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Subsurface Characterization of the Mpape Abuja Tremor in Central Nigeria Trough Source Parameters Imaging Analysis

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***Abstract*-- The Mpape area of Abuja, Central Nigeria, has experienced recurrent low–magnitude tremors that have raised concern about the region's subsurface stability and seismic potential. The study focuses on the subsurface Characterization of the Mpape tremor using source parameter imaging to determine the depth, mechanism and the structural setting of the seismic events. Seismic waveform data from local and regional networks were analyzed to derive source parameters such as seismic movement, corner frequency, Source radius, and stress drop. These parameters were subsequently modeled to image the depth distribution of the tremor source and identify the active fault zone within the basement terrain. The results indicate that the tremor originated from shallow crustal depth, ranging between 2km to 10km, suggesting reactivation of pre-existing basement fault rather than new tectonic movement. The spatial pattern of the image source corresponds with the zone of structural weakness and high stress accumulation within the granitic terrain of Mpape. The finding provides critical insights into the seismotectonic framework of central Nigeria, emphasizing the need for continuous monitoring, improved land use planning, and the development of earthquake-resistant infrastructure to mitigate potential geohazards in the fast-growing Mpape- Abuja metropolis.**

***Keywords*-- Subsurface characterization, depth, Mpape tremor and source Parameter imaging.**

I. INTRODUCTION

Mpape a rapidly growing suburb of Abuja in central Nigeria has gained attention following recurrent earth tremor events recorded over the years between 2018 and 2024. The areas lies between the precambian Basment Complex of North- Central Nigeria comprising of fractured granitic and migmatitic rocks that have been subjected to fracturing and faulting. These features serves as conduit for stress accumulation and subsequently result to tremor events recorded within the area. Earth tremors are minor involuntary seismic movement of the earth. They are often described as slight earthquakes with lesser magnitude measuring between 1- 4.5 on Richter scale Oyibo *et al*,.(2022) They are experienced by rapid rattling of the earth leading to falling of objects from shelves, breaking of glasses, small cracks on the wall and uprooting of trees.

Earthquake energy is generated by a sudden dislocation of the crust when the build-up stress exceeds the strength of the rock mass, the rock ruptures and sometimes assumes new position. These various Processes generate seismic waves that travel in all directions from the point of initial rupture NGSA, (2018). Earthquakes/tremor tends to be concentrated in particular zones which coincide with the boundaries of the tectonic plates. Such boundaries may be either convergent (subduction zones), divergent or transform boundaries. However, it is wrong to think that the countries or zones that are not contiguous with plate boundaries are aseismic. It is believed that tectonic plates are constantly moving slowly over geologic time, but sometimes frictions between them cause them to lock together and become unable to move. The waves of released energy move through the Earth's crust. Ben (2012) and cause the shaking we feel at an earthquake site in response to stresses that originate at the edge of the plate or in the deeper crust. According to Afegbu et al. (2011), earthquake occurrences are dominant along faults, tectonic plate boundaries, principally due to the sudden release of seismic energy from the failure of strained/ build-up energy. Aside from these natural factors, man's activities such as mining, deep quarrying, hydrogeological extraction or fluid disposal and other underground operations have also been known to trigger quakes. Farahan (2014) . Earthquakes mostly occur in the ocean; when it occur in large magnitude, it result in tsunamis, which have led to mass destruction of lives and properties all over the world. Continental earthquakes are also prevalent; they occur on land within the Earth's crust and at boundaries of continental plates and active blocks, usually having relatively lower magnitudes than those occurring in the ocean Elnashai and Sarno, 2008). The whole architecture of the intra -cratonic Benue Trough to the east has been traced to the Chain Fracture Zone of the Gulf of Guinea, which is also spatially related to the other fracture trends of the Atlantic Ocean. Goki et al (2020) .The faults are also suspected to be part of the Ifewara fault traceable to Zungeru and even to the Niger Republic. Earth tremors were also reported in Gembu in the Mambila Plateau in 1987 and at Ibadan in 1990, Akpan and Yakubu (2010).

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II. Structural Geologyand Tectonic Activities

The structural framework of Mpape is dominated by faults, fractures, joints, and zones associated with the Pan-African orogeny (≈600 Ma) with reactivated pre-existing structures in the Nigerian Basement Complex Rahamman, (1988). The major faults often align with deep-seated fracture zones, Akpan and Yakubu(2010) Fig 1 extend from the Niger Delta continental shelf into the inland crustal blocks around Abuja.

Mpape has experienced recurrent earthquakes, within the 2018 and 2024 seismic events, indicating ongoing crustal reactivation. These tremors are attributed to the reactivation of ancient fault lines and fracture zones under present-day tectonic stress fields. The structural and tectonic configuration makes Mpape a tectonically sensitive zone within the supposedly stable Nigerian Basement, Nwankwo and Akpan(2021).

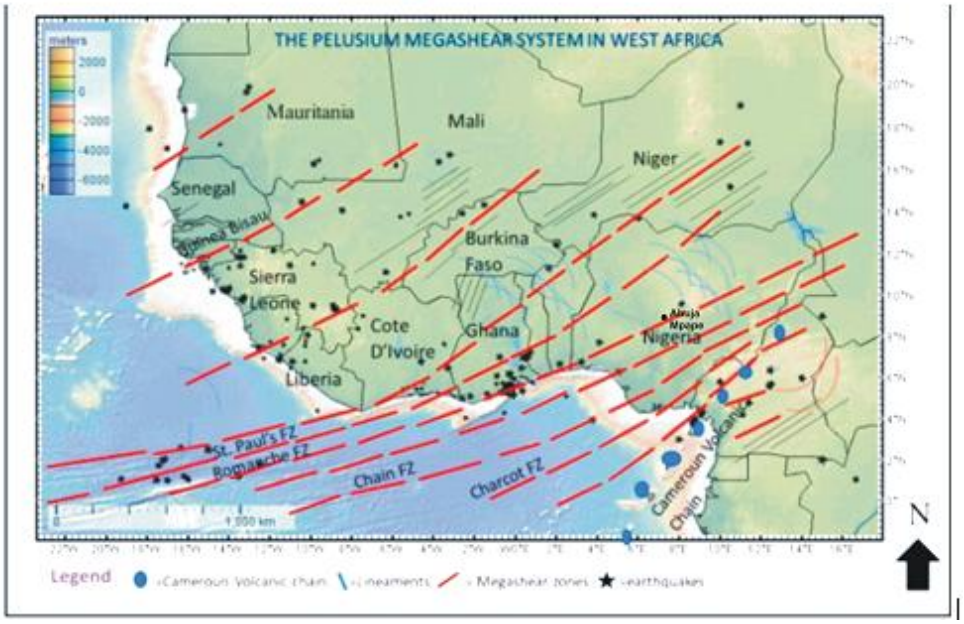

Figure 1 Tectonic map of West Africa (Akpan and Yakubu 2010).

Recent tremor occurrences in Mpape have generated public interest due to their recurrence within a region previously regarded as aseismic. These low-magnitude seismic events highlight the need to re-evaluate the geodynamic framework of the area. The earth tremor resulted in a series of vibrations felt in Mpape and part of Maitama, Wuse, and Gwarinpa from 6 – 7 September 2018. And 13-16 September2024, Centre for Geodesy and Geodynamics and Nigerian Geological Survey Agency CGG (2018) and NGSA (2024)) revealed a sequence of foreshocks from Wednesday 5 September 2018 and all through to Thursday 6 September 2018, with the main shock occurring on Friday 7, 2018. The main tremor occurred at 5:11:32 AM on Friday with a moment magnitude of 2.6 and a local magnitude of 3.0 on the Richter scale. The length stress drop from the main earthquake tremor was 2.1 bar, fault displacement was captured at 0.56km with the focal depth of about 10 – 15km. Also, the event of 13 to 14 September 2024 occurred at about 140-220am with a focal length of 10km and a magnitude of 1.11 on a Richter scale (Table) , Plate 1 below showing part of the affected building in Mpape.

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Plate 1.Cracked wall in Mpape

III. Study Area

Mpape is located within the northeasern flank of Abuja, the Federal Capital Territory of Nigeria. The area forms part of the Precambrian basement complex of North Central Nigeria, composed mainly of migmatite-gneiss, granitic intrusions and quartzite. The area is accessible by a good network of roads, and the topography varies from lower elevation around the south-western part to irregular high elevation eastward, with over 760m above the sea level.

It has a total area of 1728km2 with a population of about 1.8 million people. (Abuja master plan 2000). It lies between latitudes 8025' and 90 25'north of the equator and longitudes 60 45' and 70 45' east of the Greenwich Meridian. Mpape is located within the middle belt of Nigeria (Balogun 2001). It covers a land mass of 8,000 square kilometres. Abuja master plan, (2000). The city is drained mainly by the rivers Kada, Gurara and other smaller tributaries

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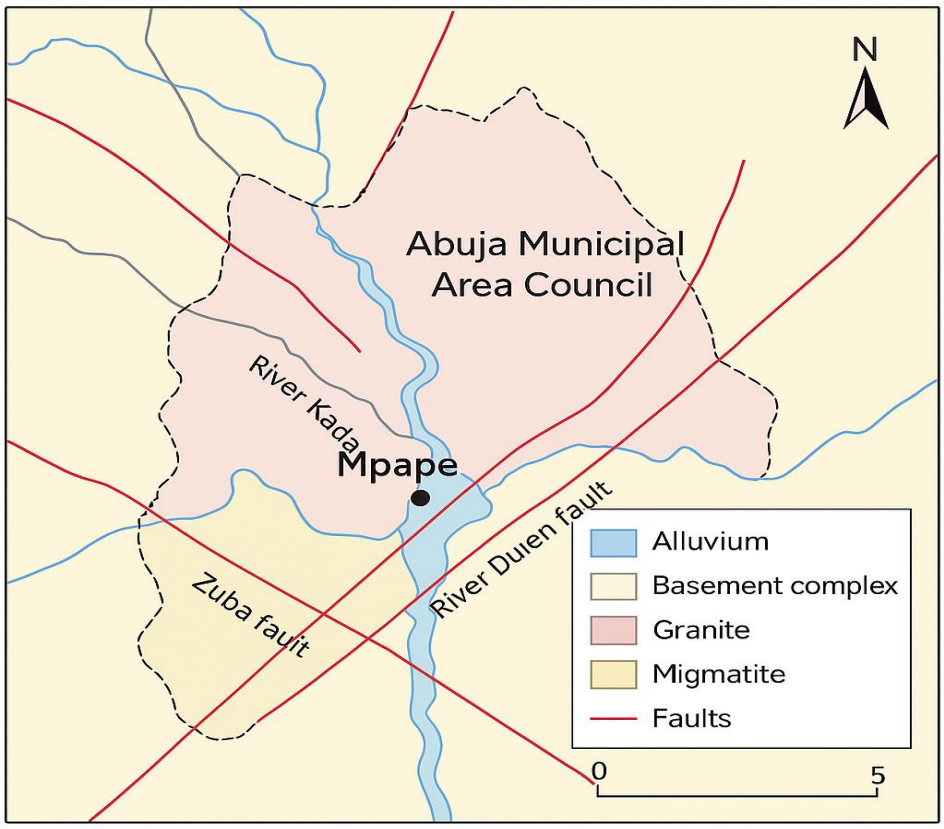

Figure 2 Map of the study area showing fault lines and rock type

IV. METHODOLOGY

Seismic waveform data obtained from local and regional stations around Mpape, Abuja, were analyzed to determine the sources of the recorded tremors. The data were processed by eliminating instrumental noise and applying a 0.5–20 Hz band-pass filter to enhance signal clarity. Event detection and phase picking were performed using the STA/LTA algorithm, and the resulting parameters were utilized to image the depth and spatial distribution of the events. MATLAB and SEISAN software were employed for data processing and modeling, while measurements were taken from seismograms recorded at the Centre for Geodesy and Geodynamics seismic station. Depth analysis of the magnetic dataset was conducted using the advanced Analytic Signal–Hilbert Solution method to estimate the depth of interpreted regional fault structures surrounding the epicenters

V. RESULTS

The source parameter imaging results indicate that the Mpape tremor are shallow magnitude resulting from reactivation of pre-existing basement faults. The dorminant N-S and NW-SE fault trends align with regional romanche and ifewara=Zugeru fault zone. The focal depth of the tremors around Mpape ranged from 1.0 km to 15km Table 1, these shallow depth correspond to areas of intense deformation and fractured basement rocks, suggesting reactivation of ancient fault system. The regional fault around Mpape area was interpreted to have a depth ranging from 8 km to 9 km. It could be concluded that the relationship between the North Atlantic Romanche Fault and the continental regional faults system (Ifewara=Zungeru fault) played a key role in the source of seismic energy that resulted in the tremor activities of central Nigeria.

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Waveform analysis from the seismogram Figure 3 indicates a shallow depth of about 5km away from the NGSA Station trending NE-SW. This trend is in tandem with the deep-seated Romanchi fault line through the study area. Recent tremor occurrences in Mpape have generated public interest due to their recurrence within a region previously regarded as aseismic. These low-magnitude seismic events highlight the need to re-evaluate the geodynamic framework of the area. The earth tremor resulted in a series of vibrations felt in Mpape and part of Maitama, Wuse, and Gwarinpa from 6 – 7 September 2018. And 13-16 September 2024, Centre for Geodesy and Geodynamics and Nigerian Geological Survey Agency (CGG and NGSA) revealed a sequence of foreshocks from Wednesday 5 September 2018 and all through to Thursday 6 September 2018 with the main shock occurring on Friday September 7, 2018. The main tremor occurred at 5:11:32 AM on Friday with a moment magnitude of 2.6 and a local magnitude of 3.0 on the Richter scale. The length stress drop from the main earthquake tremor was 2.1 bar, the length of fault displacement was captured at 0.56km, with the focal depth of about 10 – 15km. Table 2 and the recorded seismogram details.

Table 1
parameters for locating Mpape event (2018/2024)

1.	2.	3.	4.	5.	6. Epicenter	
7. Event	8. Date	9. Time	10. Magnitude	11. Focal Depth (KM)	12. Latitude (N)	13. Longitude (E)
14. Foreshock	15. 05-09-2018	16. 3:30	17. < 2.5	18.	19.	20.
21. Foreshock	22. 05-09-2018	23. 3:34	24. < 2.5	25.	26.	27.
28. Main shock	29. 07-09-2018	30. 5:11	31. 3.0	32. 15	33. 9:14	34. 7:59
35. After shock	36. 07-09-2018	37. 7:12	38. 2.5	39. 5	40. 9:16	41. 7:40
42. Main shock	43. 13-09 2024	44. 1:40	45. 1.11	46. 10	47. 9:25	48. 7:45
49. After shock	50. 14-09- 2024	51. 2:20	52. 1.11	53. 10	54. 9:13	55. 7:58

Table 2:
Waveform amplitude for the Z component (NGSA 2024).

1. S/N	2. Date	3. Maximum waveform amplitude for the Z component
4. 1.	5. September 13, 2024	6. 2,259
7. 2.	8. September 14, 2024	9. 60,991
10. 3.	11. September 15, 2024	12. 113,823
13. 4.	14. September 16, 2024	15. 393,775
16. 5.	17. September 16, 2024	18. 35,595

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The seismogram waveform of September 2018, Mpape, Abuja tremor (main shock). Fig. 3 shows a short-duration, high-frequency oscillation typical of shallow tremor. The amplitude and duration reflect a near-surface source typical of reactivation of a pre-existing fracture zone in Mpape, Abuja. The seismogram reading further confirms that the 2018 Mpape tremor was linked to structural weakness within the Precambrian basement complex.

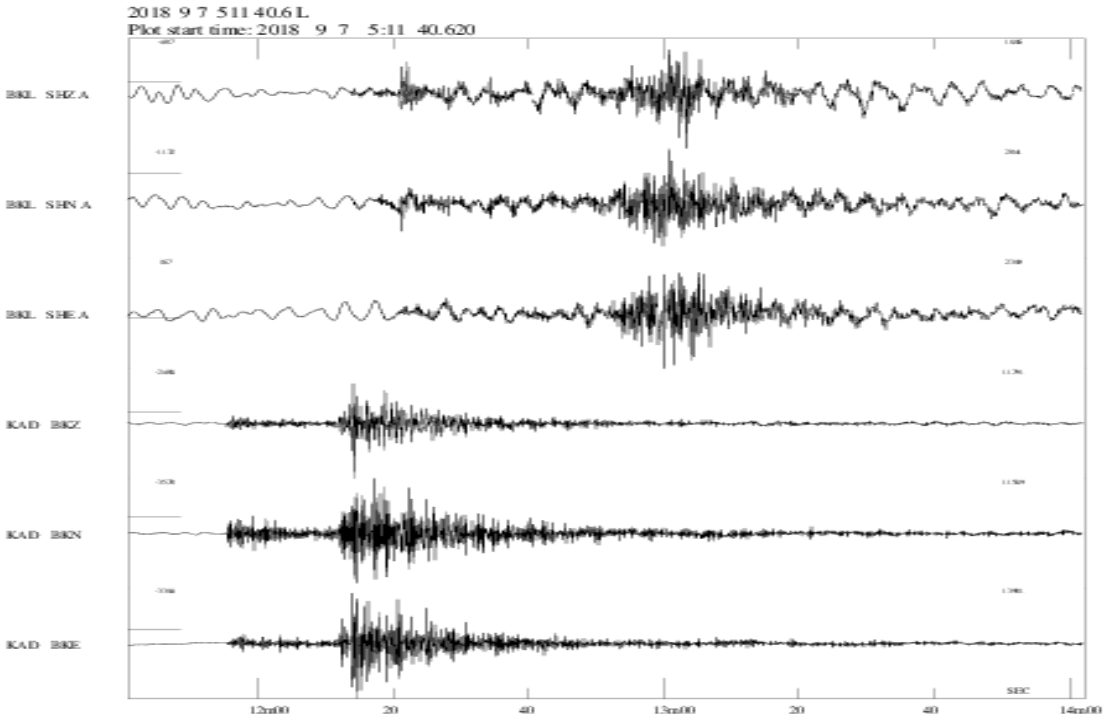

Figure 3 Seismogram of Abuja Tremor (main shock) on the 7th September, 2018

The waveform from 13th September 2024, Mpape Abuja tremor fig 4, indicates a recorded local seismic event, the short P-S interval suggests a shallow hypocenter reflecting localized stress release along a pre-existing fracture zone.

This pattern supports the inference that the Mpape tremor results from reactivation of a pre-existing fault within the Precambrian basement complex of central Nigeria.

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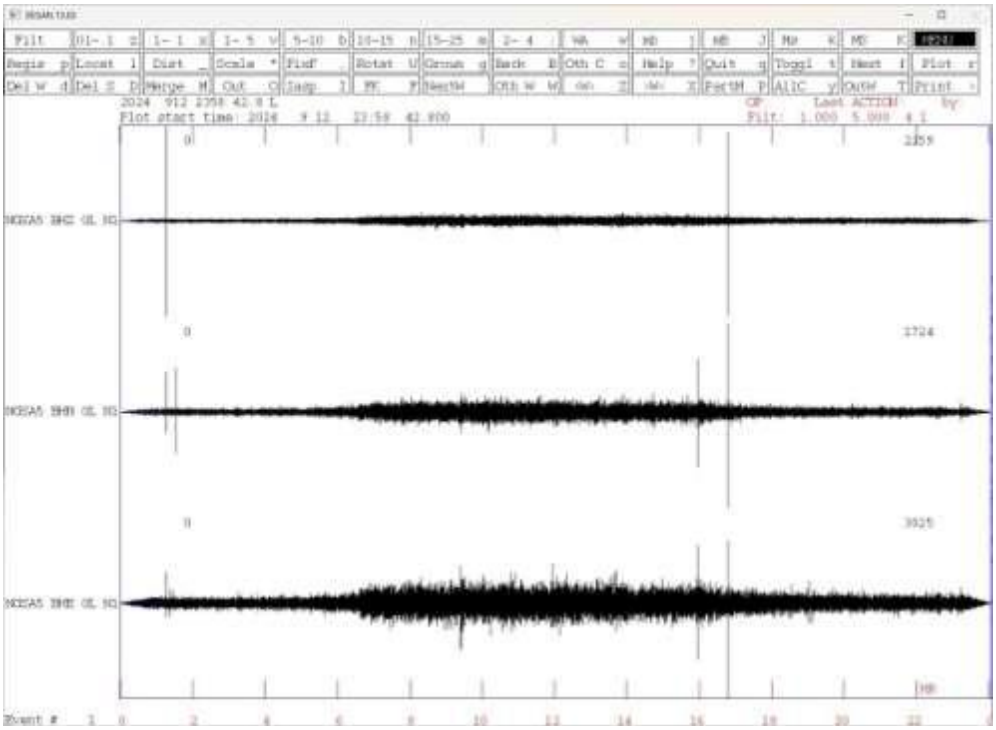

Figure 4 Waveform from 13th tremor (NGSA 2024).

The structural map of Mpape, the study area (Fig.), derived from aeromagnetic data and source parameter imaging (SPI), reveals numerous networks of structures and faults trending NE-SW, NW-SE, AND N-S that define the tectonic framework of Mpape. The (SPI) depth estimation ranges from 0.5km to 3.0km; the shallow magnetic (0.5-1.5km) is concentrated around Mpape, Bwari and Gwarinpa, suggesting a zone of weakness.

These shallow depths also coincided with the recorded epicenters of tremor occurrences within the study area. Correlation between SPI depth variation and mapped fault trends demonstrates that earthquake activities in Mpape are structurally driven as a result of reactivation of the pre-existing fault system.

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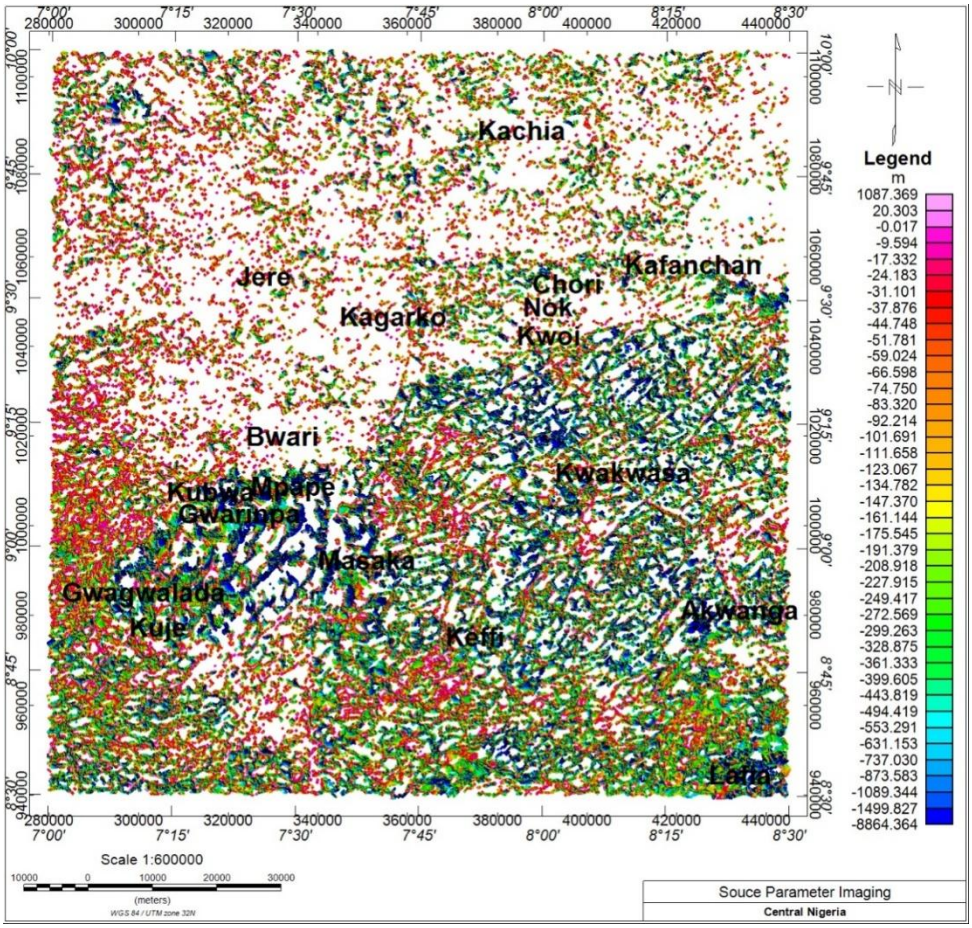

Figure 5: Parameter Imaging Map of the Study Area.

The focal depth of the epicenters of the tremors ranged from 10 km to 15km; the measurement was done using a seismogram at the Centre for Geodesy and Geodynamics seismic station. Depth analysis was carried out on the magnetic dataset using advanced Analytic Signal- Hilbert Solution depth analysis to project the depth of interpreted regional fault structures around the epicenters, to evaluate their potential of being the source of the seismic wave's energy that resulted in the tremor activities.

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The regional fault around Mpape (Fig 6) area was interpreted to have a depth ranging from 8 km to 9 km, and this was very close the focal depth range of 10 km to 12 km measured by the seismogram, It could be concluded that the relationship between the North Atlantic Romanche Fault and the regional faults system played a key role in the source of seismic energy that resulted in the tremor activities of central Nigeria.

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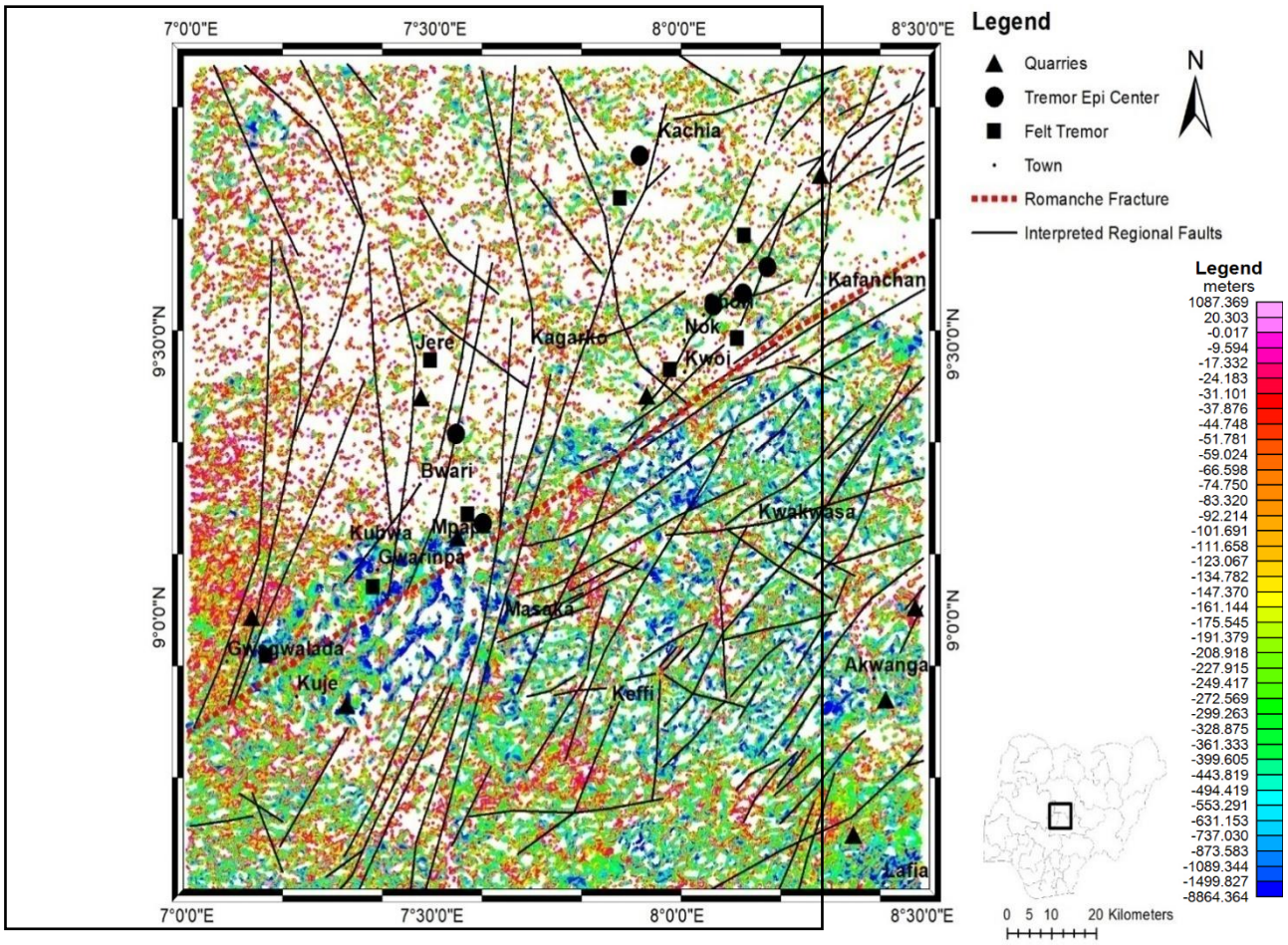

Figure 6 Depth to source map of the study area.

VI. Conclusion

Studies into the Mpape Abuja tremor of September 2018 and 2024 utilizing aeromagnetic data analysis, satellite imagery and seismological data to determine their depth to source parameter and potential causes. The result indicate that the tremor originate from shallow crustal depth associated with the reactivation of pre-existing faults. Estimated source parameter revealed low stress drop and small seismic movement, confirming the events were of low magnitude and localized in nature. The alignment of tremor foci with mapped structural trends and quarrying zone suggest a combination of natural and man- made stress as a principal triggers. These findings provides valuable insight unto the seismic behavior of the Mpape Abuja region.Continuous monitoring and geophysical investigations are vital to understanding the seismic potential and mitigating future hazards.

VII. Acknowledgements

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VIII. Conflite Of Interest

The authors hereby declare that there are no conflate of interest

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