in Nigeria, Scientific Africans,Elsevier Publishers, Vol. 7, pp 1-15.https://doi.org/10.1016/j.sciaf.2019.e00240
8. Eluyemi, A. A., Ibitoye, F.I., and Baruah, S. (2020b) Preliminary analysis of probabilistic seismic hazard assessment for nuclear power plantsite in Nigeria. Scientific Africans, Elsevier Publishers, Vol. 8, pp. 1-12. https://doi.org/10.1016/j.sciaf.2020.e00409
9. Eluyemi, A. A., Awosika, D. D., Adebisi, O. D., Isreal O. O. and Ibitoye, F.I., Baruah, S. (2022b). Alternative Method of Seismic Hazard Assessment of Moderate to Aseismic Region with interest to Nuclear Power Plant Siting. In Jelena Purenovic (Ed). Research Developments in Science and Technology Vol. 8, Page 177-181 https://doi.org/10.9734/bpi/rdst/v8/2742C
10. Delvaux, D. and Barth, A. (2010). African Stress Pattern from Formal Inversion of Focal Mechanism Data. Tectonophysics 482, 105-128. doi:10.1016/j.tecto.2009.05.009.
11. Eluyemi, A. A, Baruah, S., Sharma, S., and Baruah, S. (2019a).Recent Seismotectonic Stress Regime of most Seismically active zones of Gulf of Guinea and its Kinematic implications on the adjoining sub-Sahara West African region, Annals of Geophysics, Vol.62; Doi: 10.4401/ag-7877
12. Giardini, D. (1984). Systematic analysis of deep seismicity: 200 centroid moment tensor solutions for earthquakes between 1977 and 1980, Geophys. J. Roy. Astr. S. 7, 883–914.
13. Frohlich, C., Coffin, M. F., Massell, C., Mann, P., Schuur, C. L., Davis, S. D., Jones, T and and Davis, S. D. (1999). How well constrained are wellconstrained T, B, and P axes in moment tensor catalogs? J. Geophys. Res. 102, 5029–5041.
14. Lu, Z., and Wyss, M. (1997). Segmentation of the Aleutian plate boundary derived from stress direction estimates based on fault plane solutions, J. Geophys. Res. 101, 803–816.
15. Musumeci, C., Malone, S. D., Giampiccolo, E. and Gresta, S. (2000). Stress tensor computations at Mount St. Helens (1995–1998), Ann. Geofis. 43, 889–904.
16. Sánchez, J. J., Wyss, M., and McNutt, S. R. (2004). Temporal-spatial variations of stress at Redoubt volcano, Alaska, inferred from inversion of fault plane solutions, J. Volcanol. Geoth. Res. 130, 1–30.
17. Sanchez, J. J. and Nuuez-Cornu, F. J. (2009). Sesmicity and Stress in a Tectonically Complex Region: The Rivera Fracture Zone, the Rivera-Cocos Boundary, and the Southwestern Jalisco Block, Mexico. Bulletin Seismological Society of America, 99 (5), 2771-2783. doi:10.1785/0120080350
18. Eluyemi, A. A., Baruah, S., and Baruah, S. (2019b). Empirical relationships of earthquake magnitude scales and estimation of Guttenberg–Richter parameters in the gulf of Guinea region, Scientific African, Elsevier Publishers, Vol. 6, pp. 1-8. https://doi.org/10.1016/j.sciaf.2019.e00161
19. Dziewonski, A. M., Chou, T. A., and Woodhouse, J. H. (1981). Determination of earthquake source parameters from waveform data for studies of global and regional seismicity. J. Geophys. Res., 86, 2825-2852. doi: 10.1029/JB086Ib04p02825

20. Ekström, G., Nettles, M. and Dziewonski, A. M. (2012). The global CMT project 2004-2010: Centroid-moment tensors for 13,017 earthquakes, Phys. Earth Planet. Inter., 200-201, 1-9. doi:10.1016/j.pepi.2012.04.002
21. Michael, A. J. (1987). Stress Rotation during the Coalinga After Shock Sequence. Journal of Geophysical Research. 92 (B8), 7963-7979.
22. McKenzie, D. P. (1969). The relationship between fault plane solutions for earthquakes and the directions of the principal stresses, Bull. Seismol. Soc. Am. 59, 591–601.
23. Yin, Z. M., and Ranalli, G. (1993). Determination of tectonic stress field from fault slip data: Toward a probabilistic model, J. Geophys. Res. 98, 12,165–12,176.
24. Ekström, G., Nettles, M. and Dziewonski, A. M. (2012). The global CMT project 2004-2010: Centroid-moment tensors for 13,017 earthquakes, Phys. Earth Planet. Inter., 200-201, 1-9. doi:10.1016/j.pepi.2012.04.002
25. Eluyemi, A. A., Baruah, S., and Baruah, S. (2019b). Empirical relationships of earthquake magnitude scales and estimation of Guttenberg–Richter parameters in the gulf of Guinea region, Scientific African, Elsevier Publishers, Vol. 6, pp. 1-8. https://doi.org/10.1016/j.sciaf.2019.e00161
26. Debasis, D. M, Satyapriya, B., Manoj, K. P, and Eluyemi A. A. (2021). Possible depth and source localization of seismic anisotropy beneath Shillong Plateau and Himalayan foredeep region: An implication towards deformation mechanisms, Geological Journal, (special issue) https://doi.org/10.1002/gj.4334
27. Eluyemi, A. A., Awosika, D. D., Adebisi, O. D. and Baruah, S. (2022a). Time-lapse Seismicity Study of the sub-Sahara West Africa and the Gulf of Guinea region. In P. Elangovan (Ed). Research Developments in Science and Technology (pp. 65-72). BP International: doi.org/10.9734/bpi/rdst/v1/2741c
28. Davis, S. D., and Frohlich, C. (1995). A comparison of moment tensor solutions in the Harvard CMT and USGS catalogs, EOS Trans. American Geophysical Monograph 76, F381.
29. Karner, G. (1997). Constraints on Macquarie Ridge tectonics provided By Harvard focal mechanisms and telesiesmic earthquake locations. J. Geophys. Res. 102 (B3), 5029-5041.