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RESEARCH ARTICLE **OJPS0402001-470**

CRUSTAL THICKNESS BENEATH UTAKO ABUJA USING RECEIVER FUNCTION ANALYSIS

***Fasiku, O. B., Mallam, A. & Osagie, A. U.**

Department of Physics, University of Abuja, Nigeria

****Corresponding Author Email:** benard.fasiku2018@uniabuja.edu.ng; +2349031253202*

ABSTRACT

Understanding the Mohorovicc discontinuity (Moho depth) is crucial in unraveling the Earth's subsurface structure. In this research, we present the report of the crustal thickness and the ratio of the primary wave to the shear wave velocities (***p***-to-***s***) beneath the seismic station located at the Nigerian Geological Survey Agency (NGSA) Abuja using Receiver Function Analysis (RFA). The primary objective of this study is to determine the depth of the Moho boundary and gain insights into the geological properties of the Earth's crust and upper mantle beneath the receiver station. This analysis focused on teleseismic earthquakes that were recorded at the station between 2020 and 2021, with epicentere distances between 30^{o} and 90^{o} and magnitudes 5.5 or greater. The P wave Receiver Function (PRF) was modeled from iterative time domain deconvolution using the converted phases (Ps) at the Moho interface. The seismograms were rotated from the conventional components to the ZRT component and the vertical component was deconvolved from the transverse and radial components to extract the RF, which was stacked subsequently using the H-k stacking algorithm. Through the analysis of the seismic data, the result indicates a relatively shallow crust beneath the study area, estimated to approximately 33.15 ± 1.74 km, with a ***p***-to-***s*** wave velocity ratio of 1.73 ± 0.04, which suggests minimal impact from plate thinning or intrusion.

Keywords: *Crustal Thickness, Receiver Function, Seismic, Vp/Vs, Abuja.*

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INTRODUCTION

In this study, the crustal thickness or depth of Mohorovicic (Moho) discontinuity and the ratio of the primary wave to the shear wave (***p***-to-***s***) velocities beneath the seismic station at the NGSA have been reported. These and other physical properties are parameters that are used mostly in characterizing the crust's overall structure which are often related to the geology and tectonic evolution of a region (Zhu and Kanamori, 2000). The knowledge of crustal thickness variation in Nigeria is of significant interest since it will provide us with a crucial understanding of tectonic and geodynamic processes, especially for tracking the switch of tectonic setting and development of the lithosphere (Fangyang *et al.*, 2017). Previous studies in Nigeria (e.g., Abdullahi *et al.*, 2019) have utilized potential field data, such as gravity and magnetic anomalies to identify features and investigate subsurface structures in the uppermost crust. However, these techniques provide little or no information on the thickness of the crust, and most importantly the seismic velocity ratio in the crust. One approach that has proven to be effective consistently in estimating the crustal thickness is the use of converted phases (Burdick and Langston, 1977) known as the Receiver Functions (RF). This study aims to estimate the thickness of the crust beneath the NGSA seismic station by interpreting the ***p***-to-***s*** converted phases (***Ps***) at the Moho interface using the RF technique. This technique can provide insights into the subsurface structures along with the ratio of ***p***-to-***s*** wave velocities in the crust beneath the station.

The study area is located in Utako, Abuja which covers an approximate area of about 7,400 square km. It is situated between latitude 8°55'N and 9°08'N and longitude 7°21.6'E to 7°32.4'E, while the seismic station is located at latitude 9°03'38'' N and longitude 7°26'59'' E. The study area is in the north-central Precambrian basement complex, which forms part of the Pan-African mobile belt located between West Africa and Congo Cratons as described by Obaje (2009). Generally, the basement complex of Nigeria is composed of four major Petrolithological units (Obaje, 2009) namely: the Migmatite-Gneiss Complex (MGC), the Schist Belt (metasedimentary and metavolcanic rocks), Older Granites (Pan African Granitoids), Undeformed Acid and Basic Dykes. All the major rock categories mentioned above are represented in the study area. These rock formations are composed mainly of Migmatite, Granite Schist, Hornblende, and Feldspathic Schist which exhibit significant fragmentation and fissuring, showing three lineament patterns oriented in the NW-SE, N-S and NE-SW direction (Osotuyi *et al.*, 2020). The tectonic characteristics of the FCT exhibit NNE-SSW trends near the eastern and western boundaries, as well as easterly trends in the central area, which defines the structural features of the basement complex rocks. These observations indicate the presence of a shear zone, trending northward along the eastern side, presumed to be weak zones. In addition, a smaller shear zone trending northward is observed to the west of Abuja, where numerous NW-oriented faults and fractures intersect the basement rock. These structures are relatively young and are believed to have originated from four major Orogenic cycles. These cycles were marked by intense deformation, isoclinical folding, and regional metamorphism, followed by extensive migmatization, granitization, and gneissfication. These cycles correspond to the Liberian (2,700 Ma), the Eburnean (2,000 Ma), the Kibaran (1,100 Ma), and the Pan-African (600 Ma) periods (Black, 1980; Obaje, 2009; Osotuyi *et al.*, 2020), which shows that these structures may still be developing.

The average thickness of the crust in the basement complex from seismological studies in Nigeria is 36 km (Akpan *et al.*, 2016) compared to the Crust 1.0 model which is below 40 km (Laske *et al.*, 2013). The basement complex exhibits a similar crustal structure to other Neoproterozoic terrains across Africa. Various regions such as the Oubabanguides Belt, Zambezi Belt, Damara Belt, Mozambique Belt, and the Lufilian Arc all have average crustal thicknesses varying between 35 km and 43 km (Akpan *et al.*, 2016; Kachingwe *et al.*, 2015; Tokam *et al.*, 2010; Tugume *et al.*, 2013). This indicates that the crustal structures of the basement complex do not show significant differences compared to other Neoproterozoic terrains in Africa.

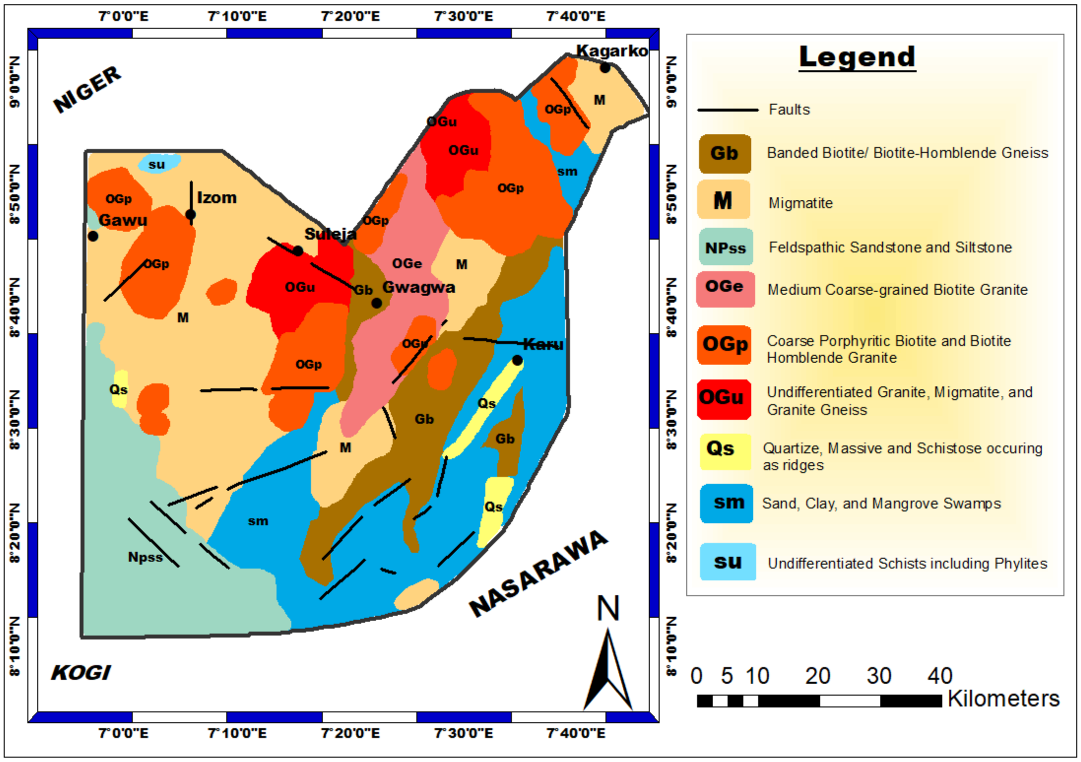

Figure 1: Geology of Abuja (Developed using the geological map of NGSA 2004 with modifications made to depict fault lines and other geologic features)

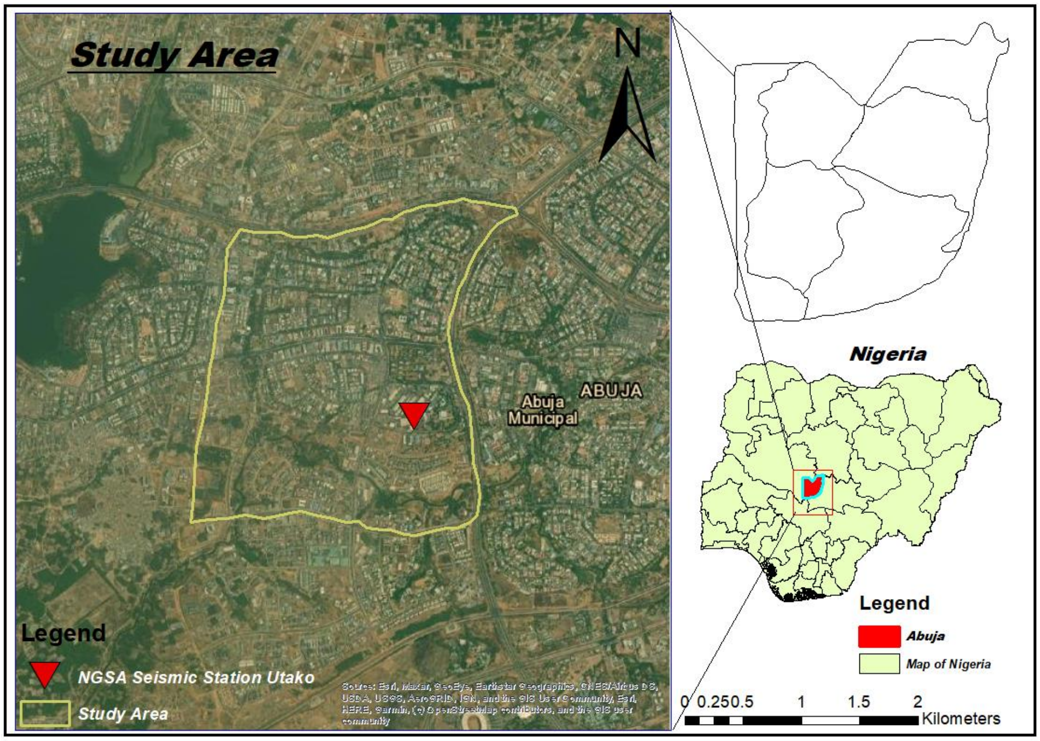

Figure 2: Location Map of the Study Area (Extracted from Google Earth Pro)

MATERIALS AND METHODS

DATA ACQUISITION

The Nigerian Geological Survey Agency (NGSA) provided the data for use in this research. The NGSA station is being monitored currently by the International Federation of Digital Seismological Networks (FDSN). The station is equipped with the Guralp 3ESPC broadband seismometer (a three-component seismograph) and Guralp Minimus Digitizer, Clock, Computer, and Power source. The event parameters used for the selection of data are body waveforms recorded at distances between 30° and 90°. This is because the waveforms mostly contain information related to the propagation effect through the mantle. The event selection was narrowed to body wave magnitudes of 5.5 or greater, recorded between 2020 and 2021. From the collected data, 20 events meet the criteria for data selection. However, that the events meet the criteria for the RFA does not mean they will be useful for the RFA.

RECEIVER FUNCTION ANALYSIS

The Receiver Function Analysis is a technique that uses distant body waveforms which mostly contain information related to the propagation effect through the mantle (Owens *et al.*, 1984; Phinney, 1964; Vinnik, 1977) to image the structure underneath an isolated seismic station. The idea is that a specific wave arrival corresponds to a distinct discontinuity in the Earth. However, the displacement at the surface of the Earth due to these arrivals is influenced by several factors such as source time function, instrument response, Earth velocity structure near the source, and the velocity structure at discontinuity, etc. (Ammon, 1991; Paoletti, 2012). These factors must be isolated and deconvolved by rotating the seismogram from the usual components (Z, N-S, E-W) to the vertical (Z), radial (R), and transverse (T) components respectively (Ligorrfa and Ammon, 1999) so that we can obtain the Earth's partial impulse response just below the receiver station.

In this study, we prepared the data for the RFA by converting the data extracted in miniSEED format to Seismic Analysis Code (SAC) standard format because the SAC format contains information like station parameters and event parameters, which are mostly needed to process the RFA. Some information missing in the SAC header was inputted manually. We decimated the data recorded at 200 samples per second to 50 samples per second which reduced the number of points on the traces. The data set after editing the header information still appears to be in raw form and needs to be prepared for PRF processing. There was a need to correct for instrument response. Hence, we converted the dataless file from the station to a station XML file and we used the output file to remove the response (Wassermann *et al.*, 2013). A low pass filter was applied during the response removal which reduced the noise spectrum on the traces. For accuracy in the phase pick, we estimated the arrival times based on the IASP91 model and compared them to the manual phase pick. In the events where there were discrepancies, corrections were made to the picks. We also observed that the number of points (npts) on the traces in the data set obviously will not fit into the program for processing PRF as most programs for RFA have limitations of npts each processed file can contain. For this reason, we cut the waveforms to 20 seconds before the P arrival, and 1000 seconds after the P arrival, encompassing both the P arrival and subsequent reverberations. The RF was calculated using the iterative time-domain deconvolution approach (Ligorrfa and Ammon, 1999) which was set to iterate 300 times or until convergence occurred. During the processing, different Gaussian width factors were tested between (0.5 to 2.5) until a width factor of 2 was evaluated as the best fit. The seismogram was rotated from the conventional components to the ZRT components. The vertical (Z) component was deconvolved from the radial (R) component and transverse (T) component to produce a signal of Ps phases and multiple reverberations. The RF was retrieved and stacked using the H-k stacking algorithm (Zhu and Kanamori, 2000). The H-k stacking method utilizes equation (1) to convert the RF from the time amplitude domain to the H-k stacking domain. A procedure that involves summing the weighted phase amplitudes at predicted arrival times for different values of H, k, and assumed $\boldsymbol{P}$ velocity (v_p).

$$s(H,k) = \sum_{j=1}^{N} \left(a_1 r_j(t_1) + a_2 r_j(t_2) - a_3 r_j(t_3) \right) \qquad (1)$$

where $\boldsymbol{a_1}, \boldsymbol{a_2},$ and $\boldsymbol{a_3}$ are weights assigned to the ***Ps***, ***PpPs***, and ***PpSs*** phases respectively, $\boldsymbol{r_j}$ is the amplitude of the radial RF, $\boldsymbol{t_1}, \boldsymbol{t_2},$ and $\boldsymbol{t_3}$ are the arrival times of the phases. We assigned (0.6. 0.3, 0.1) to the weight of stacking (Zhu and Kanamori, 2000), which corresponds to $\boldsymbol{a_1}, \boldsymbol{a_2},$ and $\boldsymbol{a_3}$ respectively. The weighted values were assigned based on the clarity observed in the generated converted phases and their multiples. We evaluated the value of the crustal thickness $\boldsymbol{H}$ using a grid search range of $20 \leq H \leq 50$, and $\boldsymbol{k}$ in the range $1.6 \leq k \leq 1.9$. Using the IASP91 model, we used a p-wave velocity of 6.3 km/s in our configuration. This value serves as a reasonable average for the crust beneath the Precambrian basement complex (Akpan et al., 2016; Christensen and Mooney, 1995).

RESULTS AND DISCUSSIONS

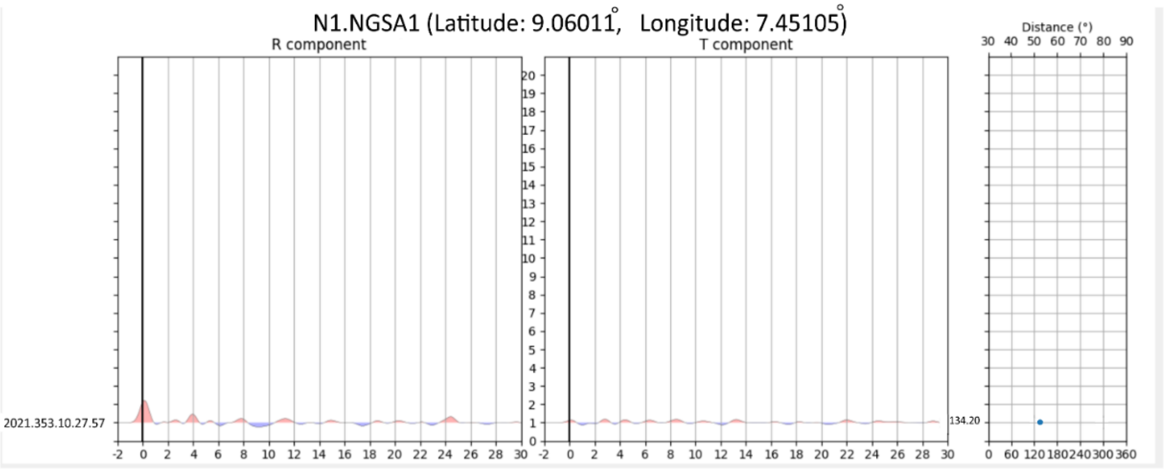

Figure 3: Receiver Function for Event 1

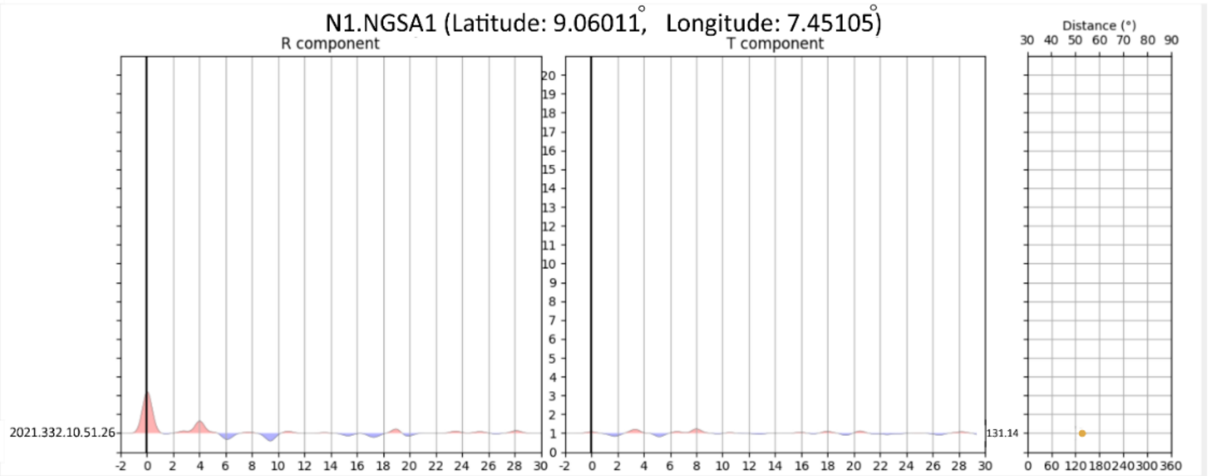

Figure 4: Receiver Function for Event 2

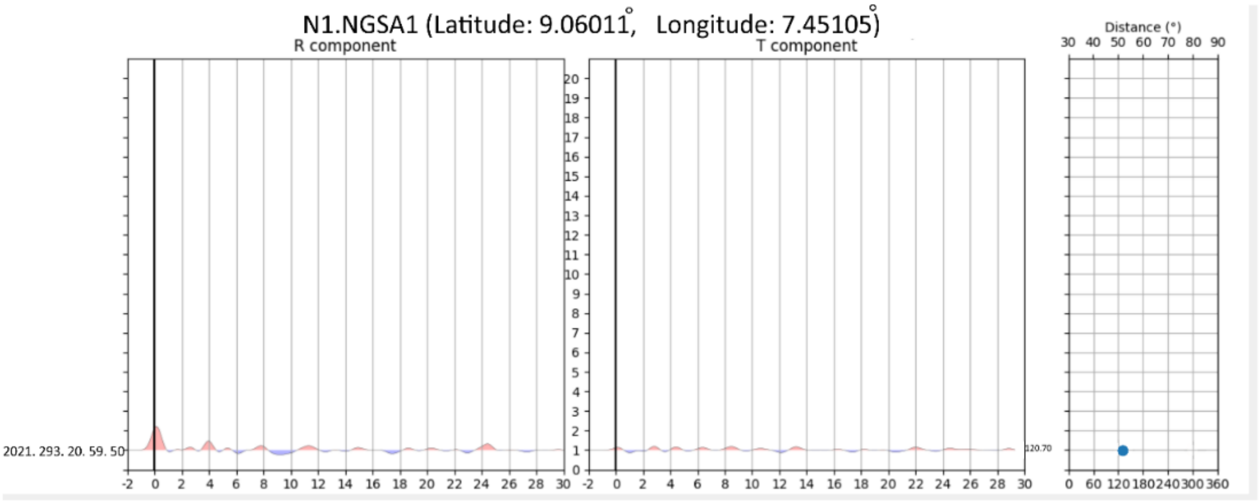

Figure 5: Receiver Function for Event 3

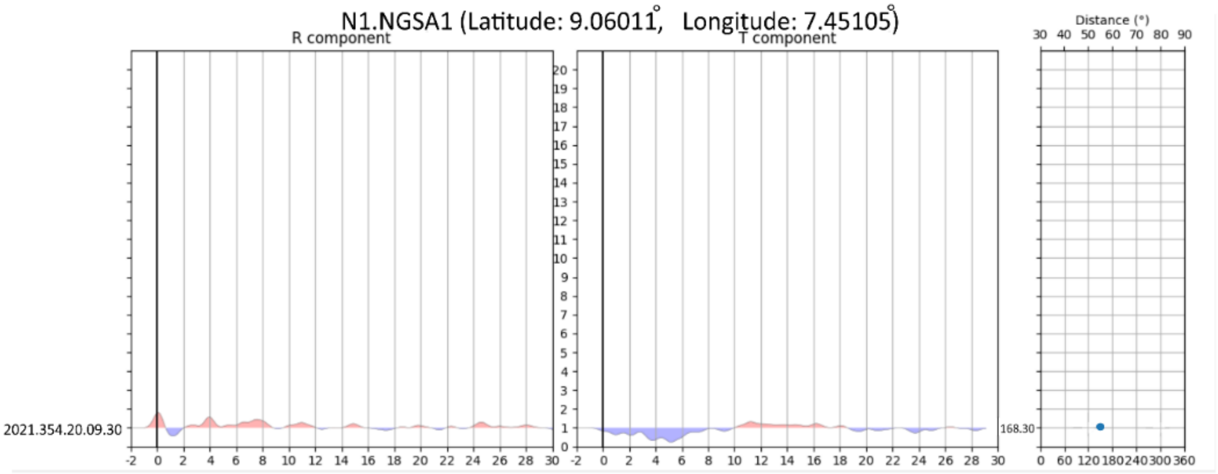

Figure 6: Receiver Function for Event 4

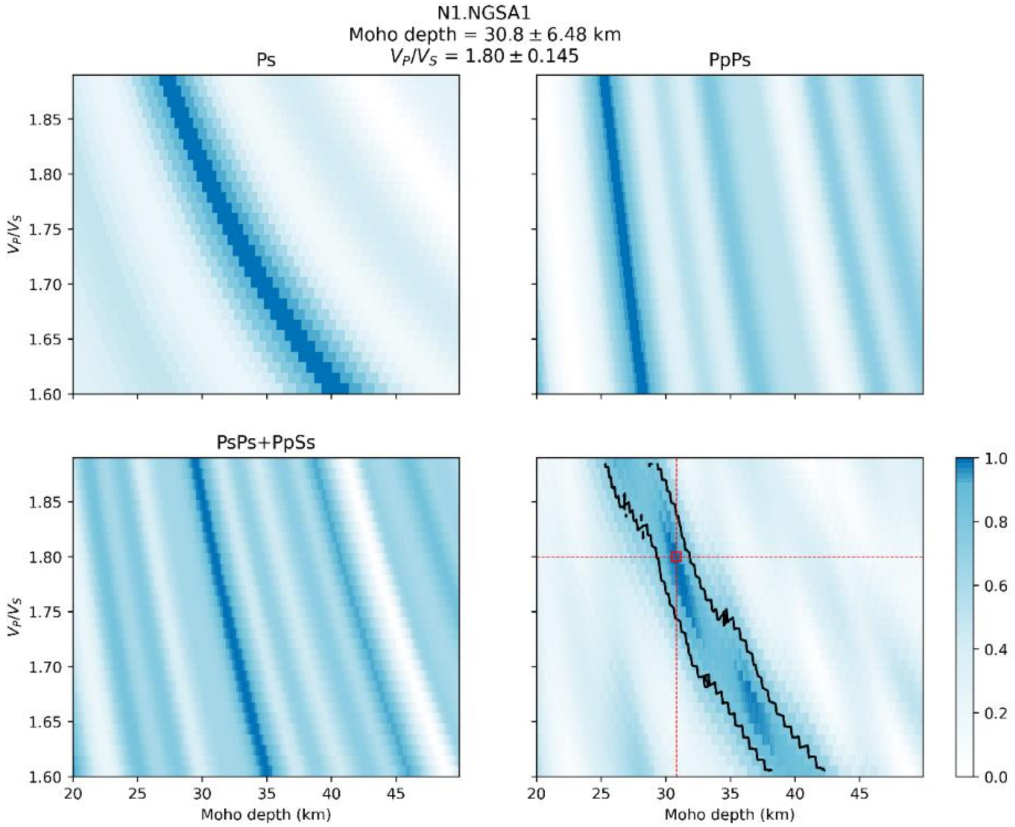

Figure 7: Moho Depth for Event 1

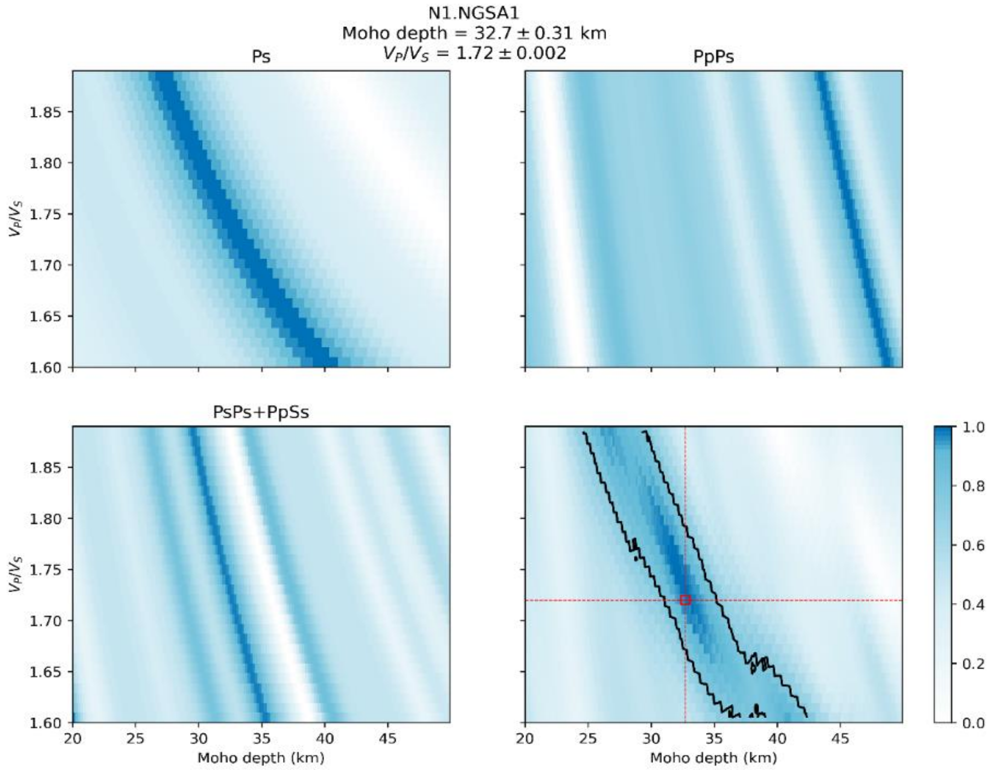

Figure 8: Moho Depth for Event 2

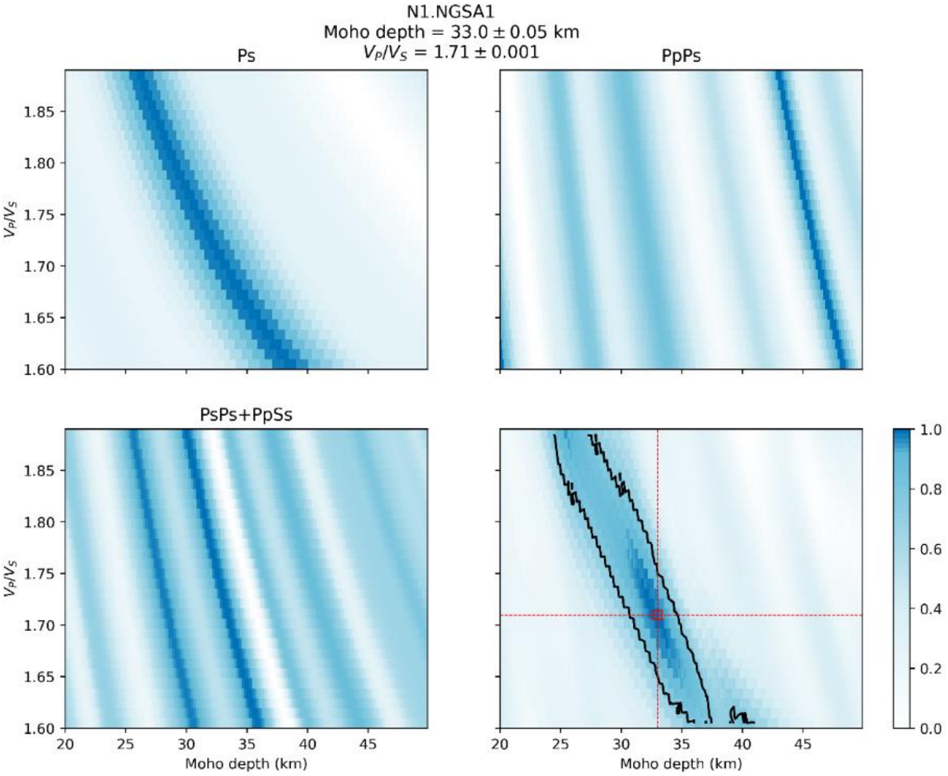

Figure 9: Moho Depth for Event 3

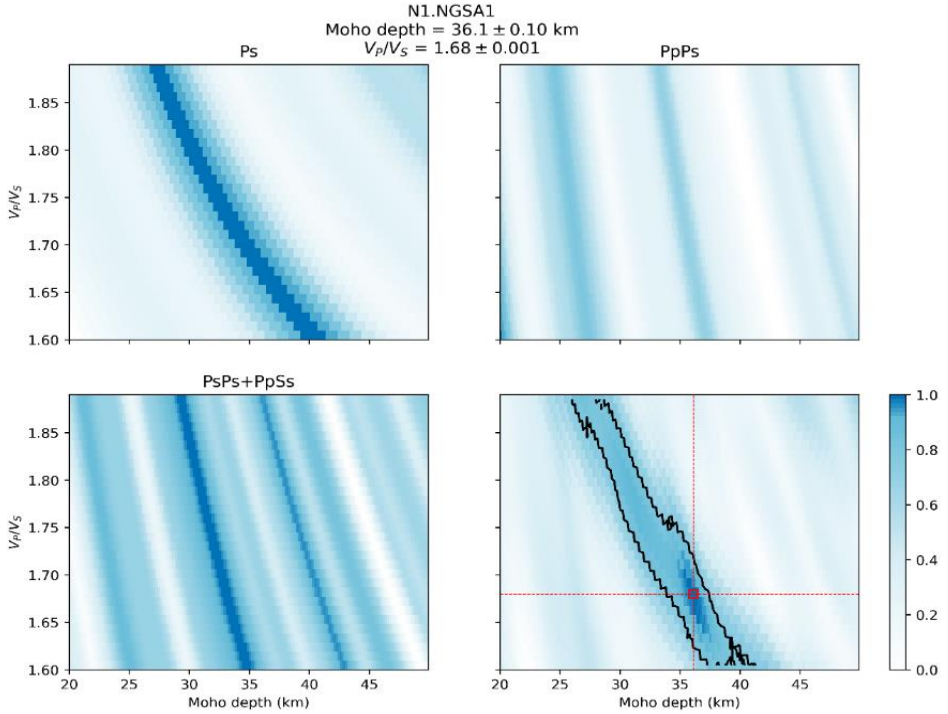

Figure 10: Moho Depth for Event 4

Table 1: Summary of the Moho Depth and Vp/Vs ratio Estimated for each Event

Events	**Moho Depth (km)**	**Vp/Vs**
Figure 7	30.8 ± 6.48	1.80 ± 0.145
Figure 8	32.7 ± 0.31	1.72 ± 0.002
Figure 9	33.0 ± 0.05	1.71 ± 0.001
Figure 10	36.1 ± 0.10	1.68 ± 0.001
Average thickness	33.15 ± 1.74	1.73 ± 0.037

The results of the H-k stacking for each event are presented in Figure 7 – Figure 10, and summarized in Table 1. The result was calculated from the PRF result in Figure 3 - **Error! Reference source not found.**6. From Figure 7 – Figure 10, the horizontal axis represents the Moho depth (km), while the vertical axis represents the ratio of $\boldsymbol{p}$-to-$\boldsymbol{s}$ wave velocity. Table 1 highlights the key parameters (Moho depth and $\boldsymbol{v_p/v_s}$) calculated in this research, including the average. The calculated average for each parameter was derived using the statistical mean method. This statistical method ensures that our conclusions are reliable and accurate. From the results, the estimated average crustal thickness beneath Utako is 33.15 ± 1.74 km (or approximately 33 km), with a corresponding v_p/v_s ratio of 1.73 ± 0.04 (or approximately 1.73). Through various processing, a considerable number of events were rejected due to misfit or not good enough for the analysis. Few events were recovered during the PRF processing after it was subjected to strict criteria to remove the bad signals. However, to ascertain the result of crustal thickness or Moho depth beneath a station, at least three events are required to perform PRF (Tokam *et al.*, 2010). Previous seismological studies (e.g. Akpan *et al*., 2016; Tokam *et al*., 2010) have also utilized fewer events to estimate the thickness of the crust for a single station. The result obtained in this study aligns closely with the typical crustal thickness range of 30 – 40 km obtained from gravity studies conducted in Nigeria and West Africa. The results are also consistent with the research conducted by Akpan *et al.* (2016), which provided an estimation of the thickness beneath the Precambrian basement complex in Nigeria to be between 30 – 36 km, with a v_p/v_s ratio of 1.70 – 1.76. Previous gravity studies (e.g., Azuwike *et al.*, 2018) have indicated that the crustal thickness in Nigeria typically ranges from 32 – 44 km, which shows that the result obtained in this research is within the estimated range. The crustal thickness estimated in this research implies that the crust is relatively shallow, which suggests minimal impact from plate thinning and intrusion, indicating a predominantly felsic to intermediate composition. This corresponds to the typical global average crustal thickness (Laske *et al.*, 2013) observed in the Precambrian basement complex, ranging from 30 to 40 km.

SUMMARY AND CONCLUSION

The Receiver Function approach for estimating crustal thickness and $\boldsymbol{v_p/v_s}$ ratio has gained global recognition within the field of seismology and we have applied it successfully to determine the crustal thickness beneath the NGSA1 station Utako in Nigeria. The PRF has been computed from the iterative time-domain deconvolution method using the teleseismic events recorded by the station between 2020 and 2021. With the data obtained from this station and after deconvolution, the PRF were stacked with the H-k stacking algorithm and we were able to estimate that the crust beneath the NGSA seismic station is approximately 33 km with v_p/v_s ratio of approximately 1.73, which does not deviate significantly from the previous studies.

In conclusion, our study on the Receiver Function Analysis has provided valuable insights into the tectonic and geological settings of the study area. The obtained result has established a fundamental reference for future research in Receiver Function Analysis and any related seismological investigation in Nigeria, despite the challenges posed by limited seismic data and inadequate seismic monitoring observatories, which are expected to improve in the future. By addressing these limitations and exploring new research directions, we aim to contribute significantly to the advancement of this field. Expanding our dataset to include diverse geographical regions, varied geological settings, and a wider range of seismic events remains a priority.

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