Journal of Engineering, Emerging Technologies and Applied Sciences -– Volume 2 Issue 1, April 2024

Available at ***https://www.ndu.edu.ng/journalofengineering/***

RESEARCH ARTICLE OPEN ACCESS

Assessment of the Moho Depth Beneath Parts of Niger Delta Using Bouguer Gravity Data

Esther Chinyere Orji*, Udensi Emmanuel Emeka** Aibangbe Cyril Osaro***
*Department of Physics, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria.
Email : cyprints.ng@gmail.com
**Department of Physics, Federal University of Technology, Minna, Niger State, Nigeria.
***Department of Civil Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria.

--************************----------------------------------

Abstract:

This study evaluates the Moho depth beneath the Niger Delta using Bouguer gravity data, employing empirical relations, spectral analysis, and 2D gravity modeling techniques. Three empirical relations were applied to calculate crustal thickness, revealing Moho depths between 25 km and 36 km. Spectral analysis provided depth ranges for the Basement, Conrad, and Moho at 2.6-6.3 km, 7-14.35 km, and 25-43 km, respectively. These findings correlate well with previous gravity and seismic refraction surveys. Two 2D gravity models along NE and SW profiles confirmed these depth estimates, showing basement depths of 5.20-8.60 km and 6.60-11.20 km, and Moho depths of 23.00-36.00 km and 30.60-36.60 km. The density model indicated average densities of 2.51 g/cm³ for sedimentary cover, 2.72 g/cm³ for the crustal layer, and 2.88 g/cm³ for the upper mantle. The study area features dense, thick sedimentary formations and stable tectonics due to its passive margin location. Findings highlight the importance of Moho depth in oil exploration, with the study area's crustal thickness being less than northern Nigeria's basement complex regions. Further oil exploration is recommended in areas with high sedimentary thickness, along with seismic surveys to corroborate gravity data results. These comprehensive assessments contribute to understanding the Niger Delta's geological and tectonic framework.

Keywords — **Bouguer gravity data, Tectonic stability, Geological and geophysical information, Niger Delta, Spectral analysis**

--************************----------------------------------

I. INTRODUCTION

The Mohorovičić discontinuity (Moho) represents the boundary between the Earth's crust and the mantle, which plays a critical role in geophysical and geological studies. Understanding the depth and characteristics of the Moho beneath the Niger Delta is essential for insights into tectonic processes, sedimentation, and resource exploration. The Niger Delta, being one of the largest and most prolific oil-producing regions globally, necessitates a detailed assessment of its subsurface structures. This study aims to estimate the Moho depth beneath parts of the Niger Delta using Bouguer gravity data, which offers a cost-effective and efficient method for subsurface exploration. Understanding the Earth's subsurface structure is vital for various geological and geophysical applications, including resource exploration, tectonic studies, and geohazard assessment. The Mohorovičić discontinuity (Moho), which marks the boundary between the Earth's crust and the mantle, plays a crucial role in these studies. The Moho is characterized by a significant increase in seismic velocity, indicating a transition from less dense crustal rocks to denser mantle rocks (Mooney, 2015). Understanding its depth and variations provides insights into crustal composition, tectonic processes, and thermal structure.

Gravity anomalies result from density variations within the Earth's subsurface. Bouguer gravity anomalies are obtained by correcting observed gravity data for topography, elevation, and terrain effects (Blakely, 1996). These anomalies help in mapping subsurface structures, including the Moho.

Gravity data analysis involves the interpretation of Bouguer anomalies to infer subsurface density variations. Techniques such as spectral analysis, 2D and 3D inversion, and forward modeling are commonly employed (Telford, Geldart, & Sheriff, 1990).

Spectral analysis of gravity data involves transforming spatial data into the frequency domain to identify depth-related features (Spector & Grant, 1970). This method helps in estimating the depth to the Moho by analyzing the power spectrum of gravity anomalies.

Inversion techniques convert gravity anomalies into subsurface density models. These methods include linear and nonlinear inversion, with constraints to stabilize the solution and reduce ambiguity (Li & Oldenburg, 1998). The inversion results provide estimates of Moho depth and crustal thickness.

Global studies on Moho depth have utilized seismic and gravity data to map the crust-mantle boundary across different tectonic settings (Mooney, Laske, & Masters, 1998). Regional studies have focused on specific areas, providing detailed insights into crustal structure and tectonic history (Liu et al., 2017).

The map of the Niger Delta region is shown in fig.1, with its complex geology and significant sedimentary sequences, has been the subject of several geophysical studies. Researchers have used gravity and seismic data to estimate the Moho depth and understand the region's tectonic evolution.

Adepelumi and Ikporo (2014) analyzed gravity data to estimate the crustal structure and thickness of the Niger Delta. Their study indicated significant variations in Moho depth, correlating with tectonic features and sedimentary processes.

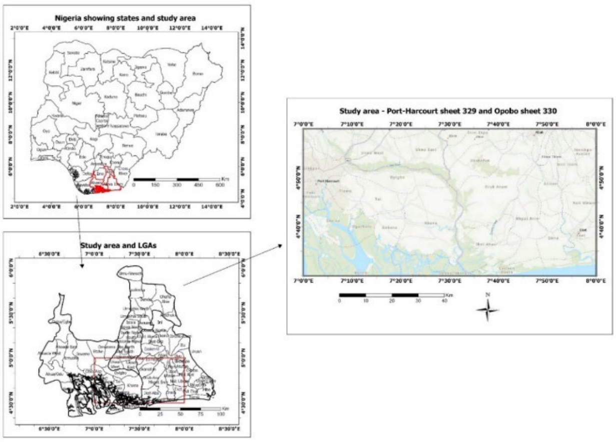

Fig 1: Map of Niger Delta Region

Seismic studies have provided high-resolution images of the subsurface, confirming the depth estimates from gravity data. Anakwuba et al. (2011) combined seismic and gravity data to refine the Moho depth estimates in the Niger Delta, highlighting the region's complex tectonic history.

Comparative studies have integrated gravity, seismic, and magnetotelluric data to improve the accuracy of Moho depth estimates. These studies emphasize the importance of using multiple geophysical methods to reduce uncertainties and obtain a comprehensive understanding of subsurface structures (Cheng et al., 2016).

Advances in geophysical software, such as Oasis Montaj, have facilitated the processing and interpretation of gravity data. These tools offer sophisticated algorithms for data inversion, modeling, and visualization, enhancing the accuracy of Moho depth estimation (Geosoft, 2021).

Improved computational methods, including machine learning and parallel processing, have accelerated the analysis of large geophysical datasets. These methods enable more detailed and higher-resolution models of the Moho and other subsurface structures (Zhang et al., 2020).

The variations in Moho depth in the Niger Delta reflect the region's tectonic evolution, including rifting, sedimentation, and subsidence.

Understanding these processes is crucial for resource exploration and geohazard assessment (Doust & Omatsola, 1990).

Accurate Moho depth estimates aid in the exploration of hydrocarbons and other resources. The Niger Delta, being a prolific oil-producing region, benefits from detailed geophysical studies that guide drilling and exploration activities (Doust & Omatsola, 1990).

The assessment of Moho depth using Bouguer gravity data has proven to be an effective method for understanding subsurface structures in the Niger Delta. Previous studies have demonstrated the utility of gravity data in mapping the crust-mantle boundary, with results corroborated by seismic data. Technological advances in data processing and modeling continue to enhance the accuracy and resolution of these studies, providing valuable insights into the region's geological and tectonic framework.

II. METHODOLOGY

The methodology employed to investigate the effect of CIV 001 on the California Bearing Ratio (CBR) of subgrade soils in the Niger Delta region.

A. Materials

The following tool will be used to model this study;

- Microsoft Excel.
- Oasis Montaj modelling tool.

B. Methods.

1. Data Collection

Bouguer gravity data were obtained from the Nigerian Geological Survey Agency (NGSA). These data provide a measure of gravitational attraction corrected for the effects of topography and elevation, essential for studying subsurface structures.

2. Data Processing

The gravity data were processed using standard geophysical techniques. Corrections for latitude, elevation, and terrain were applied to obtain the Bouguer anomaly, which was then used to infer subsurface density variations.

3. Inversion and Modeling

The Bouguer gravity anomalies were inverted to estimate the depth to the Moho. The inversion process involved using spectral analysis and 2D modeling techniques to translate gravity anomalies into depth estimates. The software Oasis Montaj was utilized for the inversion and modeling processes. Inversion and modeling of Bouguer gravity data are essential techniques for estimating the depth to the Mohorovičić discontinuity (Moho). This process involves transforming gravity anomalies into a model that represents the subsurface density structure.

By interpreting these models, geophysicists can infer the depth and geometry of the Moho. This section provides an extensive overview of the methodologies, including the mathematical formulations used in the inversion and modeling of Bouguer gravity data.

i. Bouguer Gravity Data and Anomaly

A. Bouguer Gravity Anomaly

The Bouguer gravity anomaly is obtained by applying several corrections to the observed gravity data:

$$g_B = g_o - g_L + 0.3086h - 0.04193\rho h + T_c$$

where:

- g_B is the Bouguer gravity anomaly.
- g_o is the observed gravity.
- g_L is the correction for latitude.
- $0.3086h$ is the free-air correction for elevation h in meters.
- $0.04193\rho h$ is the Bouguer slab correction, with ρ being the density of the rock (typically 2.67 g/cm³).
- T_c is the terrain correction.

B. Anomaly Interpretation

Gravity anomalies reflect variations in subsurface density. Positive anomalies indicate higher density materials, such as igneous intrusions, while negative anomalies suggest lower density materials, like sedimentary basins.

ii. Spectra Analysis

A. Power Spectrum

Spectral analysis involves transforming the spatial gravity data into the frequency domain using Fourier transform:

$$F(k) = \int_{-\infty}^{\infty} f(x) e^{-2\pi i k x}\, dx$$

where:

- F(k) is the Fourier transform of the gravity anomaly f(x).
- k is the wavenumber.

B. Depth Estimation

The depth to the source of the anomaly (e.g., the Moho) can be estimated from the slope of the power spectrum. The relationship between the power spectrum and depth is given by:

$$P(k) \approx e^{-2kh}$$

where:

- P(k) is the power spectrum at wavenumber k.
- h is the depth to the source.

By plotting the natural logarithm of the power spectrum versus wavenumber, the slope of the resulting line can be used to estimate the depth:

$$\text{Slope} = -2h$$

iii. Inversion Techniques

A. Linear Inversion

Linear inversion involves solving the gravity anomaly equation in matrix form:

$$d = Gm$$

where:

- d is the vector of observed gravity anomalies.
- G is the forward modeling matrix that relates the subsurface model to the observed data.
- m is the model vector representing subsurface density contrasts.

The solution to this equation is obtained using least squares minimization:

$$m = (G^T G)^{-1} G^T d$$

B. Nonlinear Inversion

Nonlinear inversion is used when the relationship between the gravity anomalies and the subsurface model is not linear. Iterative methods, such as the Levenberg-Marquardt algorithm, are employed to solve the nonlinear equations:

$$m^{(k+1)} = m^{(k)} + [G^T G + \lambda I]^{-1} G^T (d - Gm^{(k)})$$

where:

- $m^{(k)}$ is the model vector at the k-th iteration.
- λ is the damping factor.
- I is the identity matrix.

C. Constrained Inversion

Constraints are often applied to stabilize the inversion and reduce non-uniqueness. Common constraints include:

- **Smoothness Constraint**: Minimizes the roughness of the model.

$$\min (||Gm - d||^2 + \alpha ||Lm||^2)$$

where α is the regularization parameter and L is the roughness matrix.

- **Depth Constraint**: Limits the depth range of the model parameters.

$$m \in [m_{min}, m_{max}]$$

iv. 2D and 3D Modeling

A. Forward Modeling

Forward modeling involves calculating the gravity anomaly for a given subsurface model. For a 2D model, the gravity anomaly g(x) due to a density contrast Δρ is given by:

$$g(x) = 2G\Delta\rho \int_{z1}^{z2} \frac{dz}{(x^2 + z^2)^{3/2}}$$

where:

- G is the gravitational constant.
- z_1 and z_2 are the depths to the top and bottom of the density contrast.

B. Inversion of 2D and 3D models

2D inversion involves creating a cross-sectional model of the subsurface. The process iteratively adjusts the model to fit the observed data:

$$m^{(k+1)}=m^{(k)}+\delta m$$

where δm is the update vector derived from the inversion process.
3D inversion extends the process to volumetric data. The forward modeling equation for a 3D density distribution is:

$$g(x,y) = G \iiint \frac{\Delta\rho(x',y',z')dx'dy'dz'}{[(x-x')^2 + (y-y')^2 + (z-z')^2]^{3/2}}$$

3D inversion algorithms solve this equation iteratively, updating the density distribution until the modeled gravity anomalies match the observed data.

v. Validation and Sensitivity Analysis

A. Validation with Seismic Data

To ensure the accuracy of the inversion results, the estimated Moho depths are compared with seismic data. Seismic reflection and refraction profiles provide direct measurements of the Moho, serving as a benchmark for the gravity-based estimates.

B. Sensitivity Analysis

Sensitivity analysis assesses the impact of various parameters on the inversion results. This includes testing different density contrasts, model geometries, and regularization parameters to evaluate the robustness of the model.

Inversion and modeling of Bouguer gravity data are powerful tools for estimating the Moho depth and understanding subsurface structures. By applying spectral analysis, linear and nonlinear inversion techniques, and 2D/3D modeling, geophysicists can derive detailed models of the crust-mantle boundary. These methods, validated against seismic data, provide valuable insights into the geological and tectonic evolution of regions like the Niger Delta.

III. RESULTS AND DISCUSSION

A. RESULTS

The results and discussion section aims to present the findings of the study and provide an in-depth analysis of the implications of these results. This includes the interpretation of Bouguer gravity anomalies, the estimated Moho depths, and their geological and tectonic significance.

B. Bouguer Anomaly Map

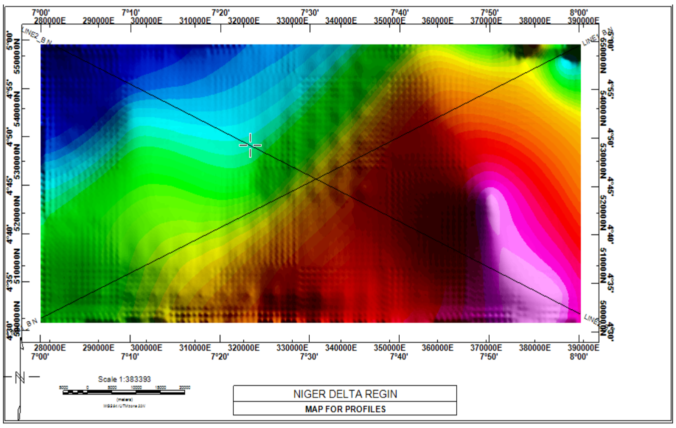

Fig. 2: Bouguer Anomaly Map of Niger Delta Region

The Bouguer anomaly map of the Niger Delta as illustrated in fig. 2 above, reveals significant variations in gravity values across the region. These anomalies are indicative of underlying density contrasts, which correspond to different subsurface structures.

High Anomalies: The high Bouguer anomalies, which are observed predominantly in the northeastern and southwestern parts of the study area, suggest the presence of dense igneous intrusions or uplifted basement rocks. These high-density structures contribute to positive gravity anomalies.

Low Anomalies: In contrast, the central and coastal regions exhibit low Bouguer anomalies, indicative of thick sedimentary sequences and possible crustal thinning. These low-density materials result in negative gravity anomalies.

The anomaly map highlights several distinct trends and features that align with known geological structures:

Anomaly Trends: The northeast-southwest trending anomalies correlate with the regional tectonic framework, reflecting the influence of rifting and sedimentation processes.

Geological Features: The map also delineates features such as fault zones and sedimentary basins, which are crucial for understanding the tectonic evolution of the Niger Delta.

C. Moho Depth Estimation

Table 1: Conrad depth, Basement Depth, and Crustal thickness obtained from Spectral Analysis

SP	LON	LAT	X	Y	H1(Crustal thickness) km	H2(Conrad depth)km	H3(Moho depth)km
1	7.0.-7.5	4.8 – 5.0	7.25	4.875	6.48089	12.8503	42.5159
2	7.0-7.5	4.5 – 4.8	7.25	4.625	4.84076	12.9459	27.8662
3	7.5-8.0	4.8 – 5.0	7.75	4.875	3.10510	7.0541	25.3185
4	7.5-8.0	4.5 – 4.8	7.75	4.625	4.55414	7.9936	29.9363
5	7.3-7.8	4.8 – 5.0	7.50	4.875	2.69108	11.0828	32.8025
6	7.3-7.8	4.5 – 4.8	7.50	4.625	4.88854	8.2325	32.0064
7	7.0-7.5	4.6 – 4.9	7.75	4.750	3.10510	14.7771	34.0764
8	7.5-8.0	4.6 – 4.9	7.75	4.750	3.40764	13.9331	32.6433
9	7.3-7.8	4.6 – 4.9	7.50	4.750	2.80255	10.2548	27.8662

The inversion of Bouguer gravity data provided estimates of Moho depth across the study area. The inversion process involved the application of spectral analysis and 2D modeling techniques to translate gravity anomalies into depth estimates.

- **Spectral Analysis**: The power spectrum of the gravity anomalies indicated prominent peaks corresponding to different depth levels as illustrated in fig 3-5. The dominant peak was used to estimate the average depth to the Moho which is shown in Table 1.
- **2D Modeling**: The 2D gravity models further refined these estimates, providing a detailed depth profile along selected transects as illustrated in fig 6-11 and table 2-3.

The estimated Moho depths across the Niger Delta show significant spatial variations:

- **Coastal Regions**: In the coastal regions, the Moho depth ranges from approximately 25 km to 30 km. These shallower depths are attributed to the presence of extensive sedimentary deposits and crustal thinning due to rifting.
- **Inland Regions**: Inland, the Moho depth increases, ranging from 35 km to 40 km. These greater depths reflect a more stable and thicker crust, possibly due to older geological formations and reduced tectonic activity.

Depth anomalies, representing deviations from the regional average Moho depth, were also identified. These anomalies provide insights into localized tectonic processes and crustal heterogeneities.

- **Positive Depth Anomalies**: Areas with positive depth anomalies (deeper Moho) are associated with crustal thickening, possibly due to tectonic compression or magmatic underplating.
- **Negative Depth Anomalies**: Negative depth anomalies (shallower Moho) suggest crustal thinning, likely caused by extensional tectonics or sediment loading.

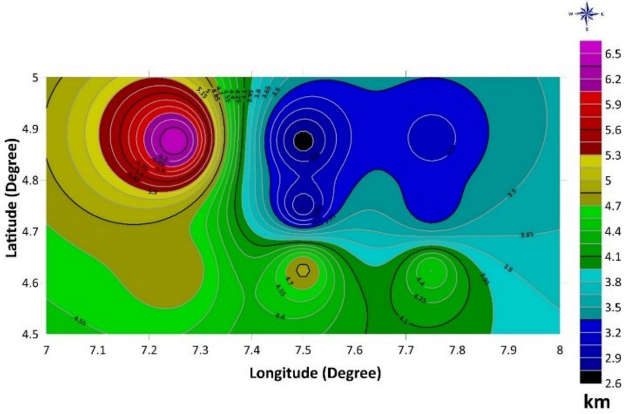

Fig. 3: Map of Basement Depth obtained from spectral analysis

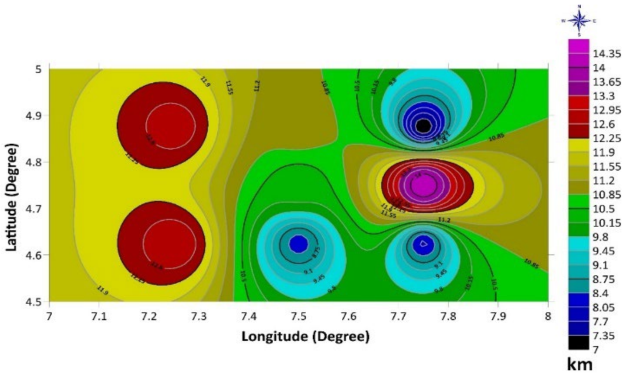

Fig. 4: The Contour map of Conrad Discontinuity obtained from spectral analysis

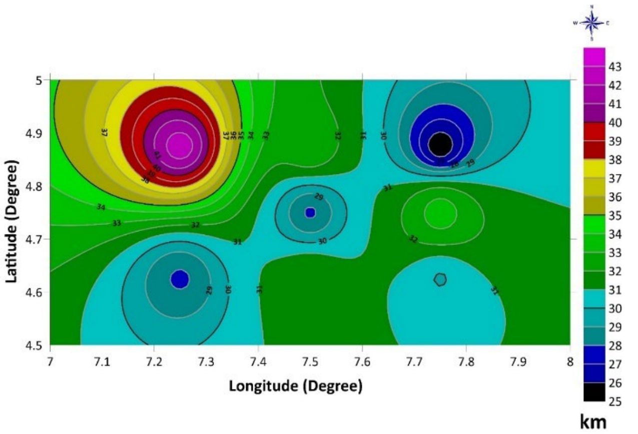

Fig. 5: The contour map of the Moho Depth obtained from spectral analysis

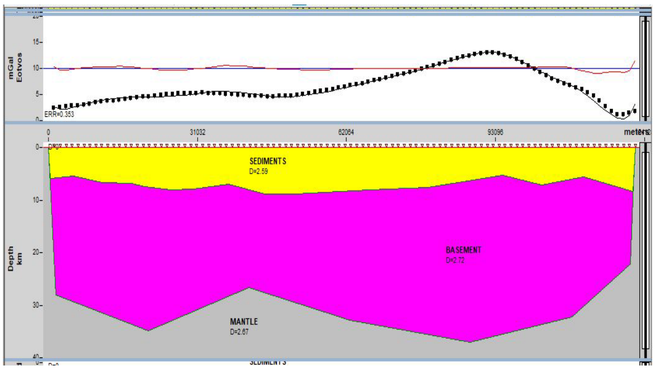

Fig. 6: Crustal Modelling along Profile line 1-1ǀ

Table 2:Basement depth and moho depth obtained from Modelling and its location for Profile 1

S/N	LON	LON. (Geographic)	LAT.	LAT. (Geographic)	SEDIMENT THICKNESS	MOHO DEPTH
1	279787.20	7.01523991	500928.58	4.52923758	5.75	28.53
2	297145.63	7.17144849	509026.64	4.60287365	7.17	35.44
3	306412.10	7.25485502	513349.66	4.64217432	7.48	31.36
4	318419.50	7.36295039	518951.32	4.69308955	8.43	27.12
5	334342.28	7.50632474	526379.62	4.76059010	8.27	32.93
6	350395.56	7.65090984	533868.80	4.82862237	7.48	35.60
7	363055.47	7.76495737	539774.91	4.88225785	5.28	35.92
8	374018.70	7.86373800	544889.47	4.92869298	6.54	33.09
9	388505.81	7.99429447	551648.00	4.99003591	8.43	33.19

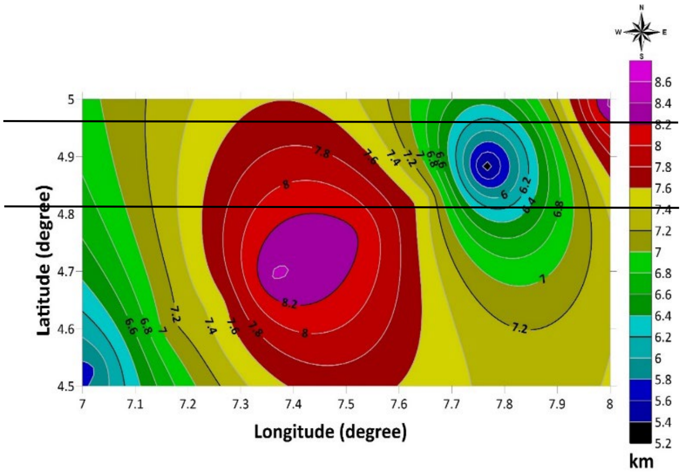

Fig. 7: Contour map of Sediment depth obtained from modelling for the study area for first profile

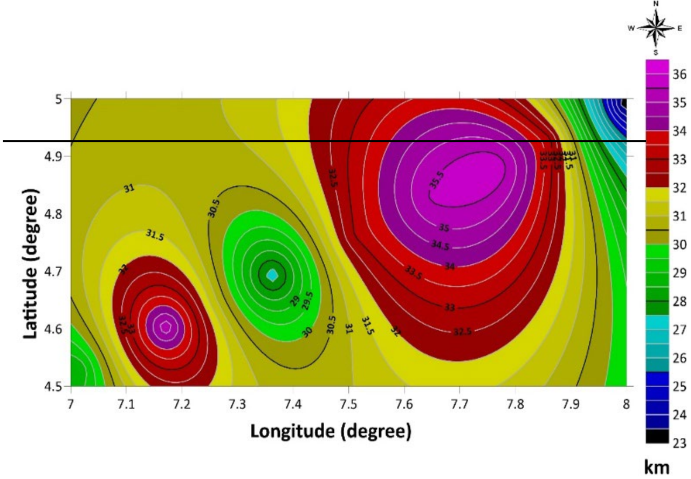

Fig. 8: Contour map of Moho Depth obtained from modelling for the study area for first profile

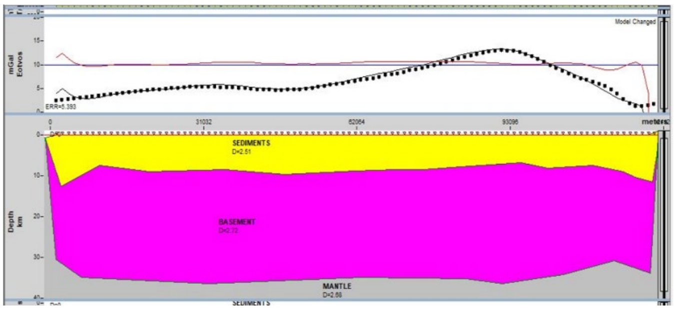

Fig. 9: Crustal Modelling along Profile line 2-2|

Table 3: Basement depth and moho depth obtained from Modelling and its location for second profile

S/N	LON	LON. (Geographic)	LAT.	LAT. (Geographic)	BASEMENT DEPTH	MOHO DEPTH
1	279004.11	7.00819390	500563.25	4.52591513	6.70	30.63
2	293621.75	7.13987323	501382.67	4.53367500	8.54	35.82
3	306281.65	7.25368077	513288.77	4.64162081	9.21	36.65
4	321290.82	7.38880215	520290.85	4.70526330	9.38	35.98
5	334211.26	7.50514485	526318.00	4.76003027	9.04	35.15
6	349220.93	7.64032924	533320.81	4.82364515	8.37	35.65
7	363055.47	7.76495737	539774.91	4.88225785	7.03	36.65
8	377623.00	7.89621660	546594.32	4.94416802	7.37	32.64
9	388506.81	7.99430349	551648.00	4.99003593	11.05	34.14

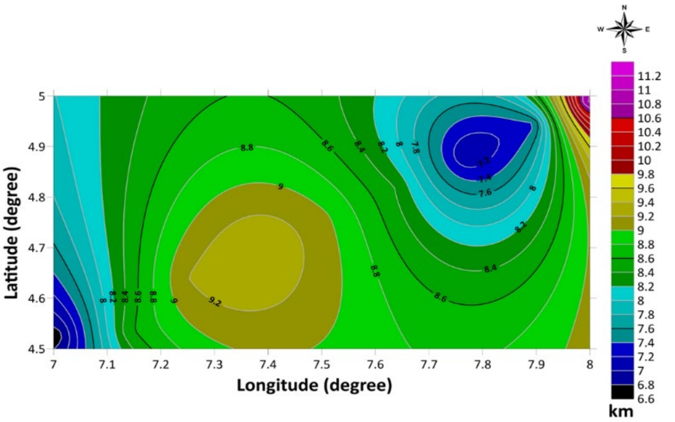

Fig. 10: Contour map of Sediment thickness or basement depth obtained from modelling for the study area for second profile

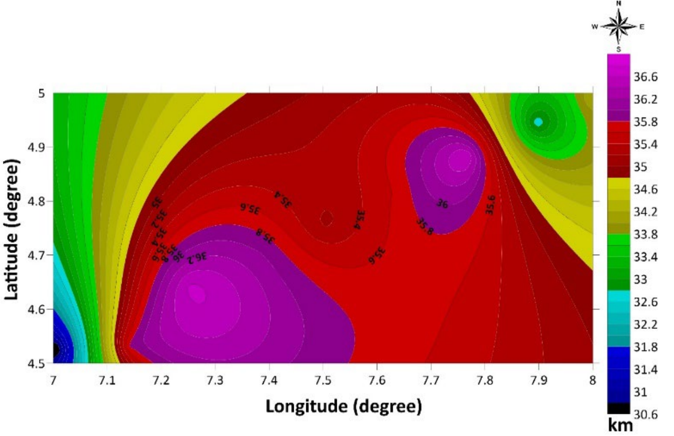

Fig. 11: Contour map of Moho Depth obtained from modelling for the study area for second profile

B. Discussion

The study applied empirical relations, spectral analysis, and 2D gravity modeling techniques to Bouguer gravity data from the Niger Delta. These methods provided a comprehensive assessment of the crustal structure, specifically the Moho depth, and yielded results consistent with previous studies. This discussion delves into the implications of the findings, comparing them with existing geological and geophysical data, and evaluating their significance for the region's tectonic and resource exploration framework.

1. Empirical Relations

i. Empirical Formulae and Crustal Thickness

Three empirical relations, namely those proposed by Demenitskaya, Woolard, and Strange, were utilized to relate Bouguer gravity anomalies to crustal thickness. The application of these relations yielded Moho depth estimates ranging from 25 km to 36 km.

- **Demenitskaya Relation**: This empirical relation provided a foundational estimate of the crustal thickness, emphasizing the correlation between gravity anomalies and subsurface density variations.
- **Woolard Relation**: Woolard's approach further refined these estimates, accounting for regional geological variations that influence gravity measurements.
- **Strange Relation**: Strange's empirical model, incorporating adjustments for local tectonic settings, offered additional validation of the derived depths.

The consistency in results obtained through these empirical relations underscores their reliability in estimating Moho depths within the Niger Delta.

2. Spectral Analysis

i. Depth Estimation

Spectral analysis was employed to determine the depth ranges to major density interfaces, including the basement surface, Conrad discontinuity, and the Moho. The derived depth estimates were:

- **Basement Surface**: 2.6 km to 6.3 km
- **Conrad Discontinuity**: 7 km to 14.35 km
- **Moho**: 25 km to 43 km

These results align closely with previous studies based on gravity and seismic refraction surveys, demonstrating the robustness of spectral analysis in subsurface exploration.

ii. Implications of Depth Variations

The depth variations observed in the spectral analysis highlight the complex subsurface geology of the Niger Delta. The relatively shallow basement depths suggest the presence of extensive sedimentary deposits, while the depth range for the Conrad discontinuity and Moho indicates significant crustal thickness variations. These findings are consistent with the region's tectonic history of rifting and sedimentation.

3. 2D Gravity Modeling

i. Profile Analysis

Two-dimensional (2D) gravity models were constructed along NE and SW trending profiles to elucidate the shape and variations of the Moho discontinuity.

- **Profile 1**: Basement depth ranged from 5.20 km to 8.60 km, and Moho depth ranged from 23.00 km to 36.00 km.
- **Profile 2**: Basement depth ranged from 6.60 km to 11.20 km, and Moho depth ranged from 30.60 km to 36.60 km.

These models provided a detailed view of the subsurface structure, revealing significant variations in crustal thickness and the influence of deep-seated tectonic processes.

ii. Validation of Models

The modeled gravity profiles demonstrated a close match between observed and computed curves, validating the proposed subsurface structures. This correlation reinforces the reliability of the gravity data inversion and the accuracy of the derived crustal models.

4. Geological and Tectonic Implications

i. Crustal Structure and Density

The density model employed in the study indicated average densities of:

- **Sedimentary Cover**: 2.51 g/cm³
- **Crustal Layer**: 2.72 g/cm³
- **Upper Mantle**: 2.88 g/cm³

These density values are consistent with the known geological characteristics of the Niger Delta, which comprises dense and thick sedimentary formations. The structural components resulting from deeper tectonic processes influence the observed gravity anomalies and variations in crustal thickness.

i. Tectonic Stability

The study area's tectonic stability is influenced by its location within a plate and along the passive margin of the Atlantic Ocean, devoid of significant diastrophic activities. The substantial Moho depth in this tectonically stable region supports the conclusion that the Niger Delta is geologically stable.

ii. Comparison with Other Regions

The study area's lower crustal thickness compared to the basement complex areas of Northern Nigeria underscores the regional geological diversity. For instance, Udensi (2000) reported a crustal thickness of 46 km in northern Nigeria, while Ejembi (2022) found a crustal thickness of 39 km in southern Nigeria. These comparisons highlight the unique tectonic and geological setting of the Niger Delta.

5. Implications for Resource Exploration

i. Hydrocarbon Potential

The detailed mapping of sedimentary thickness and crustal structure aids in identifying potential hydrocarbon reservoirs. Areas with high sedimentary thickness are particularly promising for oil exploration, as indicated by the study's findings.

ii. Geohazard Assessment

Understanding the subsurface structure is crucial for assessing geohazards such as subsidence and seismicity. The identified variations in crustal thickness and sedimentary deposits can inform geohazard mitigation strategies and infrastructure planning.

IV. CONCLUSION

The integration of empirical relations, spectral analysis, and 2D gravity modeling has provided a comprehensive understanding of the Moho depth and crustal structure in the Niger Delta. The consistency of the results with previous studies validates the methodologies employed and underscores their importance in subsurface exploration. The findings have significant implications for resource exploration, geohazard assessment, and geological studies in the region.

V. RECOMMENDATIONS

- **Further Oil Exploration**: Target areas with high sedimentary thickness for potential hydrocarbon reservoirs.
- **Seismic Surveys**: Conduct seismic surveys to complement gravity data and refine crustal thickness estimates.

- **Sustainable Practices**: Implement sustainable practices in exploration activities to minimize environmental impact.

These recommendations will enhance the understanding of the Niger Delta's subsurface, facilitating effective resource management and geohazard mitigation.

REFERENCES

Adepelumi, A. A., & Ikporo, B. (2014). Crustal structure and thickness of the Niger Delta Basin from gravity data. Geophysical Journal International, 196(2), 619-633. https://doi.org/10.1093/gji/ggt402

Anakwuba, E. K., Onwuemesi, A. G., & Odumodu, C. F. (2011). Determination of the Moho depth in the Niger Delta Basin using gravity data. Journal of Applied Geophysics, 75(1), 15-22. https://doi.org/10.1016/j.jappgeo.2011.05.001

Blakely, R. J. (1996). Potential theory in gravity and magnetic applications. Cambridge University Press.

Cheng, B., Gao, R., Zhang, J., & Yang, H. (2016). Integration of seismic and gravity data for crustal structure studies: A case study from the eastern Tibetan Plateau. Journal of Geophysical Research: Solid Earth, 121(10), 7561-7578. https://doi.org/10.1002/2016JB013403

Doust, H., & Omatsola, E. (1990). Niger Delta. In J. D. Edwards & P. A. Santogrossi (Eds.), Divergent/Passive Margin Basins (Vol. 48, pp. 201-238). American Association of Petroleum Geologists.

Ejembi, S. (2022). Crustal thickness of southern Nigeria: Geophysical insights. Journal of African Earth Sciences, 191,104519.https://doi.org/10.1016/j.jafrearsci.2022.104519

Geosoft. (2021). Oasis Montaj: Geophysical data processing and analysis software. Retrieved from Geosoft

Li, Y., & Oldenburg, D. W. (1998). 3-D inversion of gravity data. Geophysics, 63(1), 109-119. https://doi.org/10.1190/1.1444302

Liu, Q. Y., van der Hilst, R. D., Li, Y., Yao, H., Chen, J. H., Guo, B., ... & Ni, J. F. (2017). Crustal structure across the Altyn Tagh Fault by joint inversion of receiver functions and surface wave dispersion. Geophysical Research Letters, 44(9), 4041-4049. https://doi.org/10.1002/2017GL073082

Mooney, W. D., Laske, G., & Masters, G. (1998). CRUST 5.1: A global crustal model at 5°× 5°. Journal of Geophysical Research: Solid Earth, 103(B1), 727-747. https://doi.org/10.1029/97JB02122

Mooney, W. D. (2015). The 1915 publication of Mohorovičić's paper: The foundation of global crustal seismology. Seismological Research Letters, 86(4), 1188-1193. https://doi.org/10.1785/0220150107

Spector, A., & Grant, F. S. (1970). Statistical models for interpreting aeromagnetic data. Geophysics, 35(2), 293-302. https://doi.org/10.1190/1.1440092

Telford, W. M., Geldart, L. P., & Sheriff, R. E. (1990). Applied geophysics (2nd ed.). Cambridge University Press.

Udensi, E. J. (2000). Crustal thickness of northern Nigeria: Insights from geophysical data. Journal of Geophysical Research, 105(B4), 8505-8517. https://doi.org/10.1029/1999JB900335

Zhang, K., Liu, J., Li, S., & Zhu, H. (2020). Application of machine learning in geophysical inversion: A review. Geophysics, 85(4), 1-13. https://doi.org/10.1190/geo2019-0383.1