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Determination of Compressional To Shear Wave Velocity Ratio from Local Earthquakes in Nigeria between (2009-2018)

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Abstract: *The Compressional, P- and shear, S-wave velocity ratios (Vp/Vs),have been computed from five local earthquakes located in Nigeria from 2009 to 2018. Using the multicomponent seismic data from the Nigerian National Network of Seismographic Stations (NNNSS), the waveform data obtained from Toro, Ife, Nsukka, Abakaliki and Kaduna seismic stations, were processed and resulting earthquakes were located in South-western, North-Western and North-central of Nigeria respectively. The times for the first arrivals of P-wave and S-wave phases were obtained and the time difference (i.e. S-P) between them was equally determined. The Wadati analysis program in the Seisan 9.1 software was used to plot the graphs of S-P time difference against the P-time in seconds which calculated the Vp/Vs value for each event. The result shows that the Vp/Vs ratio for one of the five earthquakes was 1.75; while that of the others were determined to be 1.76, with 1.758 (~ 1.76) as the computed overall average velocity ratio for the area covered. The values obtained show that the epicenters of the earthquakes have almost similar lithology. The parameters computed for this study are very important for estimating Vp and Vs of crustal and upper mantle and the epicenters of local earthquake in Nigeria for future seismic hazard studies.*

Keyword: *P-Wave, S-Wave, Vp/Vs ratio, Local earthquake, Nigeria Seismic Stations.*

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I. Introduction

The African tectonic plate where Nigeria lies has been presumed stable and not prone to earthquakes. Contrary to this assumption, recent reports and occurrence of earth tremors at Abomey-calavi in 2009, Kwoi in 2016, Saki and Igbogenein in 2016, as well as the event in Mpape, Abuja in 2018, have erased this general perception and indicated that earthquakes are now potential natural hazards in Nigeria (CGG, 2018; Osagie, 2008; Akpan and Yakubu, 2010). Over time, earth tremors have been felt in the country especially in the south-western part (Osagie, 2008; Akpan and Yakubu, 2010). The areas which have experienced the vibrations resulting from past tremors include Lagos, Ibadan and Ile-Ife in 1939 (Ananaba, 1991), Ijebu-Ode in 1963 (Ajakaiya et al., 1987), Ibadan, Ijebu- Ode, Shagamu and Abeokuta in 1984 (Ojo, 1995), Ibadan and Ijebu-Ode in 1990 (Osagie, 2008; Akpan and Yakubu, 2010; Ojo, 1995), Okitipupa in 1997; Okitipupa, Ibadan, Ijebu-Ode, Akure, Shagamu, Abeokuta and Oyo in 2000 (Akpan and Yakubu, 2010; Elueza, 2003).

Since the inception of the Nigeria National Network of Seismographic Stations (NNNSS) in 2006, it has enabled scientists to monitor and detect local earthquakes in Nigeria. With these sensors, seismologists can determine the compressional to shear wave velocity ratio (Vp/Vs), an important property to improve local seismic events location and seismic hazard studies (Ezomo and Afegbua, 2016). The Vp/Vs has been used for many purposes, such as identifying pore fluid, lithology indicator and determining degree of consolidation an important parameter in seismology. It is also used in the determination of epicenters of local earthquakes and very useful in velocity modelling and prediction (Myung, 2003).

This study was conducted by analyzing the local seismic events within the country from four seismic stations between2009 to 2018. The focus of this study is on the fundamental theory and Physics of seismic waves of primary and secondary waves that has vital and useful information about internal structure and dynamical processes in the earth that is contained in seismograms. This study will contribute to the interpretation and calculation of a reliable interval velocity ratio, Vp/Vs, that could be used in the determination of epicenters of local earthquake and very useful in velocity modeling and prediction.

II. Geology Setting and Tectonic Activity of the Study Area

The three major litho-petrological components of Nigeria geology are the Basement complex, Younger Granites, and Sedimentary Basins (Afegbua and Ezomo, 2013; Fatoye and Gideon, 2013). The Basement Complex covers about 50% of the total surface of Nigeria (Fig. 1). It is composed of the following lithostructuralunits:- The Migmatite-Gneiss complex (MGC), The Metasedimentary and Metavolcanic rocks (the Schist Belt);the Pan-African granitoids (the Older Granites), underformed acid and basic dykes (Mohammed et al., 2015). The Migmatite-Gneiss complex is the most widespread of the main rock units in both northwestern and southwestern Nigeria (Mohammed et al., 2015).

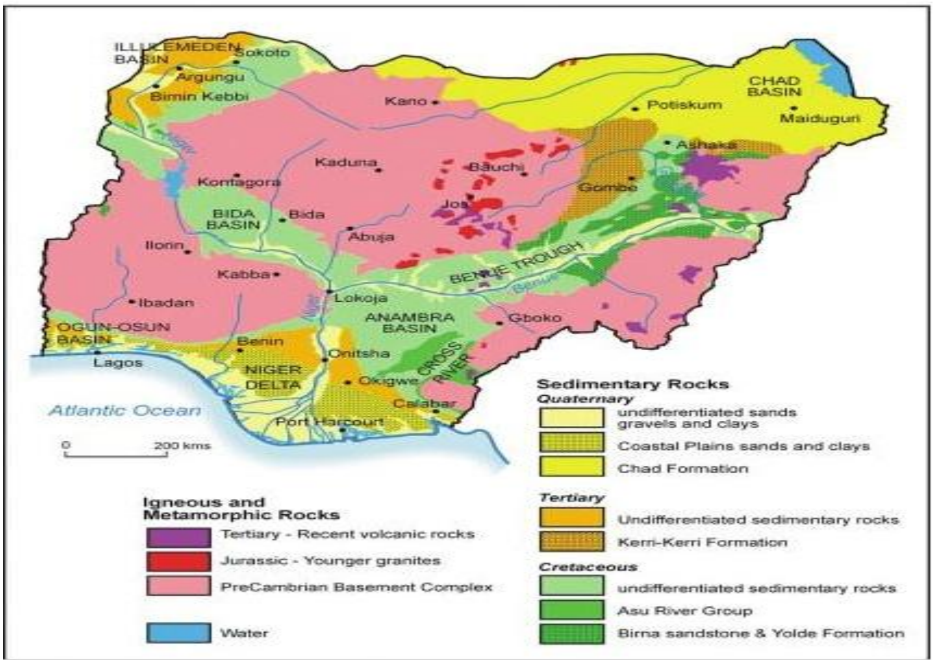

Figure 1: Geological Map of Nigeria (Adapted after MacDonald et al., 2005)

The term “Older granites” on the basis of morphology and texture distinguished the Pan African Granitiods from the Jurassic anorogenicperalkaline “Younger Granites” of the central Plateau region. (Ajibade 1979). They are composed of large volumes of granitic rocks, which intruded all pre-existing rocks including the gneiss-migmatite-quartzite complex and the schist belt. They were emplaced during the late Proterozoic to early Paleozoic (160+/-150 yrs). These granites consist of porphyritic and non-porphyritic granites, granodiorites, adamallite, tonalite and quartz –diorite. They generally occur as inselbergs in the basement. Examples of such granite hills are the OlumoRockin Abeokuta, Ogun State; Idanre Hills, Ondo State; Ikere Hills, Cross-river State; Aso Rock, Abuja etc. It is a heterogeneous assemblage including migmatites, orthogenesis, paragneisses and a series of basic and ultrabasic metamorphosed rocks. The various rock types in this complex are exposed in the north central, north eastern, southwestern and a narrow zone parallel to the eastern boundary of the country, east of River Benue covering parts of Kaduna, Plateau, Bauchi, Kano and Sokoto States; southern Nigeria, covering the greater parts of Kwara, Oyo, Ogun and Ondo States; southeast Nigeria, spanning the northern parts of Cross Rivers State and as far north as Yola; and north of Benue River in Adamawa State. These crystalline basement rocks have been subjected to deformation of different intensities throughout the geological period. Consequently, North-South (N-S), Northeast-Southwest (NE-SW), Northwest-Southeast (NW-SE), North northeast-South southwest (NNE-SSW), North northwest-South southeast (NNW-SSE) and to a lesser extent, East-West (E-W) fractures have developed (Mohammed et al., 2015).

The Sedimentary Basins, containing sediment of Cretaceous to Tertiary ages, comprise the Niger Delta, the Benue Trough, the Chad Basin, the Sokoto Basin, the Mid-Niger (Bida/ Nupe) Basin and the Dahomey Basin (Fatoye and Gideon, 2013); South Western Nigeria, especially around Ile-Ife, is principally underlain by rocks of the Precambrian basement complex of the Ife-Ilesha schist-belt. The major lithological rock units of the complex have been classified into major two groups: gneisses and schists, with minor occurrence of intrusive mafic/ultramafic rocks that probably represent fragments of an oceanic grouping (Ajibade et al., 1987).

III. Data Processing and Methodology

Seismic waveforms covering 2009–2018 were collected from the Ife, Toro, Nsukka, Abakaliki, and Kaduna seismic stations under the NNNSS (Fig. 2). The Centre for Geodesy and Geodynamics (CGG) has been managing the NNNSS since 2006. The waveform data were therefore sorted and processed to extract the local events recorded in 11th September, 2009; 11th and 12th September, 2016 and 7th September, 2018 in Nigeria. Four seismological stations located at Ile-Ife, Osun state; Nsukka, Enugu state; Abakaliki, Ebony state and Kaduna, Kaduna state were used in the study. The stations are equipped with 24- bit multi-channel broadband recorders, and 30 seconds period seismometer. The data acquired by the equipment at the stations are recorded in Miniseed format at a sampling rate of 40 samples per second (sps).

The origin time of the events, the theoretical/calculated travel time, and velocity ratio was calculated and the regional velocity ratio was determined using the average of the Vp/Vs ratios obtained from the entire region covered..

The travel time data for all the event was obtained by subtracting the origin time (time of occurrence) $T_{o,}$ of event from the observed arrival time $T_{a,}$ of the event at the station, given by:

$$T_s = T_a - T_o \qquad (1)$$

The P and S phases of each event were determined using three or more stations and the ratio of the P velocity to the S velocity (Vp/Vs) was determined. Then the Vp/Vs ratio and origin time was computed using Wadati Program in SEISAN Software Version 9.1 (Jens and Lars, 2009). A plot of S-P time versus P-time was determined by joining a single straight line of best fit to estimate the slope (Vp/Vs) and the plot of P- and S-arrival time was used to determine lateral variation of Vp/Vs ratio of the events.

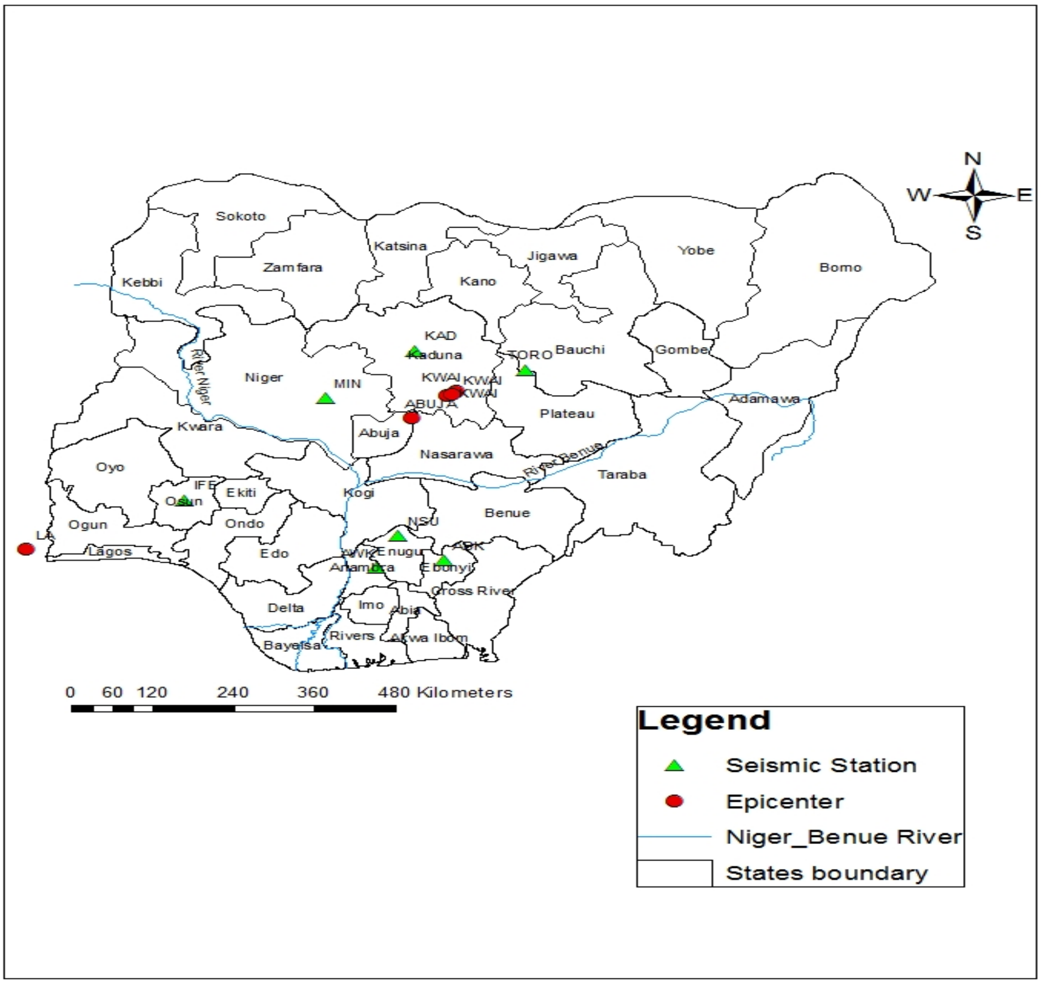

Figure 2: Map of Nigeria showing seismic stations and Epicenters of Recent Earthquake (Courtesy: Authors' Work, 2020)

IV. Results and Discussions

The P- and S- waves arrival times recorded at the various Stations are shown in Tables 1 - 5, while Figures 3 - 7 are the recorded seismograms. Figures 8 to 17 show the Travel time analysis of the signals recorded in all the Stations covered in the study.

Table 1: P- and S- Wave Arrival Time of 11th September, 2009 Earthquake in Abomey-Calavi South-Western Nigeria

STATION CODE	P-Wave First Arrival Time (HH MM SEC)	S-Wave First Arrival Time (HH MM SEC)
KAD	311 55. 29	313 05. 20

NSU	311 35. 45	312 30. 59
IFE	310 59. 16	311 26. 65

Table 2: P- and S- Wave Arrival Time of 11th September, 2016 Earthquake in Kwoi, Kaduna State, North-Western Nigeria.

STATION CODE	P-Wave First Arrival Time (HH MM SEC)	S-Wave First Arrival Time (HH MM SEC)
NSU	1228 51. 93	1229 21. 36
KAD	1228 29. 27	1228 41. 85
IFE	1229 11. 66	1229 56. 88
BKL	1228 58. 88	1229 33. 03

Table 3: P- and S- Wave Arrival Time of 12th September, 2016 Earthquake in Kwoi, Kaduna State, North-Western Nigeria.

STATION CODE	P-Wave First Arrival Time (HH MM SEC)	S-Wave First Arrival Time (HH MM SEC)
NSU	311 22. 46	311 50. 65
KAD	311 2. 85	311 16. 62
IFE	311 44. 09	312 28. 54
BKL	311 30. 48	312 05. 30

Table 4: P- and S- Wave Arrival Time of 12th September, 2016 Earthquake in Kwoi, Kaduna State, North-Western Nigeria

STATION CODE	P-Wave First Arrival Time (HH MM SEC)	S-Wave First Arrival Time (HHMM SEC)
NSU	311 54. 23	312 23. 98
KAD	311 31. 72	311 45. 23
IFE	312 14. 66	313 0. 69
BKL	312 0. 75	312 35. 87

Table 5: P- and S- Wave Arrival Time of 7th September, 2018 Earthquake in Abuja, Federal Capital Territory, North-Central Nigeria.

STATION CODE	P-Wave First Arrival Time (HH MM SEC)	S-Wave First Arrival Time (HH MM SEC)
KAD	616 58. 19	617 15. 06
NSU	617 19. 20	617 52. 19
BKL	617 23. 20	617 59. 01

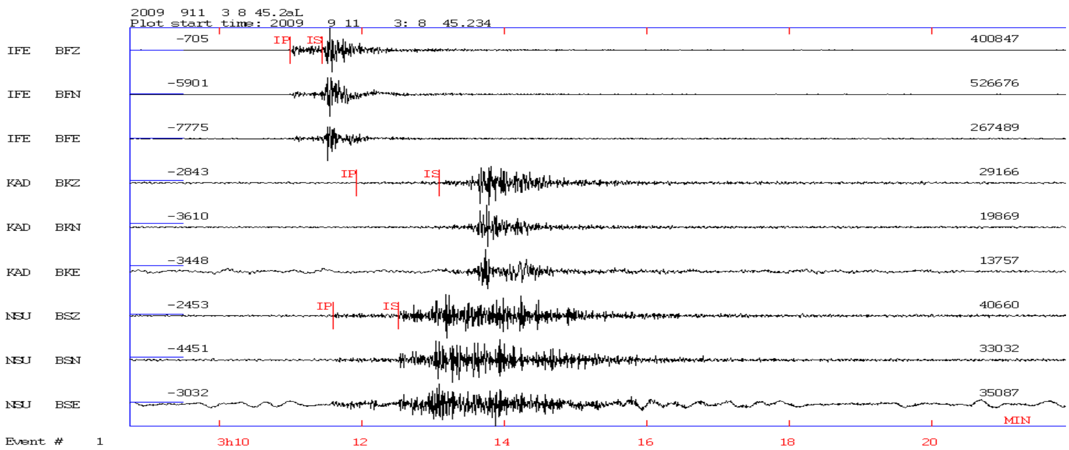

Figure 3: Seismogram of 11th September, 2009 Earthquake in Abomey-Calavi South-Western Nigeria(From Authors' work)

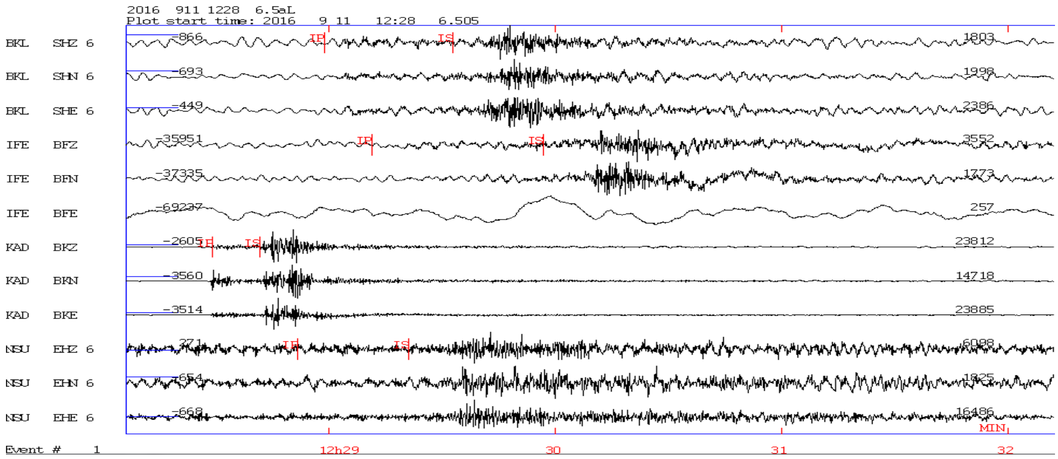

Figure 4: Seismogram of 11th September, 2016 Earthquake in Kwoi, Kaduna State, North-Western Nigeria.(From Authors' work)

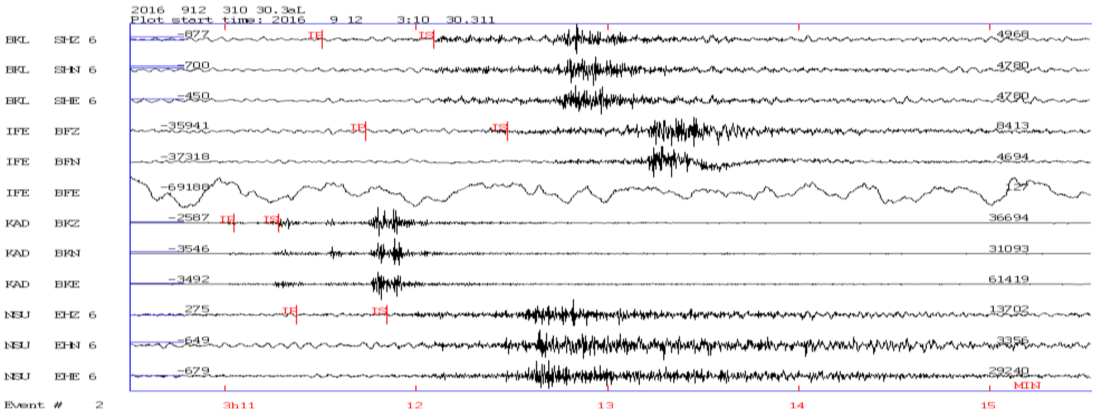

Figure 5: Seismogram of 12th September, 2016 Earthquake in Kwoi, Kaduna State, North-Western Nigeria.(From Authors' work)

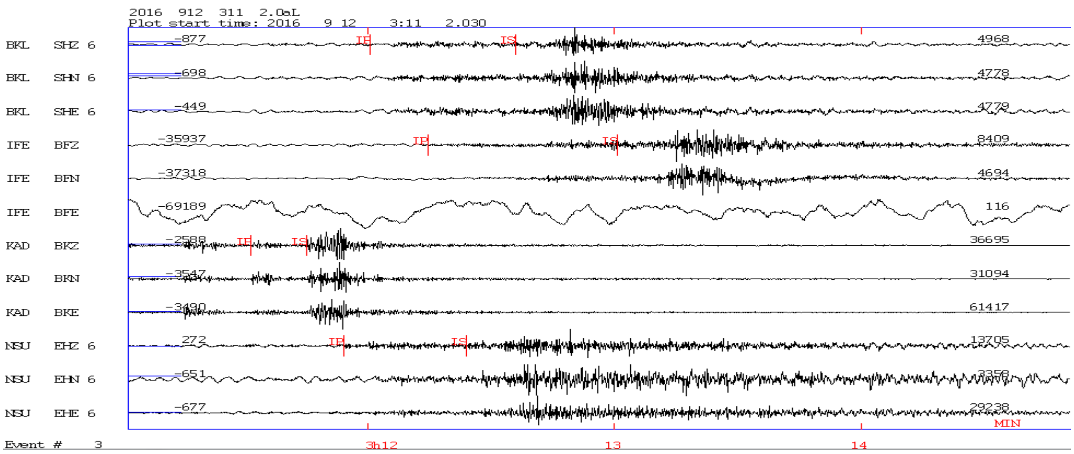

Figure 6: Seismogram of 12th September, 2016 Earthquake in Kwoi, Kaduna State, North-Western Nigeria.(From Authors' work)

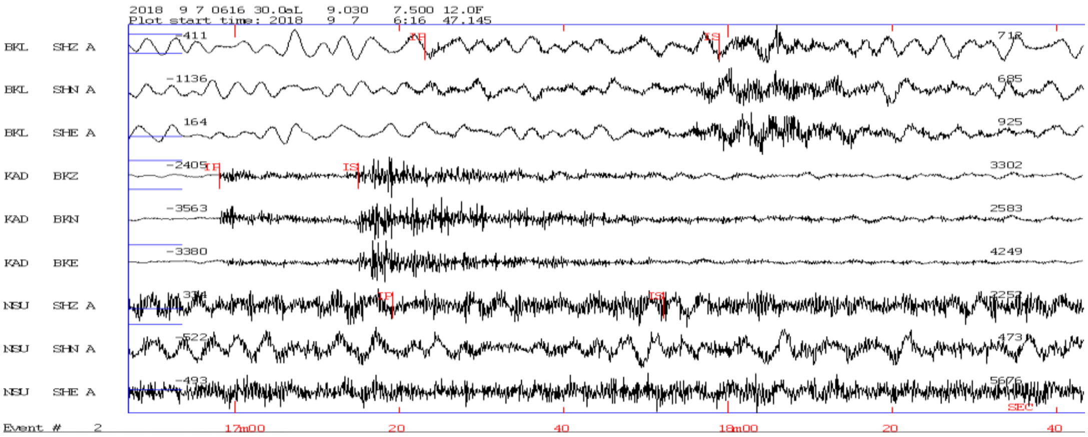

Figure 7: Seismogram of 7th September, 2018 Earthquake in Abuja, Federal capital Territory, North-Central Nigeria. (From Authors' work)

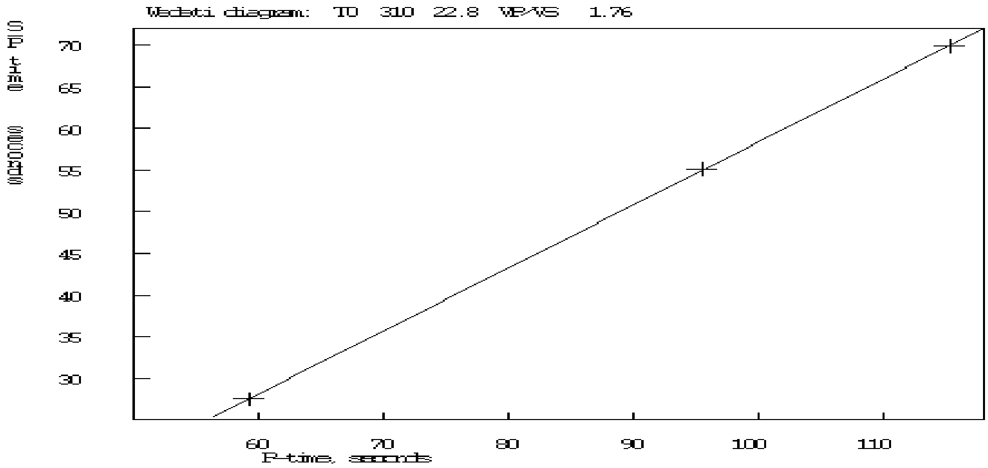

Figure 8: Wave Arrival Time Analysis of 11th September, 2009 Earthquake in South-Western Nigeria

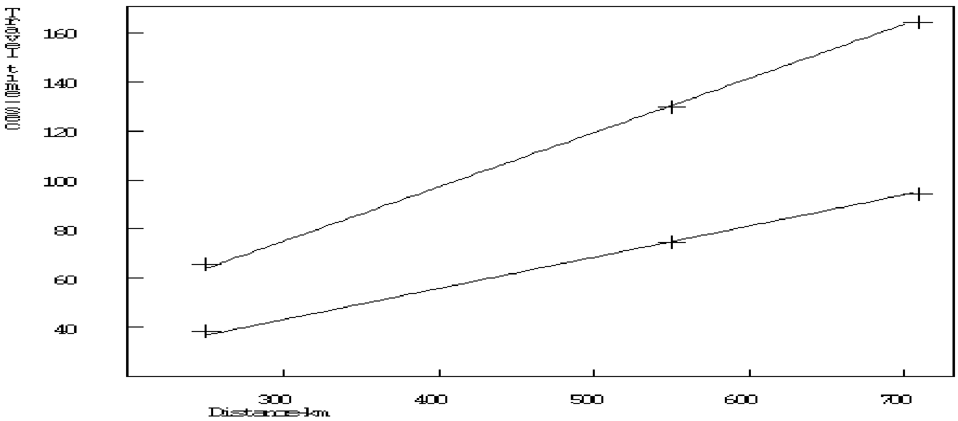

Figure 9: Travel Time Wave Arrival of 11th September, 2009 Earthquake in Abomey-Calavi South- western Nigeria. (Above margin is P wave below is S wave)

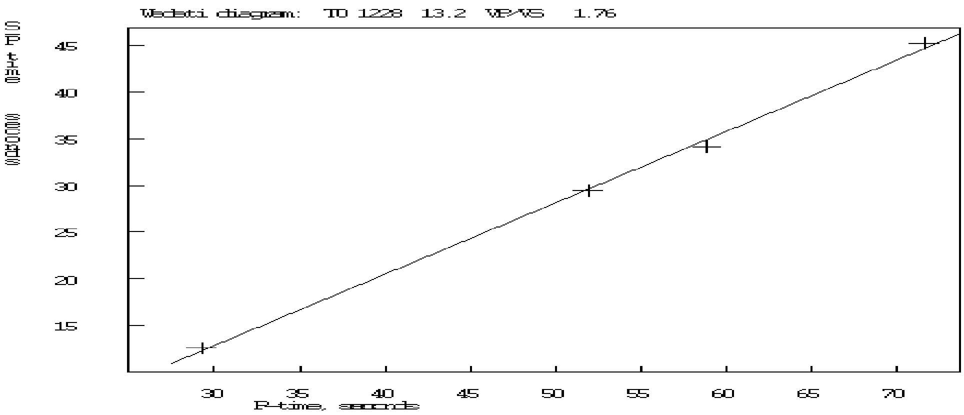

Figure 10: Wave Arrival Time Analysis of 11th September, 2016 Earthquake in Kwoi, Kaduna State North-Western Nigeria.

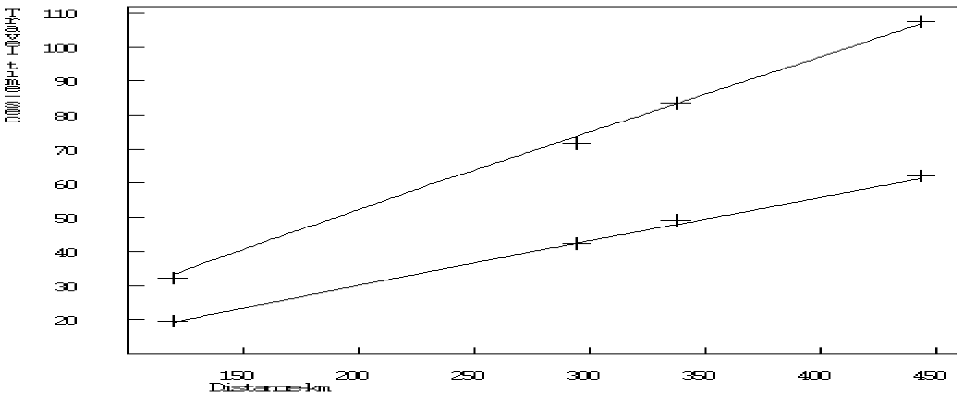

Figure 11: Travel Time Wave Arrival of 11th September, 2016 Earthquake in Kwoi, Kaduna State North-Western Nigeria. (Above is P wave below is S wave)

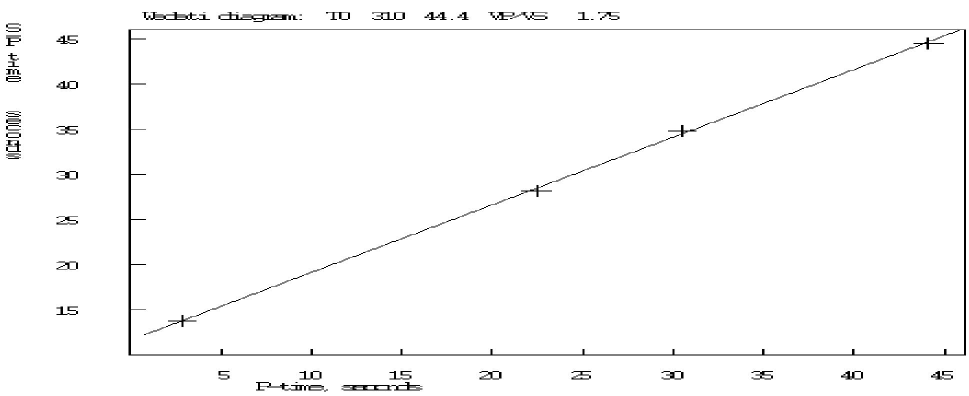

Figure 12: Wave Arrival Time Analysis of 12th September, 2016 Earthquake in Kwoi, Kaduna State North-western Nigeria.

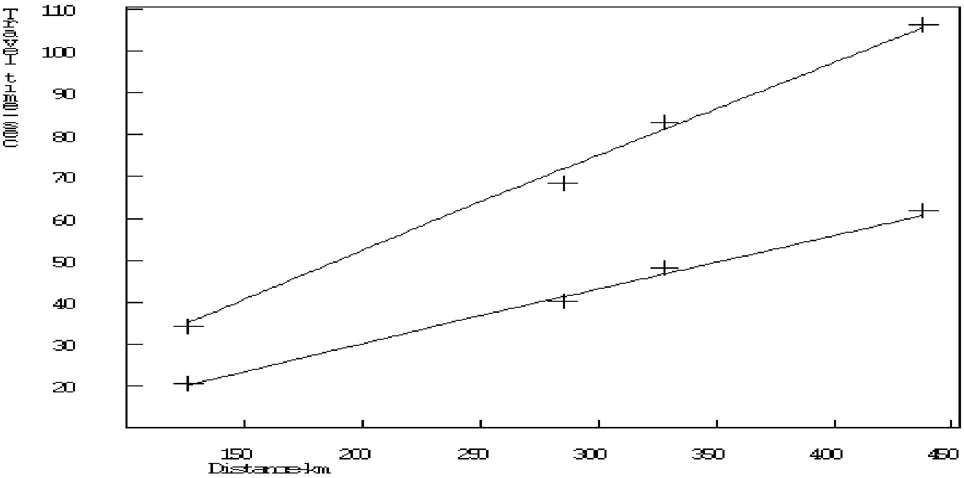

Figure 13: Travel Time Wave Arrival of 12th September, 2016 Earthquake in Kwoi, Kaduna State North-Western Nigeria. (Above is P wave below is S wave)

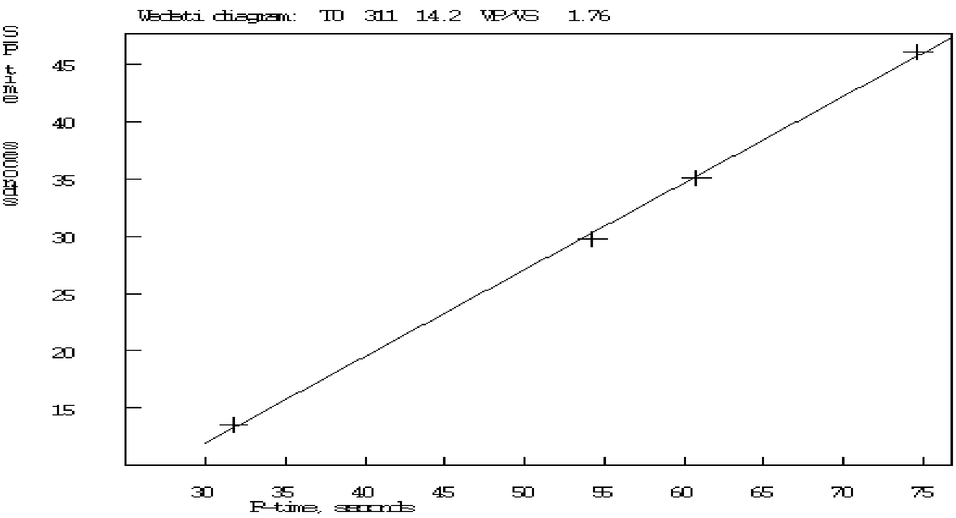

Figure 14: Wave Arrival Time Analysis of 12th September, 2016 Earthquake in Kwoi, Kaduna State, North-Western Nigeria.

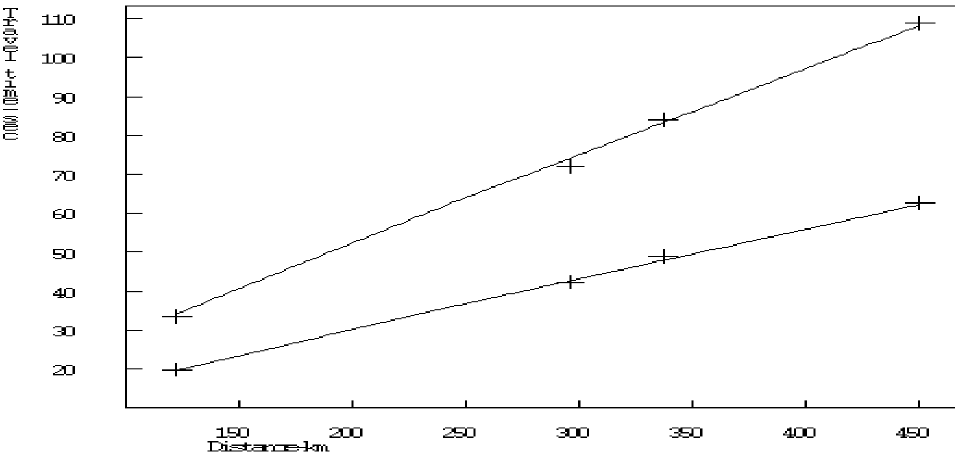

Figure 15: Travel Time Wave Arrival of 12th September, 2016 Earthquake in Kwoi, Kaduna State North-Western Nigeria. (Above is P wave below is S wave)

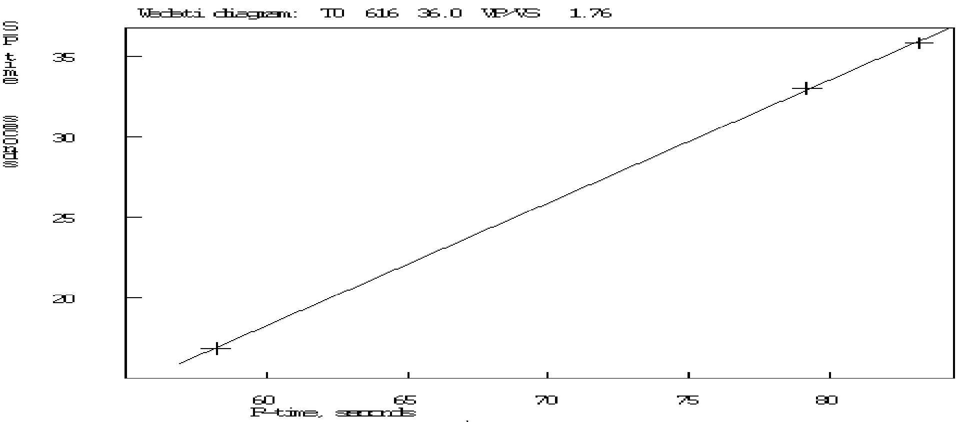

Figure 16: Wave Arrival Time Analysis of 7th September, 2018 Earthquake in Abuja, Federal Capital Territory, North-Central Nigeria.

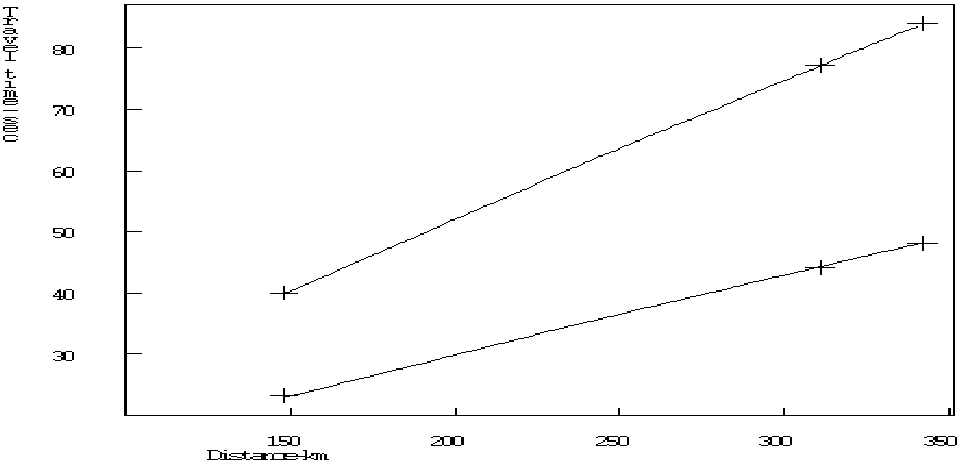

Figure 17: Travel Time Wave Arrival of 7th September, 2018 Earthquake in Abuja, Federal Capital Territory, North-Central Nigeria. (Above is P wave below is S wave)

The resulting Vp/Vs ratio of local earthquake in Nigeria provides detailed insights into the lithology and the Vp/Vs value of the crust and uppermost mantle of Nigeria. The earthquake in the country from 2009 to 2018 is characterized by Vp/Vs ratio ranges from 1.75 to 1.76. The Vp/Vs ratio obtained from 11th September, 2009; 11th September, 2016; the first event of 12th September, 2016 and 7th September, 2018 was determine to be 1.76, while that of the second event of 12th September, 2016; was determine to be 1.75.

The ratio of compressional to shear velocity, Vp/Vs, is an effective lithology indicator because each lithology exhibits a defined trend that is independent of porosity and depth (Pickett, 1963; Eastwood and Castagna, 1987). However, because the Vp/Vs ratio is affected by formation anisotropy, the ratio values may not be absolute indicators of a particular lithology (Johnston et al., 1993). The Vp/Vs value obtained from epicenters of each event in this research are characterized by almost similar rock types on a Basement complex which is shown on the geological map of Nigeria (Fig.1). The average of the velocity ratio is 1.758 (~ 1.76) which represents the Vp/Vs ratio of the crust and uppermost mantle of Nigeria.

Scholars such as Akpan et al, (2014), and Isogun et al. (2018) had earlier estimated the Vp/Vs ratio to be 1.72 and 1.76 respectively. Akpan et al., (2014) used data from September, 11 2009 local earthquake while Isogun et al. (2018) used data from 2009 to 2016 of four local earthquake but this study used data from five local earthquake from 2009 to 2018. The average Vp/Vs ratios obtained in this research are in agreement with Isogun et al. (2018) which implies that bulk Nigeria crustal and uppermost mantle lithologies on the average are of intermediate rocks (i.e. diorites).

V. Conculsion

The Vp/Vs ratios have been computed using five local earthquakes whose epicenters were located in Nigeria. The waveform data which were obtained from Toro, Ife, Abakaliki, Nsukka and Kaduna seismic stations in Nigeria, covered the period of 2009 to 2018. Results from analysis showed the average of the Vp/Vs to be 1.76, which is in good agreement with earlier studies carried out in the Area.

The values obtained show that the epicenter of each event has lithology that is characteristic of the rock types in the area investigated. Therefore, the parameters computed from this study have contributed in improving the knowledge of crust and upper mantle structure in the entire area covered, and have prospects of improving epicenter's determination for local earthquakes to assist in future seismic hazard studies in Nigeria.

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