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Geotechnical investigation of near surface lithological unit using downhole seismic method

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Abstract

Downhole seismic survey stands as one of the best method for determining the velocity distribution within different lithological unit, and to infer the different lithology within these layers. The aim of this research work is to make use of downhole seismic method for site characterization, determination of velocity distribution and establishment of the lithology within the various layers. Four boreholes were investigated for the purpose of this research work. The methodology employed involves putting a hydrophone inside the borehole, with the energy source on the surface at an offset distance of 3 m from the borehole. A stack of 5 shots were use to generate seismic signals that were detected by a hydrophone and recorded with a seismograph. The recording was carried out at interval of 3 m within the borehole. The result of the survey revealed that the range of p waves velocity within the survey area is from 995 m/s to 2695 m/s, and the s wave velocity ranges from 582 m/s to 1489 m/s. It was identify base on their velocity that the various lithologies within the boreholes are clays, wet sand and saturated shale. The poisons ratio which ranges from 0.24 at the top layer to 0.28 at the bottom, gave an indication of relative thick overburden made up sandyclay, underlain by consolidated layer of sand. The values of poisons ratio which increased with depth ruled out the possibility of velocity anisotropy within the various lithological unit.

Keynote : Downhole, Lithology, Site Characterization, near surface, Poison's ratio.

Introduction

Downhole survey is one of the best methods of carrying out near surface investigation to determine the weathering and sub-weathering thicknesses and velocities. A downhole survey normally requires taking shots on or near the surface and at a distance from the borehole, and using geophones/hydrophones to measure the arrival times. (Agoha *et al*, 2015).

Downhole seismic method was recently carried out for the purpose of site characterization. A comprehensive geotechnical survey was required at a site where heavy structure like large "Condensate Storage Tanks" are to be put in place. To avert any structural failure, thorough investigation was carried to make sure that no high speed layer is underlain by low speed layer. The lithology which specify the different soil types that makes up the formation has to be identify, especially for clay that undergoes an uneven expansion and contraction when it absorb water or loss water has to be delineated. The load bearing capacity of the different formations has to be estimated by measuring the soil elastic parameters. To achieve these result the p waves and s waves velocity distribution within the subsurface has to be determined.

Some of the pitfalls encountered in crosshole test, could be avoided by conducting other type of tests such as uphole or downhole survey (Dwain and Joseph, 1981). Surface seismic surveys are suitable for mapping gently to moderately dipping reflectors, otherwise downhole surveys are preferable (Alireza et al, 20132).

Location of the study area

The study area is located at Oben Edo State Nigeria, bounded by the following geographical latitude and longitude: 6^{o} 07' 44.54''N, 5^{o} 27' 18.99''E; 6^{o} 07' 30.57''N, 5^{o} 47' 4.58''E; 5^{o} 53' 30.76''N, 5^{o} 46' 33.54''E; 5^{o} 53' 02.50''N, 5^{o} 28' 10.99''E, with an average elevation of 41 m above mean sea level. The image map of the survey area is shown in figure 1.

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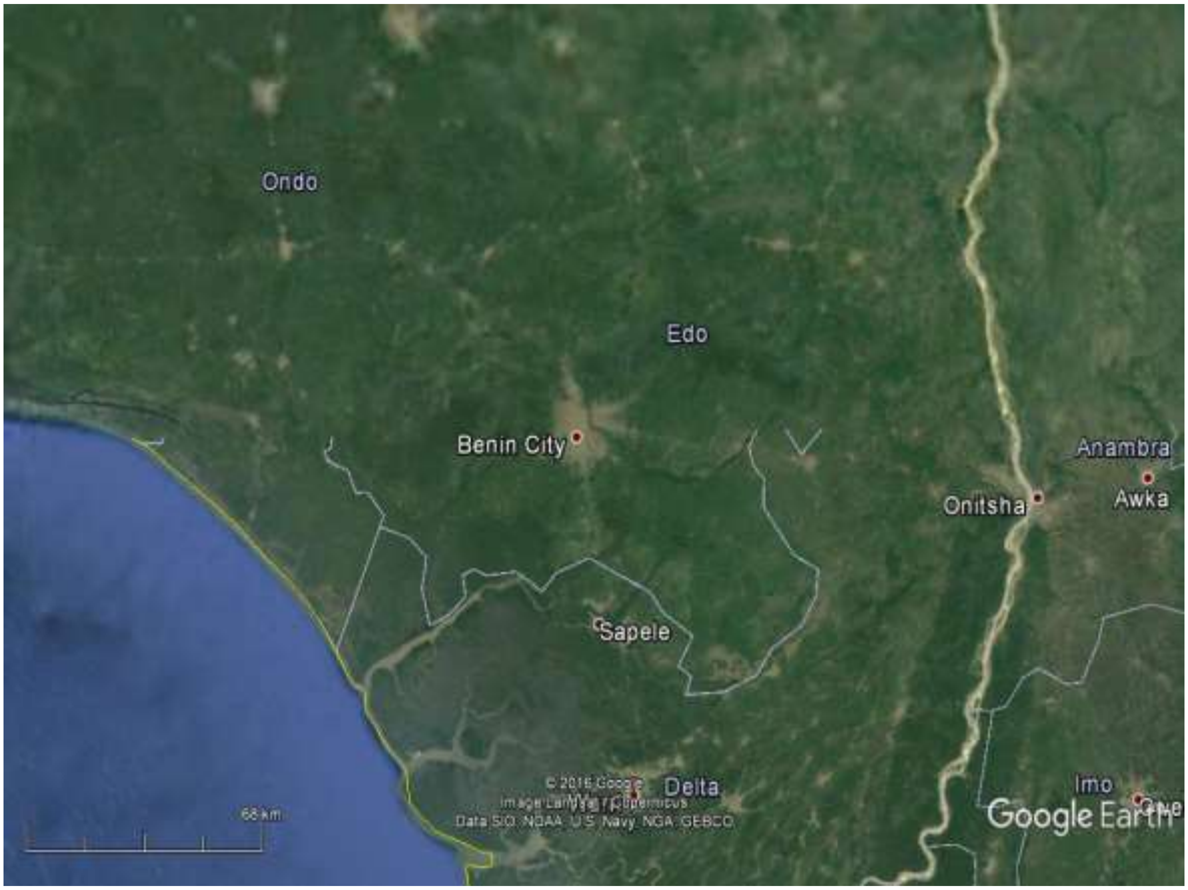

Figure 1: Image Map of the survey area: Adapted from Google Earth 2016.

Geology of the study area

The formation of the present Niger Delta started during Early Paleocene as a result of the built up of fine grained sediments eroded and transported to the area by the River Niger and its tributaries. The regional geology of the Niger Delta consists of three lithostratigraphic units, Akata, Agbada and Benin Formations, overlain by various types of Quaternary Deposits (Short and Stauble, 1967), (Wright *et al*, 1985), (Kogbe, 1989). These Quaternary Sediments, according to (Osakuni and Abam, 2004) are largely alluvial and hydromorphic soils and lacustrine sediments of Pleistocene age.

Methodology (Data acquisition)

The equipment used for this survey include; Digital seismograph, Hydrophone, Reel of cable with take-out points, Trigger Geophone, Trigger cable, sledge Hammer as energy source and 12V Battery. The Downhole seismic data were acquired using an offset distance of 3 m from the borehole at the surface, and at an interval of 3 m inside the borehole, from a depth of 30 m, down to a depth of 40 m. A depth of 30 m was chosen because it lies within the formations of interest under investigation. During the data acquisition, the hydrophone was lowered at an intervals of 3 m, after a stack of 5 shots at the surface. The generated seismogram was recorded for onward processing in geophysical laboratories.

Data Processing

The data processing flow started with importing the raw data into the processing software. The gain filter was applied to remove the effect of geometrical spreading and signal attenuation. The first arrival times were picked at the first "kink" point, and used to calculate the seismic p wave and s wave velocities, by taking advantage of the difference in depth and travel times between two points of recording within the borehole. The interval velocities for the p and s waves were plotted, and the passion's ratio was also calculated base on the p and s wave values.

The extracted and processed seismic wiggles showing arrival times, and the picked first arrival times for Borehole A1 (BH A1), Borehole A2 (BH A2), Borehole B3 (BH B3) and Borehole B4 (BH B4) are all shown in figure 2 to 5.

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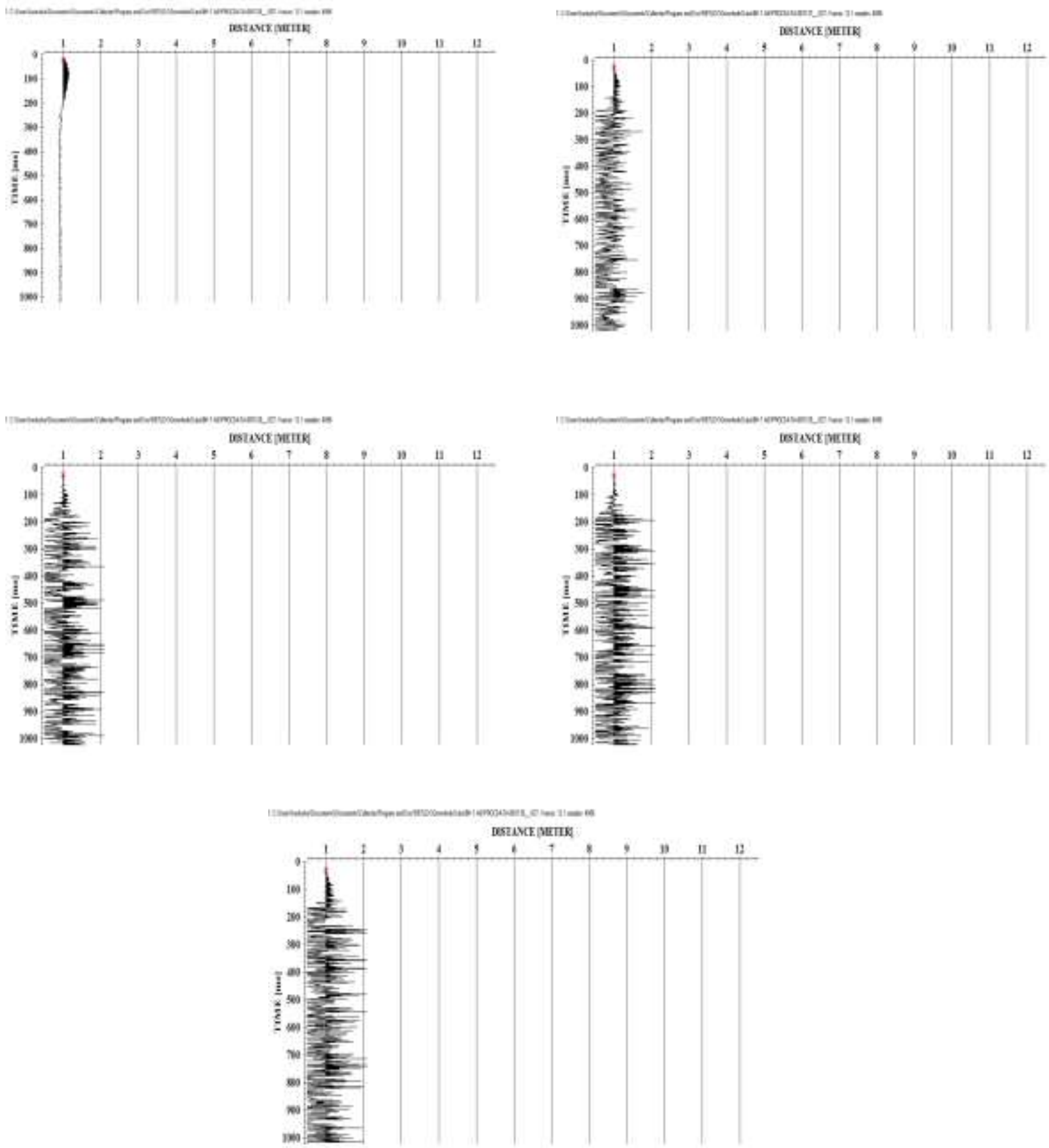

Figure 2**:** Seismic traces for Borehole A1 (BH A1), at a depth of 30 m to 42 m.

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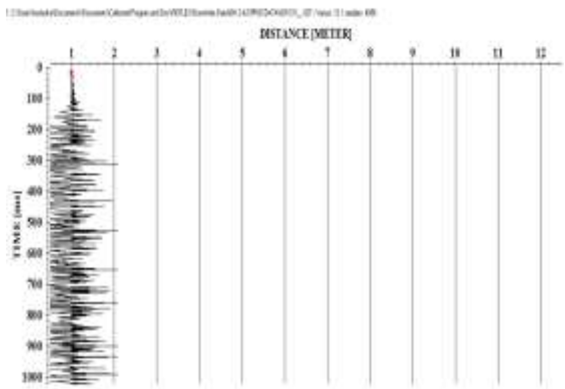

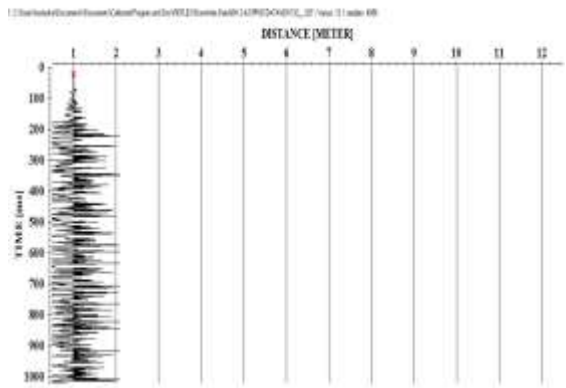

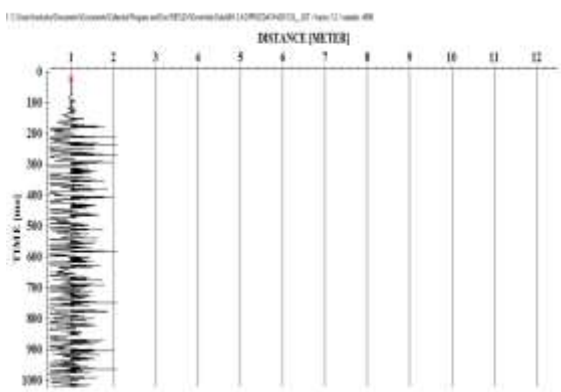

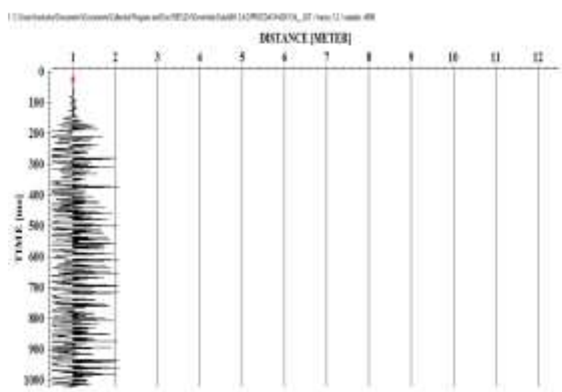

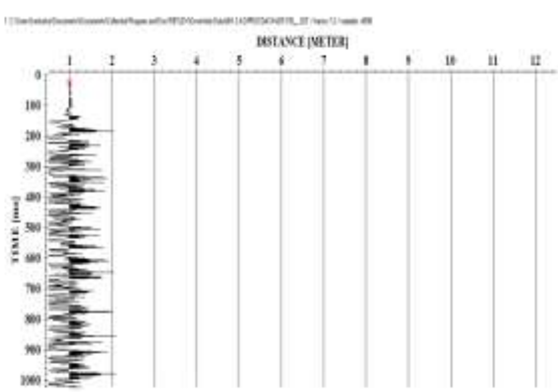

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Figure 3**:** Seismic traces for Borehole A2 (BH A2), at a depth of 30 m to 42 m.

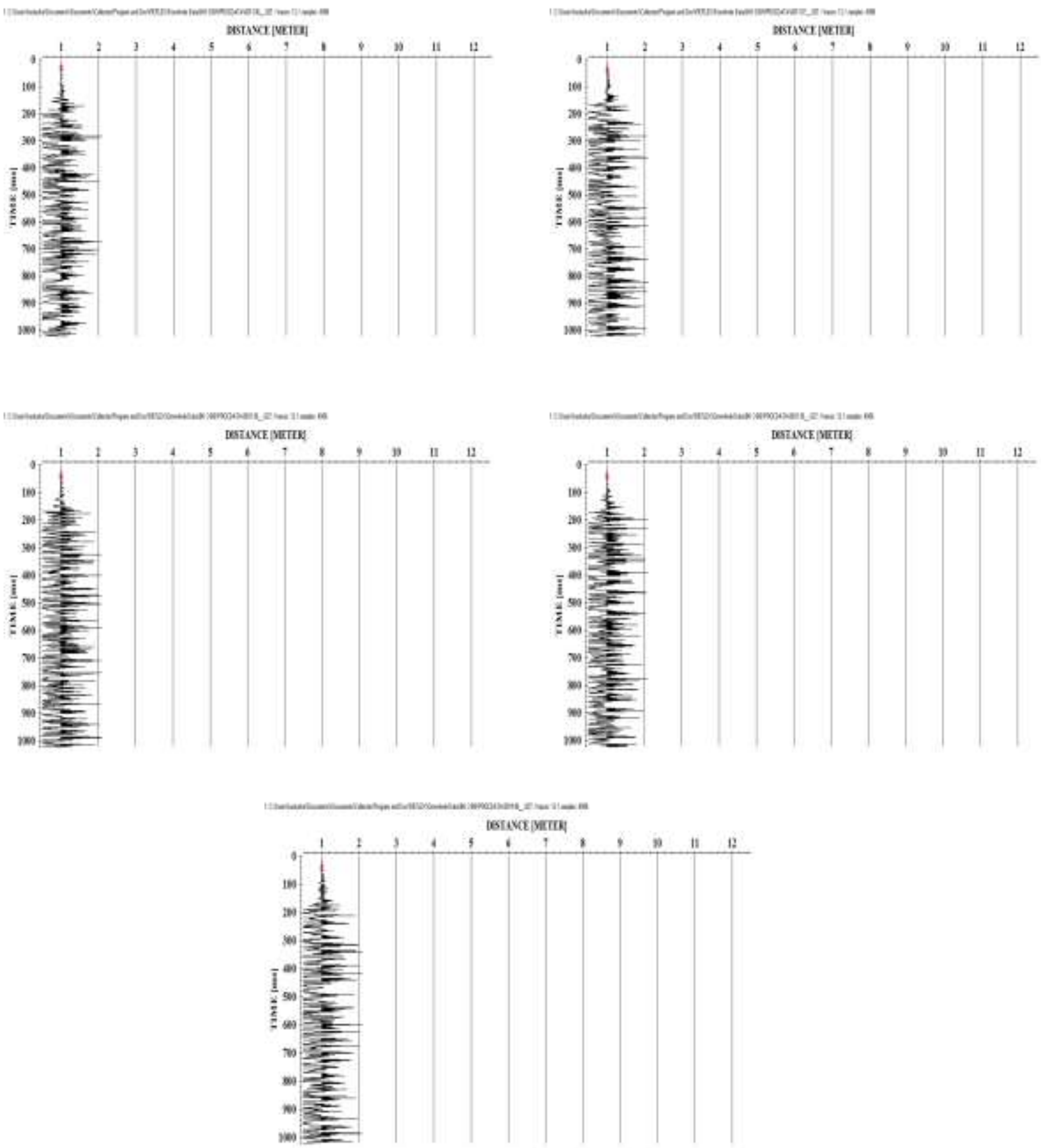

Figure 4**:** Seismic traces for Borehole B3 (BH B3), at a depth of 30 m to 42 m.

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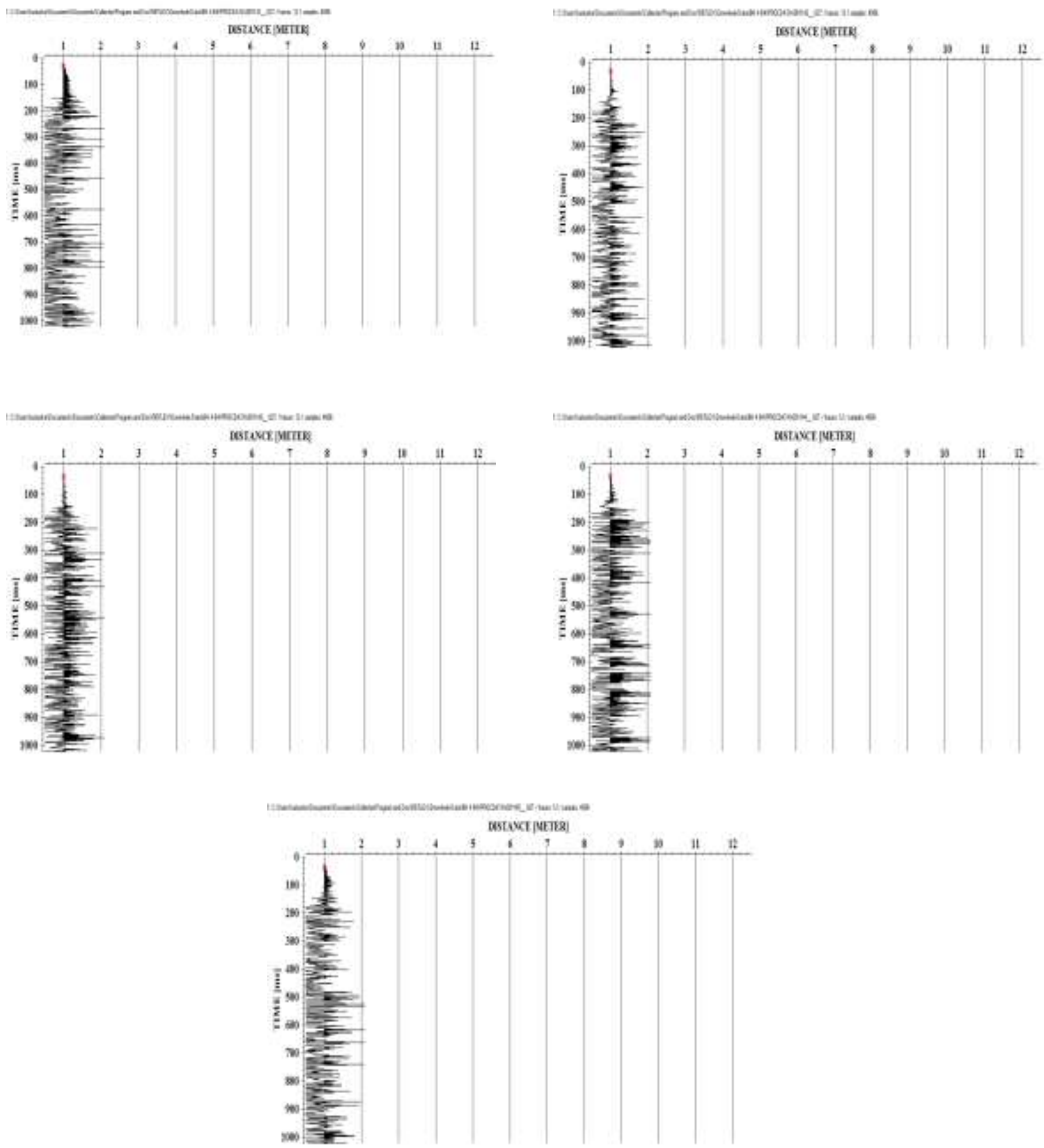

Figure 5**:** Seismic traces for Borehole B4 (BH B4), at a depth of 30 m to 42 m.

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Results and Discussion

Table 1 and figure 6 shows the data generated from Borehole A1 (BH A1). The p waves velocity ranges from 1030 m/s to 2535 m/s, and the range of s waves velocity is between 602 m/s to 1401 m/s. From the table it can be seen that the p waves and s waves generally increase with depth. The interval velocity plot for p waves and s waves confirm the increase with depth of the p and s waves velocities. The interval velocity has also shown that they is no velocity anisotropy, were a high speed layer is underlain by a low speed layer. The range of value of the poison's ratio is between 0.24 to 0.28. Table 2 and figure 7 depict the data generated from borehole A2 (BH A2). The range of p waves and s waves velocity is between 995 m/s to 2452 m/s and 582 m/s to 1355 m/s. The interval velocity plot for both p waves and s waves velocity showed a general increase of velocity with depth. The poison's ratio ranges between 0.24 to 0.28. Table 3 and figure 8 shows the data generated from BH B3. The p and s waves have a range of velocity of 1030 m/s to 2514 m/s and 602 m/s to 1389 m/s respectively, and registered a general increase of velocity with depth. The interval velocity plots for BH B3 also confirm the general increase of p and s waves velocities with depth. The value for poison's ratio, ranges from 0.24 to 0.28. Table 4 and figure 9 data were generated from borehole B4 (BH B4). The p and s waves velocities show a general increase of velocity with depth with a range of velocity of 1078 m/s to 2695 m/s for p waves, and 630 m/s to 1489 m/s for s waves. The range of poison's ratio is between 0.24 to 0.28. The interval velocity plot for p and s waves showed in figure 9, confirmed the general increase of velocity with depth. The average p waves velocity at a depth of 30m is about 1033 m/s, while the average corresponding s waves velocity is 604 m/s. The average value of the p waves velocity at a depth of 39 m is 2549 m/s, while the corresponding average s waves velocity is 1408 m/s. The average range of seismic p waves velocity for the survey area ranges between 1033 m/s to 2549 m/s, which also fall within the standard velocities of clay and sand. The standard velocity for sand and clay ranges from 200 m/s to 2500 m/s (Dry Sand has a standard velocity of 200 m/s to 1000 m/s, water saturated sand 800 m/s to 2500 m/s, clay 1000 m/s to 2200 m/s after (Philip, Michael and Ian, 2002). and (Burger, 1992). When the average range of velocity obtained from the survey, is related to standard velocity, it gave a clear indication that the region under investigation is characterized with alternate layer of clay and sand. The upper lay is made up of sandy clay, which is underlain by a layer of clay. The layer of clay is underlain by a layer of saturated sand based on the observed velocity. The range of poison’s ratio (0.24 to 0.28) which is basically the same for the entire four boreholes showed that the boreholes penetrated into the same formation in all the four points of the investigation. The poisons ratio also gave a clear indication that we are moving from a consolidated formation at a depth of 30 m, to a more consolidated formation at a depth of 39 m.

Conclusion

The p and s waves for all the boreholes show a general increase of velocity with depth. This was confirmed by the interval velocity plot for each borehole. The p wave velocity in the survey area ranges between 995 m/s to 2695 m/s, with an average value of 1033 m/s to 2549 m/s, while the s wave velocity ranges between 582 m/s to 1489 m/s, with an average value of 604 m/s to 1408 m/s at a depth of 30 m and 39 m. The range of p wave and s wave velocities falls within the p wave and s wave values of sandy clay, clays and Saturated sand, after Gary 2015. The range of the value of poison’s ratio (0.24 to 0.28), gave an obvious indication that the boreholes passed through a consolidated formation to a more consolidated formation.

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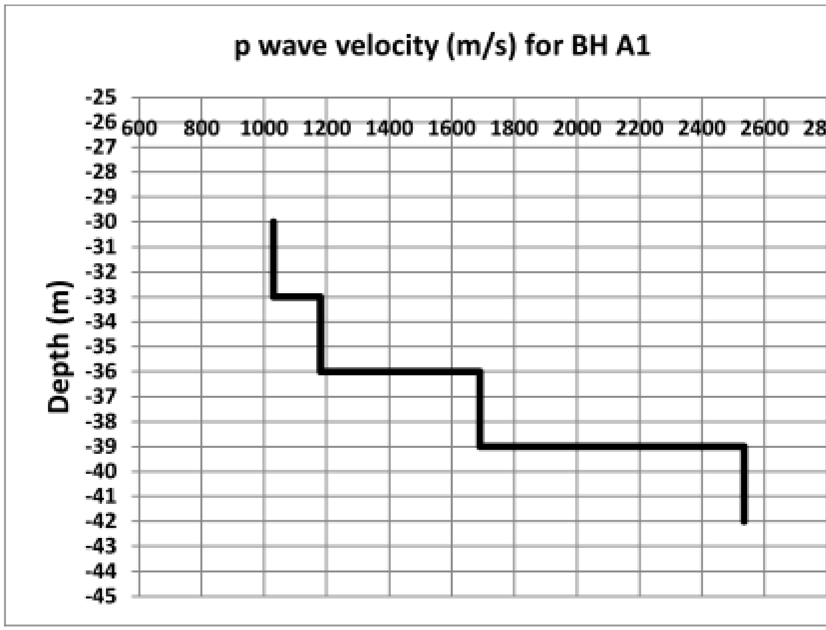
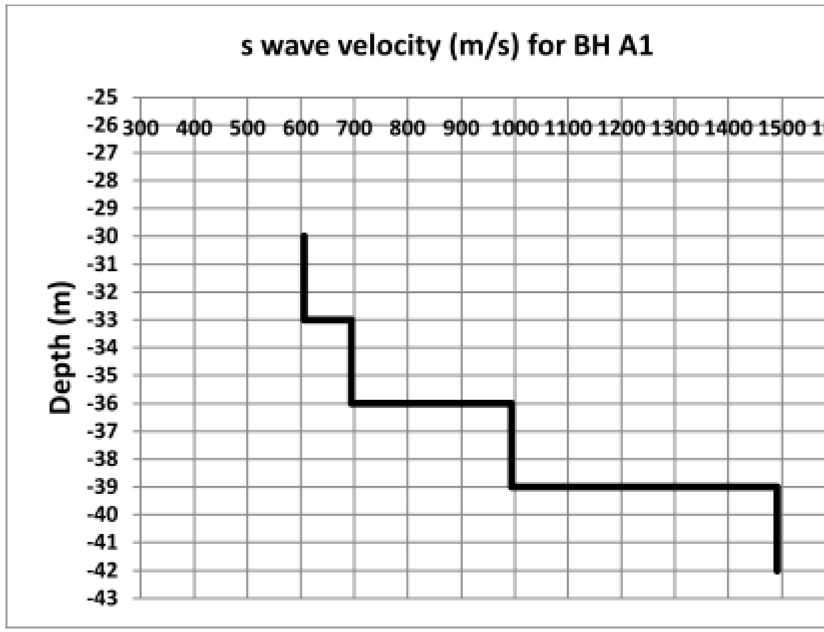
Table1: Data from BH A1 showing: Offset, depths, Ray Path (R), picked arrival time (t), p and s waves velocities and Poisson's ratio.

offset x (m)	Depth z (m)	R1 (m)	R2 (m)	Delta R (m)	t1(ms)	t2(ms)	t1(s)	t2(s)	delta t (s)	p wave (m/s)	s waves (m/s)	Poisson's ratio
3	30	30.15	33.14	2.99	22.21	25.11	0.02221	0.02511	0.0029	1030	602	0.24
3	33	33.14	36.12	2.99	25.11	27.64	0.02511	0.02764	0.00253	1181	687	0.24
3	36	36.12	39.12	2.99	27.64	29.41	0.02764	0.02941	0.00177	1690	977	0.25
3	39	39.12	42.11	2.99	29.41	30.59	0.02941	0.03059	0.00118	2535	1401	0.28
3	42	42.11										



(a)



(b)

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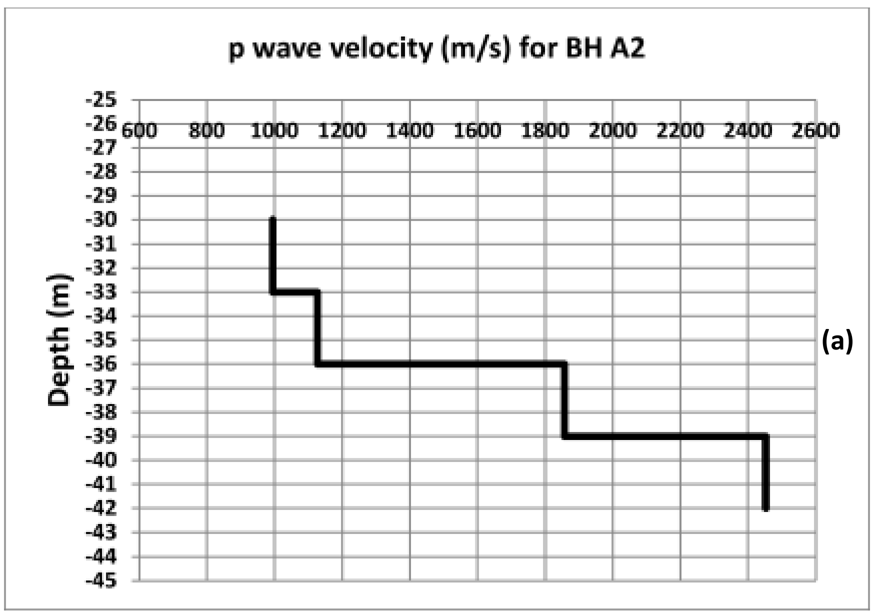
Figure 6: Interval velocity plot for Borehole A1 (BH A1), (a) p wave velocity (m/s) (b) s wave velocity (m/s)

Table2: Data from BH A2 showing: Offset, depths, Ray Path (R), picked arrival time (t), p and s waves velocities and Poisson's ratio.

offset x (m)	Depth z (m)	R1 (m)	R2 (m)	Delta R (m)	t1(ms)	t2(ms)	t1(s)	t2(s)	delta t (s)	P wave (m/s)	S waves (m/s)	Poisson's ratio
3	30	30.15	33.14	2.99	18.31	21.31	0.01831	0.02131	0.003	995	582	0.24
3	33	33.14	36.12	2.99	21.31	23.96	0.02131	0.02396	0.00265	1128	656	0.24
3	36	36.12	39.12	2.99	23.96	25.57	0.02396	0.02557	0.00161	1857	1074	0.25
3	39	39.12	42.11	2.99	25.57	26.79	0.02557	0.02679	0.00122	2452	1355	0.28
3	42	42.11	0.00									



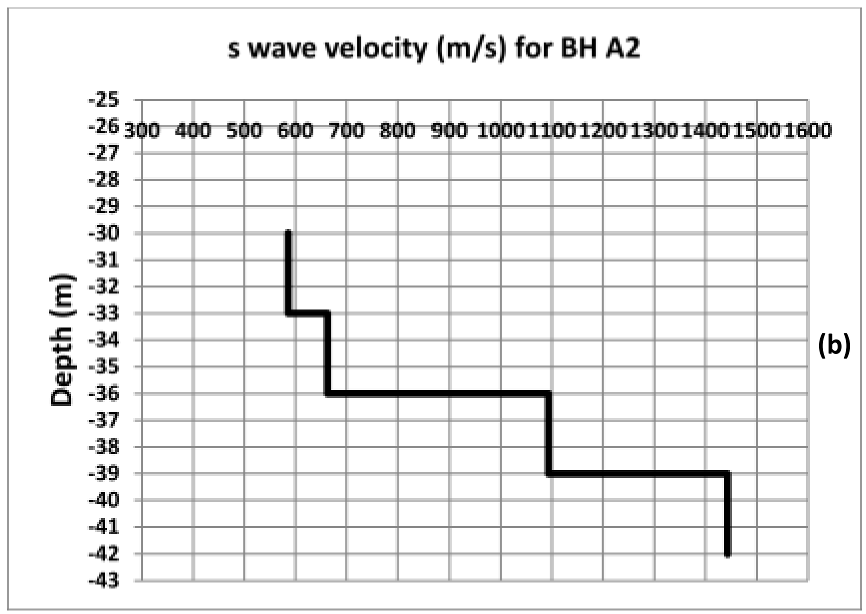


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Figure 7: Interval velocity plot for Borehole A2 (BH A2), (a) p wave velocity (m/s) (b) s wave velocity (m/s)

Table3: Data from BH B3 showing: Offset, depths, Ray Path (R), picked arrival time (t), p and s waves velocities and Poisson's ratio.

offset x (m)	Depth z (m)	R1 (m)	R2 (m)	Delta R (m)	t1(ms)	t2(ms)	t1(s)	t2(s)	delta t (s)	P wave (m/s)	s waves (m/s)	Poisson's ratio
3	30	30.15	33.14	2.99	34.20	37.1	0.0342	0.0371	0.0029	1030	602	0.24
3	33	33.14	36.12	2.99	37.10	39.71	0.0371	0.03971	0.00261	1145	666	0.24
3	36	36.12	39.12	2.99	39.71	41.68	0.03971	0.04168	0.00197	1518	877	0.25
3	39	39.12	42.11	2.99	41.68	42.87	0.04168	0.04287	0.00119	2514	1389	0.28
3	42	42.11	0.00									

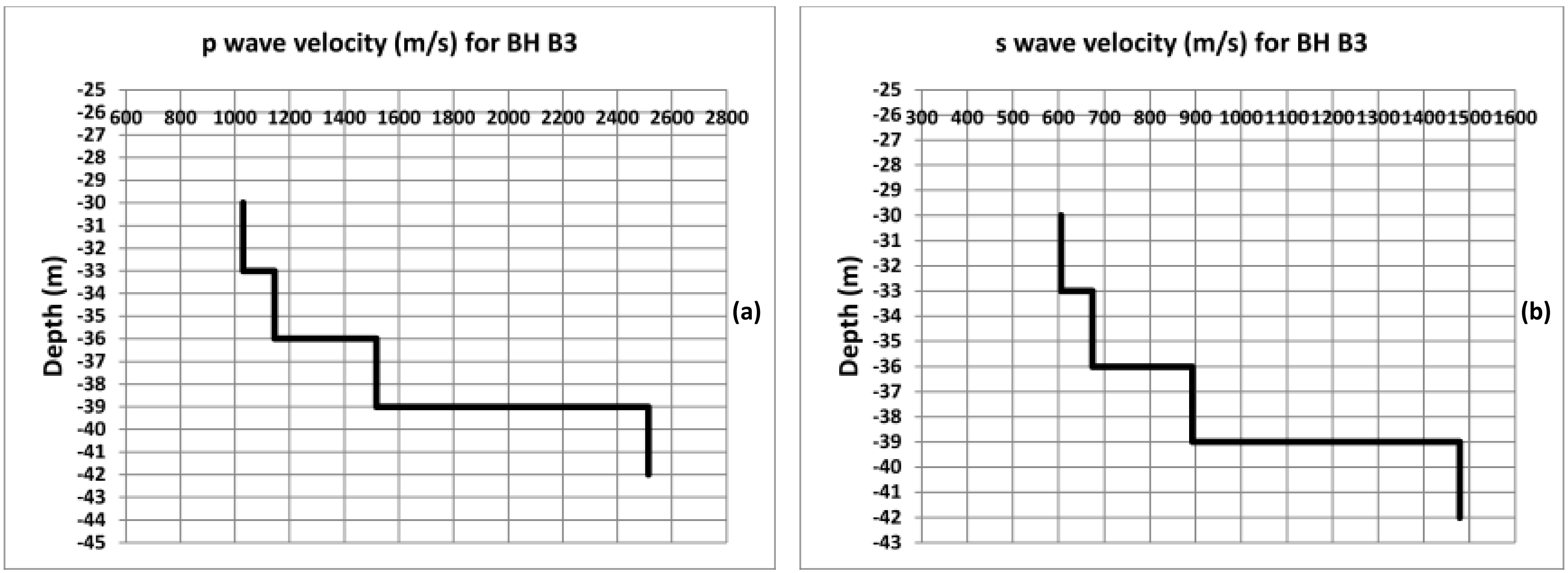

Figure 8: Interval velocity plot for Borehole B3 (BH B3), (a) p wave velocity (m/s) (b) s wave velocity (m/s)

Table4: Data from BH B4 showing: Offset, depths, Ray Path (R), picked arrival time (t), p and s waves velocities and Poisson's ratio.

offset x (m)	Depth z (m)	R1 (m)	R2 (m)	Delta R (m)	t1(ms)	t2(ms)	t1(s)	t2(s)	delta t (s)	P wave (m/s)	s waves (m/s)	Poisson's ratio
3	30	30.15	33.14	2.99	28.88	31.65	0.02888	0.03165	0.00277	1078	630	0.24
3	33	33.14	36.12	2.99	31.65	34.15	0.03165	0.03415	0.0025	1195	695	0.24
3	36	36.12	39.12	2.99	34.15	36.45	0.03415	0.03645	0.0023	1300	752	0.25
3	39	39.12	42.11	2.99	36.45	37.56	0.03645	0.03756	0.00111	2695	1489	0.28
3	42	42.11	0.00									

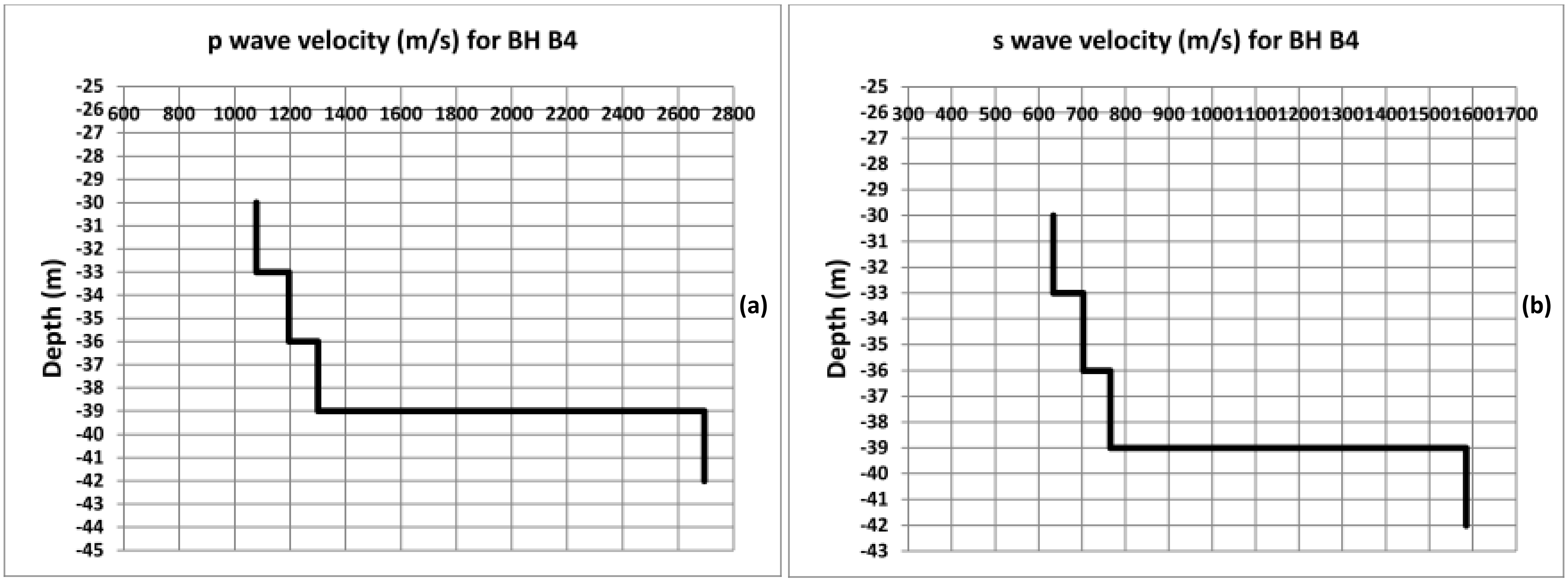

Figure 9: Interval velocity plot for Borehole B4 (BH B4), (a) p wave velocity (m/s) (b) s wave velocity (m/s)

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