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Investigation of the relationship between the p wave and s waves within the basement complex of Northern Nigeria

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ABSTRACT

The relationship between p wave and s wave is dynamic, and it is majorly a function of terrain. Knowing the relationship between p wave and s waves for any particular terrain is of vital important for both seismic exploration and geotechnical analysis. The aim of this research work is to establish an absolute relationship between the p waves and s wave seismic velocities within the basement complex. This factor (ratio) will be a guide to a better estimate of shear wave velocity during data analysis that will enhance exploration and site characterization in areas where vertical geophones will be exclusively used for data acquisition. With a bid to achieving this aim, seismic survey was carried out within some locations in the basement complex. The data was processed to generate the p wave velocity models and s wave velocity models independently. The result revealed that both the p waves and s waves from the tomographic model generally increase with depth. The ratio of these p waves and s waves velocities ranges between 1.767981 to 1.999435347. The average representative value for these p waves and s waves velocities ratio was determined to be 1.794860218. The result also revealed that the ratio of p waves and s waves does not genially increase with depth. Therefore, a value of 1.8 approximated to one decimal place, can be taken as a representative value for the ratio between p waves and s waves down to a depth of 40 m within the basement complex. However a value of 1.9 to 2.0 can be adopted as a ratio between p and s wave velocity within the basement complex beyond the depth of 40 m.

Introduction

The p wave and s wave relationship is well established for the sedimentary terrain, this could be attributed to the fact that a major part of seismic exploration activity has been carried out within the sedimentary terrain. This paper therefore is aimed at establishing the relationship between the p wave and s wave within the basement complex. This relationship is of paramount important for seismic investigation within the basement complex and for geotechnical investigation and analysis. The results established by earlier researcher show that:

Average vp/vs ratios are 1.60 for sandstones and 1.89 for limestone and shale. Complex lithologies have vp/vs ratios which plot between the values of their component rock types. This may cause ambiguities in interpretation. vp is approximately linearly correlated with vs in the lithologies studied here. [7].

Dry P-wave and shear modulus has an intrinsic correlation. These correlations offer a quality control for seismic velocities and interpretation. It also provides a new method to estimate shear velocity based on P-wave modulus and Gassmann's equation. [1].

P wave velocity can be lower than its value in air. Most importantly, it should be emphasized that vp/vs ratio was found to be about 1.5 for top-soil (about 0.6 m). [5].

To first order, we conclude that shear wave velocity is nearly linearly related to compressional wave velocity for both water saturated and dry elastic silicate sedimentary rocks. [4].

Location of the study area

The survey area is located in the North Eastern Nigeria of Gombe state and in the North Central Nigeria of Kaduna state bounded with 10^{o} 56' 22.12''N 11^{o} 28' 33.67''E, and 11^{o} 04' 03.15''N, 7^{o} 41' 43.80''E. The Imagery map of the survey areas is shown in Fig. 1.

Figure 1. Imagery map of the survey area. With profile areas indicated with red circle

Geology of the study area

The geology of Nigeria is made up of three major litho-petrological components, namely, the Basement Complex, Younger Granites, and Sedimentary Basins. The Basement Complex, which is Precambrian in age, is made up of the Migmatite-Gneiss Complex, the Schist Belts and the Older Granites. The Younger Granites comprise several Jurassic magmatic ring complexes. They are structurally and petrologically distinct from the Older Granites [2].

The Zaria granite batholith belong to a suite of syn and late tectonic granites and granodiorites that marked the intrusive phase of the late Precambrian to early Palaeozoic Pan-African Orogeny in Nigeria [6]. These granites and granodiorites intruded into low grade meta-sediments and gneisses and were

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collectively called the "Older granites" to distinguish them from the Mesozoic "Younger Granite" [3]. of the Jos plateau and surrounding areas.

Methodology

The seismic data were acquired by placing both the shot and receivers on a straight line. The geophones used for the survey where placed at an interval of 10 meters for the 12 channel seismograph and 5 m for the 24 channels seismograph. Offset distances of 5 to 60 m were used in acquiring seismic data for the different profiles. When all the connection was completed the seismograph was "armed" to receive the generated seismic signal. Shots were fired at an offset distance before the first geophone point, at each geophone point and in between the geophone, and at an offset distance beyond the last geophone. The sledge hammer which is the energy source was position at an angle to the vertical in other to enhance the generation of seismic wave. The generated seismogram Fig. 2, was saved for onward processing at the geophysical laboratory.

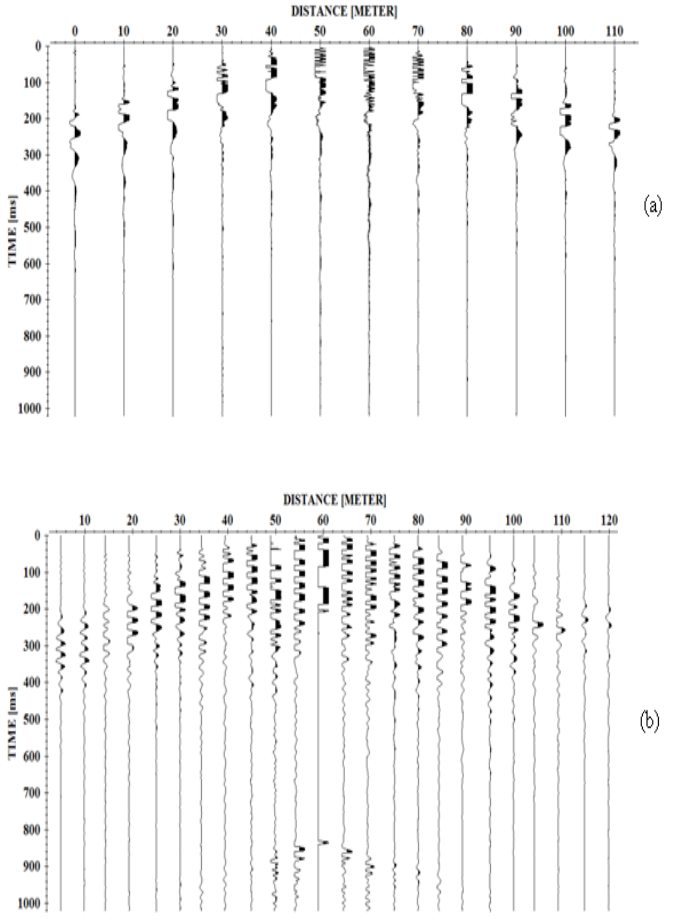

Figure 2. Generated raw seismic data (Seismogram), (a) from 12 channels (b) from 24 Channels

Data Processing

The data processing started with the importation of the seismogram into a dedicated geophysical software use for the processing. The band-pass filter was applied to remove every undesired signal. The gain filter was applied, to remove the effect of geometrical spreading (Fig. 3 Processed seismic data). The first arrivals were picked, which were iteratively used to generate the tomography models for both p waves and s waves. The p wave velocity values were picked from the p wave tomography model, while the s wave velocity values were picked from s waves tomography model at various depth, for analysis, down to a depth of 40 m. Some statistical analysis were carried to determine the average of the result.

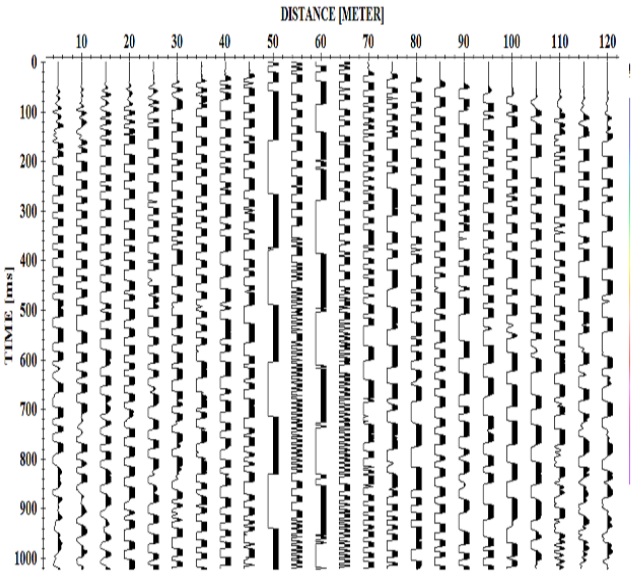

Figure 3. Processed seismic data displayed in distance and time

Results and interpretation

The resultant models from the inversion of the picked travel times for both p and s waves are displayed in figure 4 to 13. Attached to each model is a colour scale bar, with velocity values attached to each colour. Please note that the model should be interpreted not just base on the colour appearance, but it should be interpreted base on the velocity values attached to each colour.

Profile 1 to 3, were generated at the North Eastern Nigeria of Gombe state, While profile 4 and 5 were generated at the North Central Nigeria of Kaduna state. A general overview of the models showed that they represent a general increase of velocity with depth. The models velocity of the p waves ranges from 400 m/s to 4000 m/s, while the models velocity of s waves ranges from 200 m/s to 2000 m/s.

The tomography models were able to delineated the overburden with velocity range of 400 m/s to 1400 m/s. the weathered basement with velocity range of 1800 m/s to 2900 m/s, and the fresh basement with a velocity range of 3000 m/s and above. There are remarkable undulations in the basement topography in most of the profiles.

Velocity values where extracted from the models at the point indicated by an arrows showed in figure 4 to 13, from a depth of 0 m (at the surface) to a depth of 40 m, which form the minimum depth limit for all the model.

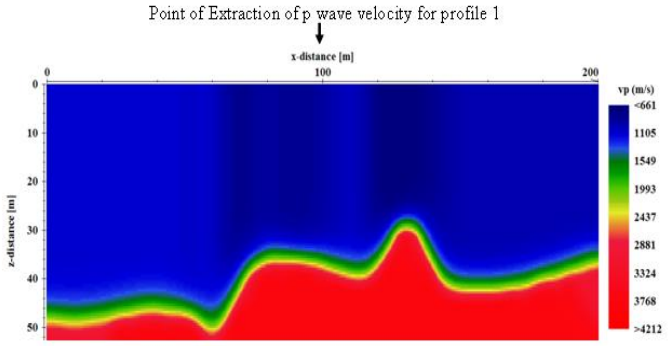

Figure 4. 2D tomography model of subsurface distribution of p waves velocity along profile 1

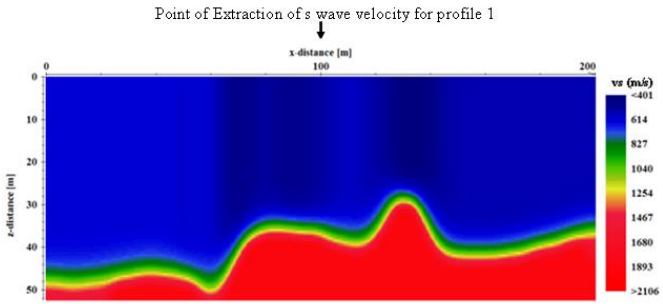

Figure 5. 2D tomography model of subsurface distribution of s waves velocity along profile 1

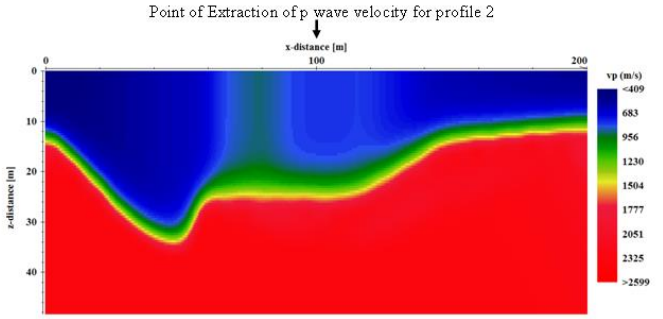

Figure 6. 2D tomography model of subsurface distribution of p waves velocity along profile 2

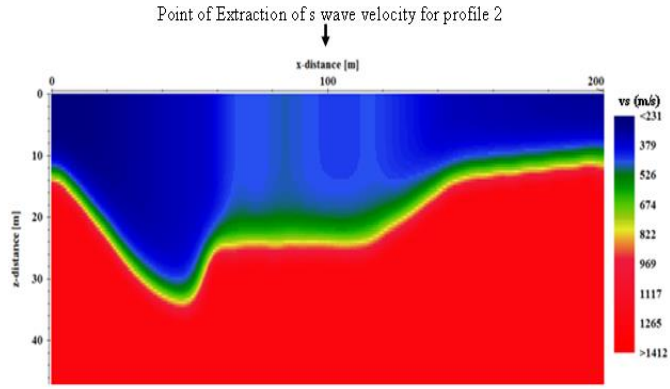

Figure 7. 2D tomography model of subsurface distribution of s waves velocity along profile 2

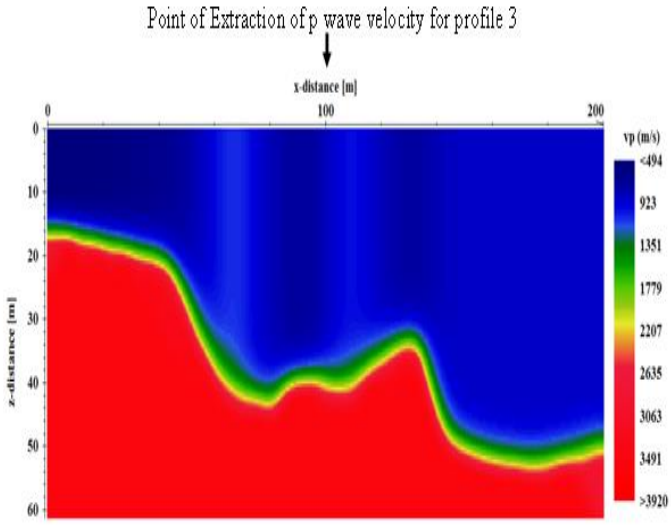

Figure 8. 2D tomography model of subsurface distribution of p waves velocity along profile 3

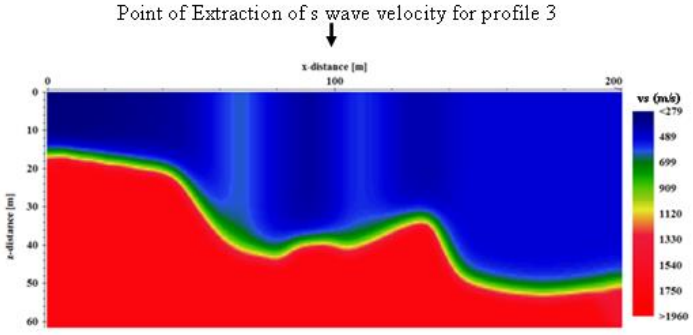

Figure 9. 2D tomography model of subsurface distribution of s waves velocity along profile 3.

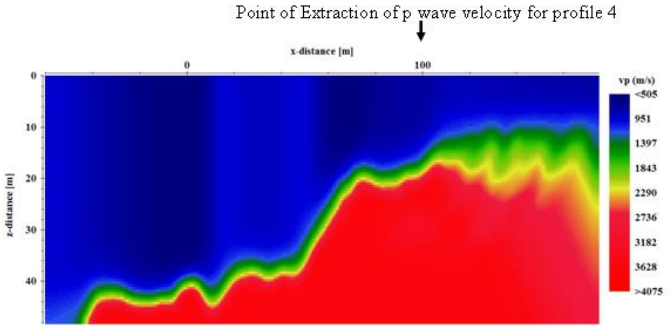

Figure 10. 2D tomography model of subsurface distribution of p waves velocity along profile 4

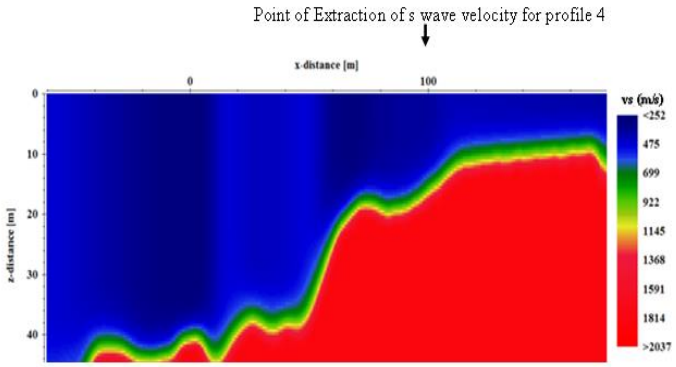

Figure 11. 2D tomography model of subsurface distribution of s waves velocity along profile 4

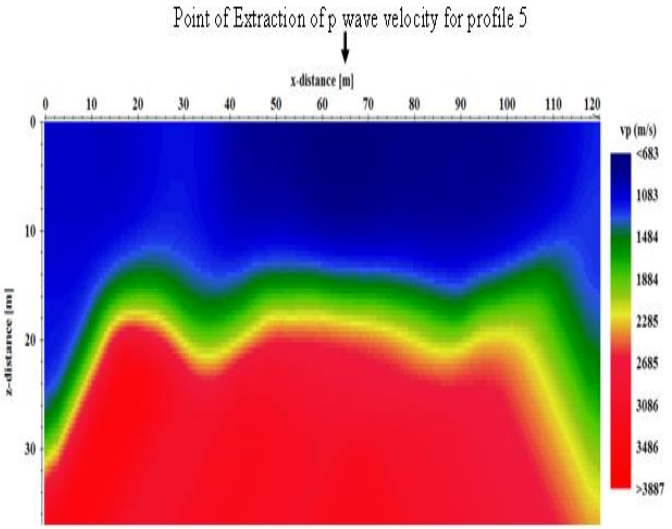

Figure 12. 2D tomography model of subsurface distribution of p waves velocity along profile 5

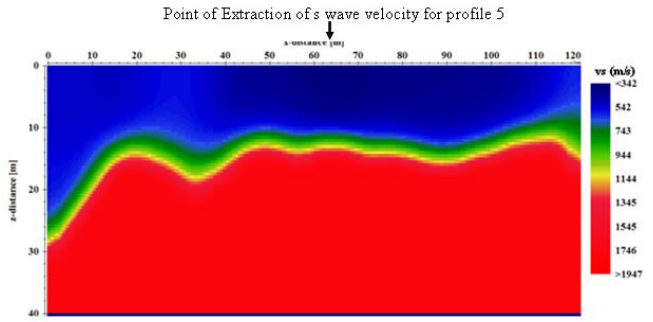

Figure 13. 2D tomography model of subsurface distribution of s waves velocity along profile 5

The extracted velocity values for p and s waves are shown in table 1 to 5. In all cases both the extracted p and s wave values showed a general increase of velocity with depth. The ratio of the p waves and s waves were also generated by diving the each of the p wave values by their corresponding s wave values table 1 to 5. Therefore, each of the ratios represents an instantaneous relationship between p wave and the corresponding s waves.

The p waves and s waves ratio ranges from 1.767981 in profile 5 to 1.999435347 in profile 1. The row average of each of the p waves s waves from each of the profiles were calculated as shown in table 6. The average value of the p and s wave velocity ratio the entire profiles was calculated to be 1.794860218.The difference in ration between the underlying layer and the layer above was also determine (Table 6), and it revealed that the ratio between p and s wave velocity does not generally increase with depth.

Table 1. The extracted velocity values for p and s waves and their ratio for profile 1

Profile 1 Depth (m)	P wave Velocity (m/s)	S wave Velocity	Ratio
0	949	536	1.7705223
2	949	536	1.7705223
4	949	536	1.7705223
6	949	536	1.7705223
8	949	536	1.7705223
10	949	536	1.7705223
12	949	536	1.7705223
14	949	536	1.7705223
16	949	536	1.7705223
18	949	536	1.7705223
20	949	536	1.7705223
22	949	536	1.7705223
24	952	538	1.7695167
26	958	541	1.7707948
28	980	554	1.7689530
30	1045	590	1.7711864
32	1149	649	1.7704160
34	1292	730	1.7698630
36	1739	966	1.8002070
38	2500	1351	1.8504811
40	3541	1771	1.9994353

Table 2. The extracted velocity values for p and s waves and their ratio for profile 2

Profile 2 Depth (m)	P wave Velocity (m/S)	S wave Velocity (m/s)	Ratio
0	814	460	1.769565217
2	814	460	1.769565217
4	814	460	1.769565217
6	814	460	1.769565217
8	814	460	1.769565217
10	814	460	1.769565217
12	815	460	1.77173913
14	821	464	1.769396552
16	836	472	1.771186441
18	873	488	1.788934426
20	954	533	1.789868668
22	1112	621	1.790660225
24	1334	745	1.790604027
26	1875	1047	1.790830946
28	2058	1150	1.789565217
30	2138	1194	1.790619765
32	2274	1270	1.790551181
34	2328	1272	1.830188679
36	2354	1279	1.840500391
38	2362	1284	1.839563863
40	2362	1284	1.839563863

Table 3. The extracted velocity values for p and s waves and their ratio for profile 3

Profile 3 Depth (m)	P wave Velocity (m/S)	S wave Velocity (m/s)	Ratio
0	869	491	1.769857434
2	869	491	1.769857434
4	869	491	1.769857434
6	869	491	1.769857434
8	869	491	1.769857434
10	869	491	1.769857434
12	869	491	1.769857434
14	869	491	1.769857434
16	869	491	1.769857434
18	869	491	1.769857434
20	869	491	1.769857434
22	869	491	1.769857434
24	869	491	1.769857434
26	870	492	1.768292683
28	873	493	1.770791075
30	885	494	1.791497976
32	907	507	1.788954635
34	991	551	1.798548094
36	1150	639	1.799687011
38	1384	769	1.799739922
40	1939	1021	1.899118511

Table 4. The extracted velocity values for p and s waves and their ratio for profile 4

Profile 4 Depth (m)	P wave Velocity (m/S)	S wave Velocity (m/s)	Ratio
0	779	438	1.778538813
2	783	440	1.779545455
4	785	441	1.780045351
6	793	446	1.778026906
8	803	446	1.80044843
10	858	477	1.798742138
12	945	525	1.8
14	1107	615	1.8
16	1403	779	1.801026958
18	1930	1072	1.800373134
20	2857	1587	1.800252048
22	3516	1923	1.828393136

24	3670	1932	1.899585921
26	3672	1933	1.899637869
28	3676	1935	1.899741602
30	3684	1939	1.899948427
32	3691	1943	1.899639732
34	3704	1949	1.900461775
36	3784	1982	1.909182644
38	3804	2002	1.9000999
40	3806	2003	1.900149775

Table 5. The extracted velocity values for p and s waves and their ratio for profile 5

Profile 5 Depth (m)	P wave Velocity (m/S)	S wave Velocity (m/s)	Ratio
0	758	428	1.771028037
2	762	431	1.767981439
4	775	438	1.769406393
6	806	455	1.771428571
8	865	489	1.768916155
10	972	549	1.770491803
12	1152	651	1.769585253
14	1417	801	1.769038702
16	1774	1002	1.770459082
18	2177	1230	1.769918699
20	2584	1460	1.769863014
22	2729	1542	1.769779507
24	2827	1597	1.770194114
26	2906	1642	1.769792935
28	3015	1703	1.770405167
30	3157	1784	1.769618834
32	3263	1844	1.769522777
34	3299	1864	1.769849785
36	3394	1918	1.769551616
38	3494	1941	1.80010304
40	3594	1957	1.836484415

Table 6. p and s wave velocity ratio row average and difference

Depth (m)	Row average of the ration at various depth	Difference between the upper and lower layer ratio with Depth	Approximation of Ratio to 1 decimal place
0	1.771902378		1.8
2	1.771494386	-0.000407991	1.8
4	1.771879357	0.00038497	1.8
6	1.771880103	7.46618E-07	1.8
8	1.775861925	0.003981822	1.8
10	1.775835796	-2.61289E-05	1.8
12	1.776340841	0.000505045	1.8
14	1.775763015	-0.000577826	1.8
16	1.77661046	0.000847445	1.8
18	1.779921216	0.003310756	1.8
20	1.78007271	0.000151494	1.8
22	1.785842538	0.005769828	1.8
24	1.799951645	0.014109107	1.8
26	1.799869851	-8.17935E-05	1.8
28	1.799891226	2.13747E-05	1.8
30	1.804574289	0.004683063	1.8
32	1.80381687	-0.000757419	1.8
34	1.81378227	0.0099654	1.8
36	1.82382574	0.010043471	1.8
38	1.83799757	0.01417183	1.8
40	1.894950382	0.056952812	1.9
General Average	**1.794860218**	**Approximate General average**	**1.8**

The p and s wave velocity ratio were approximated to 1 decimal place, which resulted in a representative ratio of 1.8 (1.794860218**)**, except for the ratio of 1.9 at 40 m depth. Therefore on a bold assumption 1.8 (1.794860218**)** to one place of decimal could be used as a representative ratio value between p wave and s wave within the basement complex.

Conclusion

Investigation has been carried out into the p and s wave velocity relationship by analyzing their ratio. The result of their ratio turned out to be within the range of 1.767981 to 1.999435347. The average reprehensive ratio for p and s wave velocity turned out to 1.794860218. Therefore, a value of 1.8 approximated to one decimal place, can be taken as a representative value for the ratio between p waves and s waves down to a depth of 40 m within the basement complex. However a value of 1.9 to 2.0 can be adopted as a ratio between p and s wave velocity within the basement complex beyond the depth of 40 m.

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