ISSN: 2634 - 8853

Journal of Engineering and Applied Sciences Technology

SCIENTIFIC Research and Community

Research Article

Open Access

Evaluation of Lithological Influence on Seismic Wave Velocity in Part of Niger Delta, Nigeria

Chukwu C Ben[1]*, Ngeri A Paddy[1] and Udota S Benjamin[2]

[1]Department of Physics, Faculty of Science, Rivers State University, Nkpolu-Oroworukwo Port Harcourt, Nigeria

[2]Department of Geology, Faculty of Science, Rivers State University, Nkpolu-Oroworukwo Port Harcourt, Nigeria

ABSTRACT

This study is aimed at evaluating the influence of lithology on seismic wave velocity in part of Niger Delta. A suite of geophysical well log comprising of gamma ray, sonic and density logs in Log Ascii Standard (LAS) format from two exploratory wells (OKO 5 and OKO 7) within the study area was used for this study. Gamma ray log was used to identity and delineate the lithology into shale and sand units, seismic wave velocity was categorized into compressional wave velocity Vp and shear wave velocity Vs. The former was computed from interval transit time while the later from compressional wave velocity. The results of this study show that seismic wave velocity is very much affected by difference in the lithology of formation. Compressional wave velocity (Vp) is higher than shear wave velocity (Vs) in shale and sand lithologies in the two wells. The values of the compressional wave velocity, shear wave velocity, percentage volume of shale and percentage volume of sand ranges from 3485 to 6620m/s, 2159 to 3932m/s, 2682 to 5323m/s, 1736 to 3161m/s, 11 to 60%, 13 to 59%, 40 to 89% and 29 to 87% for the two wells respectively. The knowledge of this study can be applied in civil engineering and engineering geophysics activities like foundation for high rise buildings, dams, bridges and road construction.

***Corresponding author**

Chukwu C Ben, Department of Physics, Faculty of Science, Rivers State University, Nkpolu-Oroworukwo Port Harcourt, Nigeria.

E-mail: benedict.chidi@yahoo.com

Received: February 25, 2022; **Accepted:** March 17, 2022; **Published:** March 23, 2022

Keywords: Lithology, Seismic waves, Interval transit time, Sandstone, Shale

Introduction

Lithology is simply defined as the study of the composition and general physical characteristics or properties of a rock unit which gives distinct geologic features to such unit and distinguishes it from other rock units based on the mineralogical composition, grain size, grain shape, texture etc. The lithostratigraphic units of sedimentary rocks are the easiest to identify and distinguish due to the homogeneity of the lithological characteristics of the different layers of the rock units, classified rocks based on the lithologic chemical composition such as; quartz, feldspar, mica, dolomite etc. Other rocks are lithologically classified based on their texture. There are some other rocks classified according to the shape of the formation particles such as conglomerates and breccia, whereas some other rocks are also classified based on the particle sizes, mode of deposition and mineralogy [1-3].

Velocity is one of the primary (basic or major) petrophysical parameters used in hydrocarbon exploration and other geophysical surveys to easily determine and predict horizons, faults, facies, interfaces (strtigraphic boundaries), unconformities, geologic structures etc. The knowledge of velocity at any given depth is very important in the recognition of reflectors and refractors with dip or plane horizontal beds. In geophysical point of view, velocity is defined as the ratio of the displacement of a seismic wave or signal to the time it takes the wave or signal to travel the space between energy source and receiver. The optimization of a petroleum or gas field operations has proven successful for the effective imaging of the subsurface geology by characterizing the propagation of seismic or acoustic waves which travel through the rocks [4,5].

Reflection seismology also referred to as seismic reflection is the most widely used and well-known geophysical technique. It has been the most successful seismic method for identifying subsurface geologic conditions favourable to the accumulation of oil and gas. In reflection seismology surveys, seismic energy pulses are reflected from subsurface interfaces and recorded at near-normal incidence at the surface [6]. The depth of different geologic boundaries can be determined using the required time for the seismic wave to return to the surface and the velocity of travel. The velocity value of the wave carries information on the type of sediments or rocks. Reflection surveys are most commonly carried out in areas of shallowing dipping sedimentary sequences. In such areas velocity varies as a function of depth, due to the differing physical properties of the subsurface materials or rocks present in the individual layers [6]. As seismic waves encounter a medium with different elastic properties and density, compressional and shear waves are generated. Acoustic (seismic or sound wave) velocity is a geophysical parameter which measures the rate of change of displacement as sound wave propagates through the subsurface materials or rocks or from the source to the receiver [2]. The variation of seismic velocity with depth can be attributed to the variation in the properties of earth materials or rocks in the subsurface [7,8].

Geology of the Study Area
This research is carried out within the Niger Delta, Southern part of Nigeria in West Africa. The Niger Delta is situated along the Southern part of Nigeria on the Gulf of Guinea on the west coast of Africa. It lies within latitudes 4o-6oN and longitude 4 o -9o E. The Delta covers an area of about 259,000 sq km as shown in Figure 1 [9].

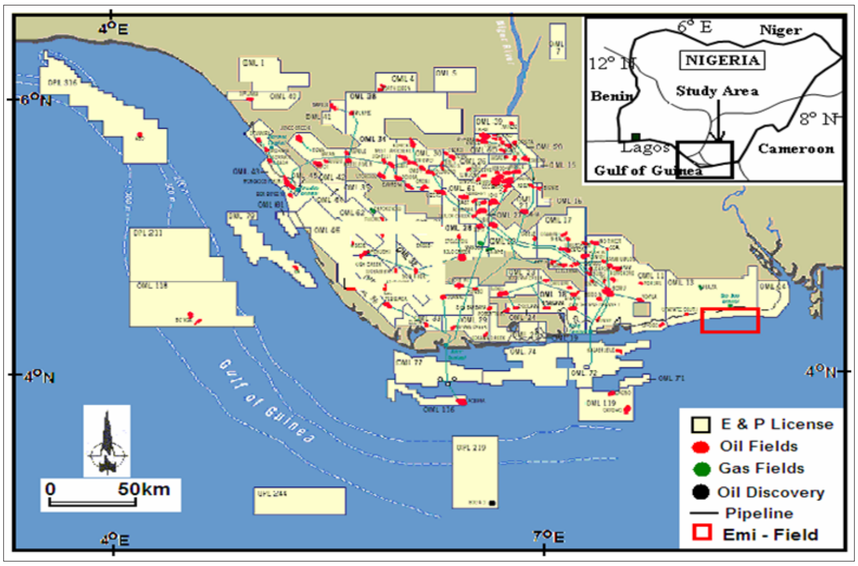

Figure 1: Map Showing Location of the Study Area [9]

Stratigraphy of the Study Area
The study area comprised of three major structural geologic formations, namely Akata, Agbada and Benin formations that indicate how the basin was formed as shown in Figure 2.

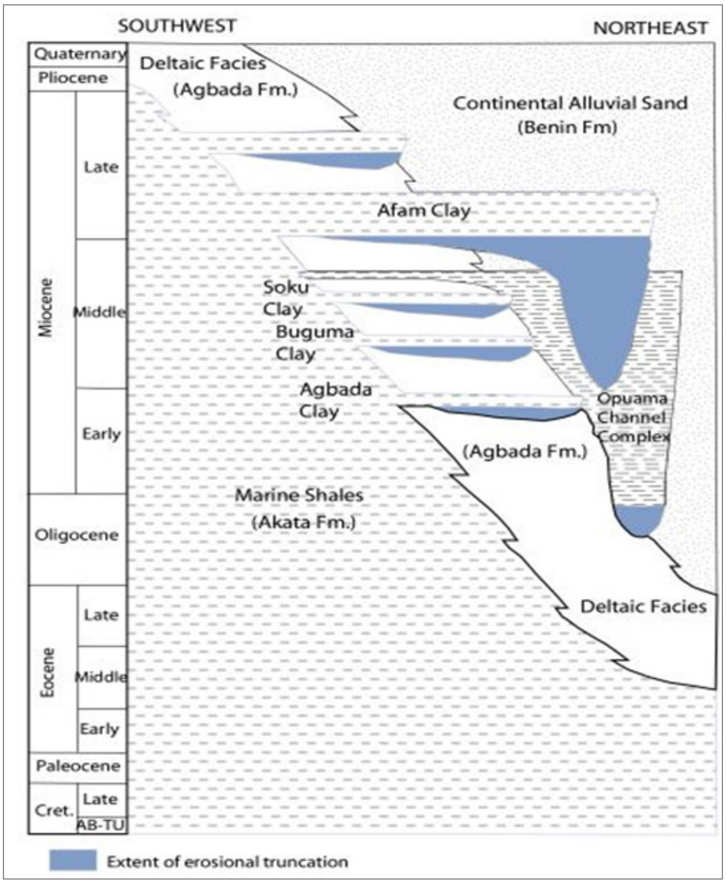

Figure 2: Stratigraphy of the Study Area [10]

Akata Formation

Akata Formation underlies the entire delta and originates from marine deposits. It is made up of minute amount of silt and clay and contains shale successions, which serves as potential source rock. Akata Formation started from Paleocene to recent, and was formed during lowstands, this condition permitted the deposition of clays and organic matter in deep waters estimated the formation to be about 21,000 feet thick and it is usually over pressured [10].

Agbada Formation

Agbada Formation is of fluvio-marine origin and it overlies the Akata Formation. Its thickness is about 3,700m consisting of intercalations of sand and shale. Its Sandstones and sands house the produced hydrocarbon. According to these hydrocarbons are entrapped by rollover anticlines associated to growth fault [11].

Benin Formation

Benin Formation is the uppermost part of the unit. It overlies Agbada Formation and consists of mainly sands and gravels, which bear fresh water stated that Benin Formation consist of alluvial sands with thickness of about 200m deposited in early Eocene to recent [12].

Materials and Method

Materials

A suite of geophysical well log (comprising gamma ray, sonic and density logs) in Log Ascii Standard (LAS) format, petrel software and microsoft excel spreadsheet are the materials used for this study.

Methods

To achieve the aim of this study, well log data set from two exploratory wells (OKO 5 and OKO 7) within the study area were used to evaluate the parameters of interest at 10m depth interval. The flowchart of the method used in this study is shown in Figure 3 and explained in the following subheadings (sub-sections).

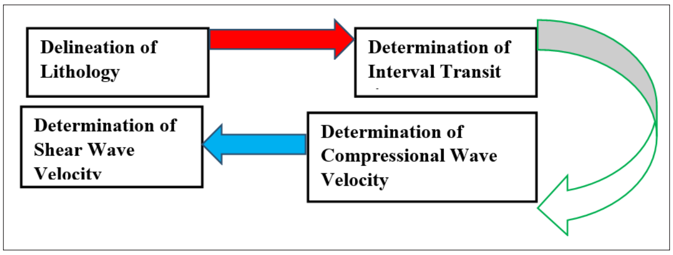

Figure 3: Flowchart of the method used

Delineation of Lithology

Gamma ray log was used to delineate the lithology into two litho-facies which are sand and shale units or strata, compute the percentage of shale and sand by volume using equations 1 to 4 according to [13]. Gamma ray log values range from 0.00 to 150.0 API, as the reading increases towards the higher values shale units are delineated whereas as the reading decreases towards the lower values sand units are delineated.

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

$$V_{sh} = 0.33(2^{2I_{GR}} - 1.0) \quad (2)$$

$$\%Shale = V_{sh} \times 100\% \quad (3)$$

$$\%Sand = 100 - \%Shale \quad (4)$$

Where I_{GR} = Gamma ray index
$\%Shale$ = Percentage volume of shale
$\%Sand$ = Percentage volume of sand
GR_{log} = Gamma ray log reading of the formation
GR_{min} = Gamma ray log reading in sand zone.
GR_{max} = Gamma ray log reading in shale zone.

Determination of Interval Transit time, Δt

Interval transit time is the time sound (seismic or acoustic) waves take to travel a certain distance in the formation [14]. It is represented as the reciprocal of the velocity of travel of travel of seismic wave and was computed from sonic log using equation 5.

$$\Delta t_{log} = \frac{1}{V_P} \quad (5)$$

Where Δt = Interval transit time in μs/ft read directly from the log
V_p = Compressional wave velocity of travel of seismic wave in m/s

Determination of Compressional Wave Velocity, Vp

Compressional wave velocity, Vp in meter per second (m/s) was computed using equation 6 obtained from equation 5.

$$V_P = \frac{1}{\Delta t_{log}} \quad (6)$$

Determination of Shear Wave Velocity, V_s

Shear wave velocity (V_s) was computed from compressional wave velocity (V_p) using empirical equations which relates shear wave velocity, Vs and compressional wave velocity V_p for shale and sand beds [15].

For shale;

$$V_S = 0.769V_P - 0.867 \quad (7)$$

For sand;

$$V_S = 0.804V_P - 0.856 \quad (8)$$

Results and Discussion

Results

Data Presentation

The numerical values obtained from the digitization of the well log from the two wells and computation of the various parameters required for this study are presented in Tables 1 and 2 which show the selected depth values in metre(m), gamma ray log values in American Petroleum Institution (API) unit, interval transit time in micro seconds per feet (μs/ft), percentage volume of shale (% shale), percentage volume of sand (% sand), compressional wave velocity (V_p) in meter per second (m/s) and shear wave velocity, V_s in meter per second (m/s) for the two wells.

Cross Plot Analysis

Figures 4 to 15 shows the cross plots of compressional wave velocity (V_p) versus percentage volume of shale (%shale), compressional wave velocity (V_p) versus percentage volume of sand (%sand), shear wave velocity (V_s) versus percentage volume of shale (%shale), shear wave velocity (V_s) versus percentage volume of sand (%sand), depth versus compressional wave velocity (V_p) and depth versus shear wave velocity (V_s) for the two wells.

Table 1: Showing Depth, Interval Transit Times, GR(API), %Shale and %Sand, Compressional Wave Velocity (Vp) and Shear Wave Velocity(Vs) Relationship for Well OKO 5

S/N	Depth (m)	Δt (μs/ft)	GR (API)	%Shale	%Sand	V_p(m/s)	V_s (m/s)
1	1216	60.23	48	32	68	5062	4070
2	1226	76.40	22	14	86	3991	3208
3	1235	75.08	22	14	86	4061	3264
4	1244	77.47	23	14	86	3936	3164
5	1253	66.07	26	17	83	4614	3710
6	1262	75.54	73	48	52	4036	3245
7	1271	81.24	26	17	83	3753	3017
8	1280	77.22	55	36	64	3948	3174
9	1290	77.18	26	17	83	3950	3176
10	1299	76.97	29	19	81	3961	3184
11	1308	76.21	29	19	81	4001	3216
12	1317	77.38	26	16	84	3940	3168
13	1326	67.79	70	46	54	4498	3616
14	1335	87.47	77	51	49	3485	2682
15	1345	78.18	24	15	85	3900	3135
16	1354	78.81	24	15	85	3868	3110
17	1363	78.22	33	21	79	3898	3133
18	1372	75.03	21	13	87	4063	3267
19	1381	72.51	21	13	87	4205	3380
20	1390	75.54	22	14	86	4036	3245
21	1399	74.90	19	12	88	4071	3273
22	1409	73.14	21	14	86	4168	3351
23	1418	74.09	23	15	85	4115	3308
24	1427	76.21	28	18	82	4000	3216
25	1436	69.75	43	28	72	4371	3514
26	1445	74.09	23	15	85	4115	3308
27	1454	69.36	20	13	87	4396	3534
28	1463	71.33	22	14	86	4274	3436
29	1473	71.33	21	13	87	4274	3436
30	1482	77.89	29	19	81	3914	3147
31	1491	69.52	17	11	89	4386	3526
32	1500	69.75	21	13	87	4371	3514
33	1509	71.49	31	20	80	4265	3429
34	1518	76.45	29	19	81	3988	3206
35	1527	72.12	21	14	86	4227	3399
36	1537	70.70	24	15	85	4312	3467
37	1546	66-37	19	12	88	4594	3693
38	1555	69.28	18	11	89	4400	3538
39	1564	68.66	32	21	79	4440	3570
40	1573	72.93	26	17	83	4180	3361
41	1582	68.77	33	21	79	4433	3564
42	1591	70.40	27	17	83	4331	3482
43	1601	65.76	26	17	83	4636	3728
44	1610	71.79	28	18	82	4247	3414
45	1619	67.24	24	16	84	4534	3645
46	1628	71.03	71	47	53	4292	3451
47	1637	72.62	36	23	77	4198	3375

48	1646	67.96	21	14	86	4486	3606
49	1655	69.49	24	16	84	4387	3527
50	1665	68.19	20	13	87	4471	3595

Table 2: Showing Depth, Interval Transit Times, GR(API), %Shale and %Sand, Compressional Wave Velocity (Vp) and Shear Wave Velocity(Vs) Relationship for Well OKO 7

S/N	Depth (m)	Δt(μs/ft)	GR (API)	%Shale	%Sand	V_p (m/s)	V_s (m/s)
1	1372	141.18	27	17	83	2159	1736
2	1381	136.72	27	18	82	2230	1792
3	1390	130.36	83	55	45	2339	1799
4	1399	123.71	26	17	83	2464	1981
5	1409	124.37	25	16	84	2451	1970
6	1418	119.11	40	26	74	2560	2057
7	1427	118.53	26	17	83	2572	2068
8	1436	122.55	26	17	83	2488	2000
9	1445	114.98	25	16	84	2652	2131
10	1454	128.72	35	23	77	2369	1904
11	1463	120.35	30	20	80	2533	2036
12	1473	117.92	24	16	84	2585	2078
13	1482	120.44	23	15	85	2531	2035
14	1491	120.48	24	16	84	2531	2034
15	1500	120.28	30	20	80	2535	2037
16	1509	125.30	25	16	84	2433	1956
17	1518	119.84	20	13	87	2544	2045
18	1527	118.82	24	15	85	2566	2063
19	1537	107.42	28	18	82	2838	2282
20	1546	117.24	24	15	85	2600	2090
21	1555	117.10	26	17	83	2604	2093
22	1564	109.90	30	19	81	2774	2230
23	1573	111.92	23	15	85	2724	2190
24	1582	123.67	75	50	50	2465	1982
25	1591	116.68	62	41	59	2613	2100
26	1601	112.17	33	21	79	2718	2185
27	1610	118.22	34	22	78	2579	2073
28	1619	94.35	21	13	87	3231	2598
29	1628	122.36	23	15	85	2492	2003
30	1637	110.97	26	17	83	2747	2208
31	1646	114.13	106	71	29	2671	2055
32	1655	114.28	24	16	84	2668	2144
33	1665	113.90	80	53	47	2677	2059
34	1674	114.75	27	18	82	2657	2136
35	1683	109.43	37	24	76	2786	2240
36	1692	120.08	65	43	57	2539	2041
37	1701	108.48	79	52	48	2810	2162
38	1710	131.31	75	50	50	2322	1866
39	1720	122.55	37	24	76	2488	2000
40	1729	122.15	27	18	82	2496	2006
41	1738	117.90	29	19	81	2586	2079
42	1747	119.45	43	28	72	2552	2052
43	1756	118.04	61	40	60	2583	2076

44	1765	125.04	81	54	46	2438	1960
45	1774	116.48	26	17	83	2617	2104
46	1784	115.45	30	19	81	2641	2123
47	1793	118.72	46	30	70	2568	2064
48	1802	106.33	81	54	46	2867	2206
49	1811	122.33	63	42	58	2492	2003
50	1820	107.81	32	21	79	2828	2273

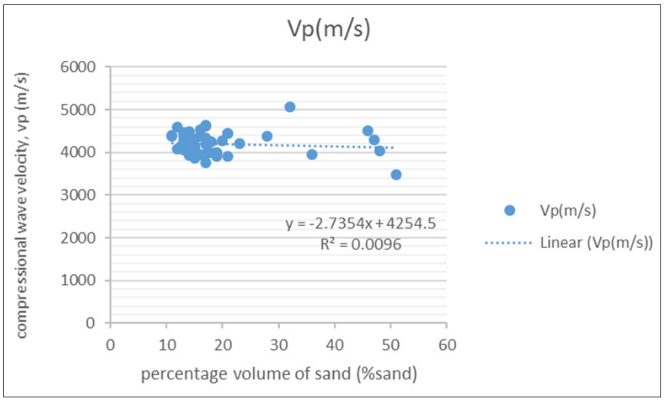

Figure 4: Compressional Wave Velocity (Vp) versus Percentage Volume of Shale (%Shale) for Well OKO 5

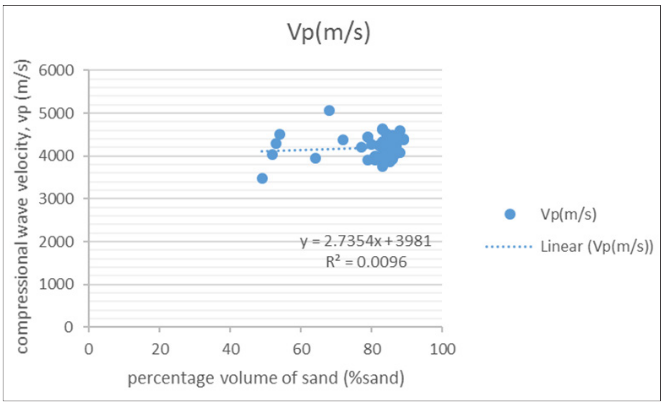

Figure 5: Compressional Wave Velocity (Vp) versus Percentage Volume of Sand (%Sand) for Well OKO 5

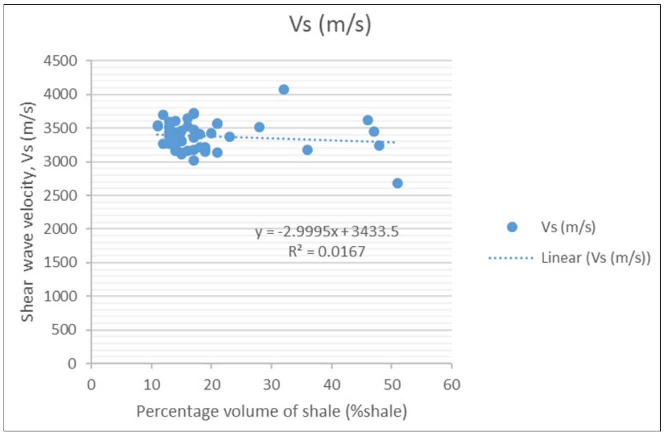

Figure 6: Shear Wave Velocity (Vp) versus Percentage Volume of Shale (%Shale) for Well OKO 5

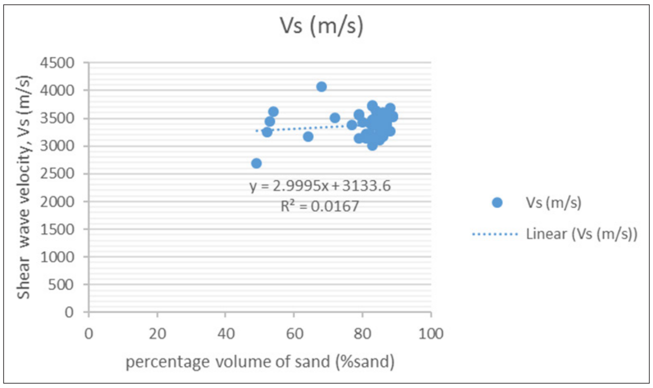

Figure 7: Shear Wave Velocity (Vp) versus Percentage Volume of Sand (%Sand) for Well OKO 5

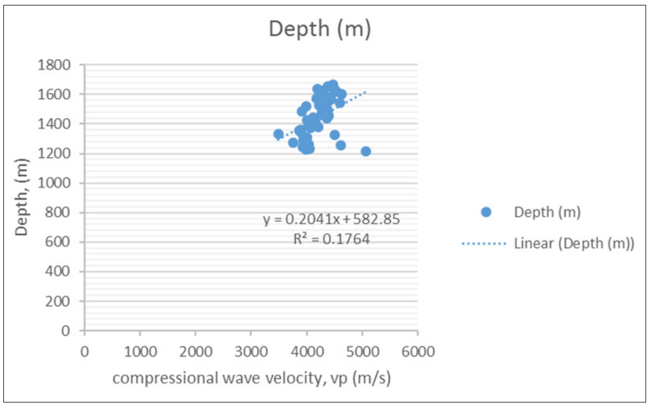

Figure 8: Depth versus Compressional Wave Velocity (Vp) for Well OKO 5

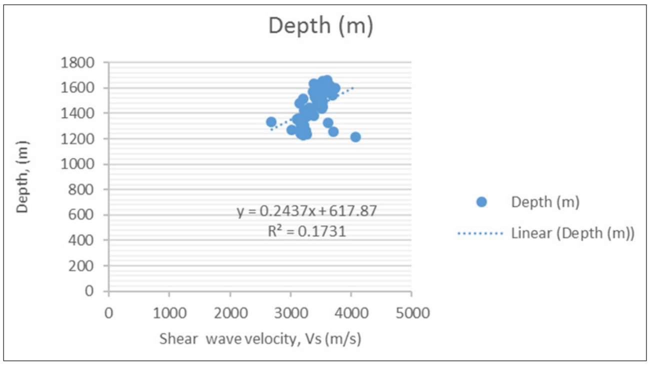

Figure 9: Depth versus Shear Wave Velocity (Vs) for Well OKO 5

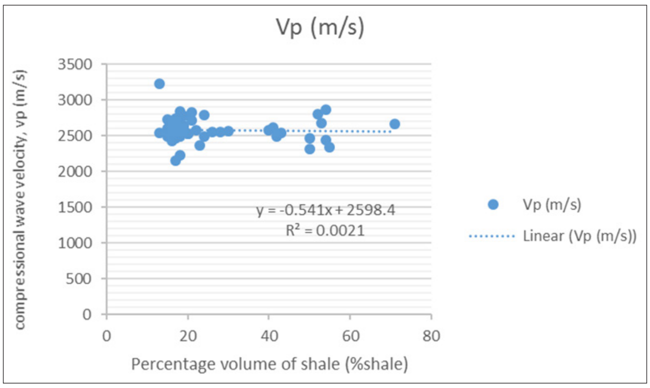

Figure 10: Compressional Wave Velocity (Vp) versus Percentage Volume of Shale (%Shale) for Well OKO 7

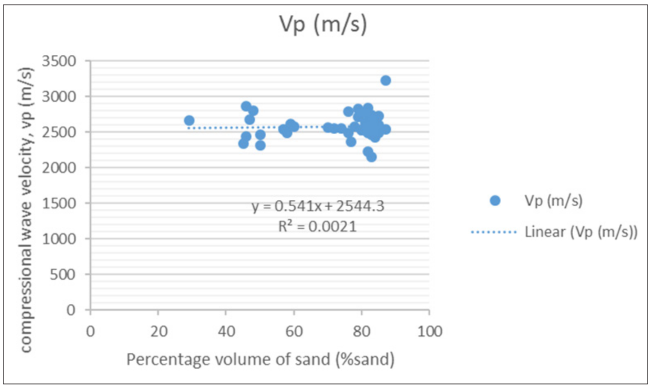

Figure 11: Compressional Wave Velocity (Vp) versus Percentage Volume of Sand (%Sand) for Well OKO 7

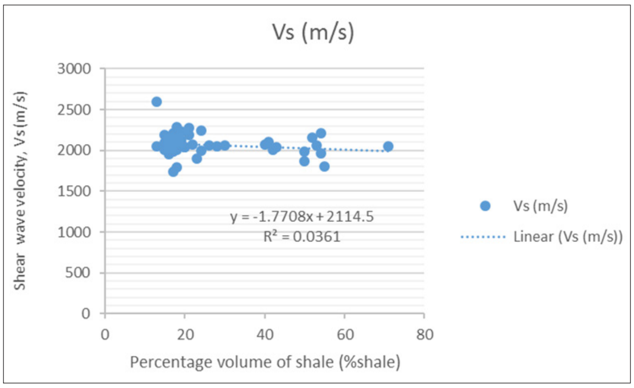

Figure 12: Shear Wave Velocity (Vp) versus Percentage Volume of Shale (%Shale) for Well OKO 7

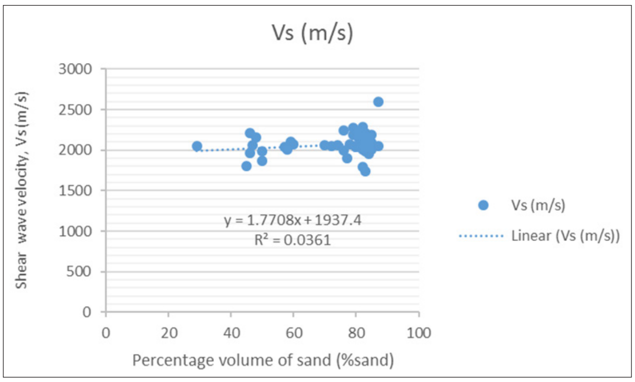

Figure 13: Shear Wave Velocity (Vp) versus Percentage Volume of Sand (%Sand) for Well OKO 7

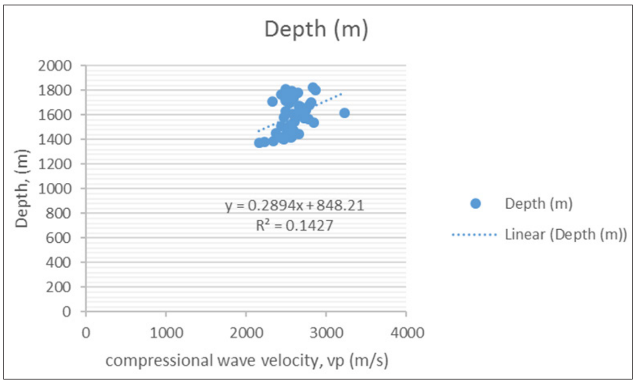

Figure 14: Depth versus Compressional Wave Velocity (Vp) for Well OKO 7

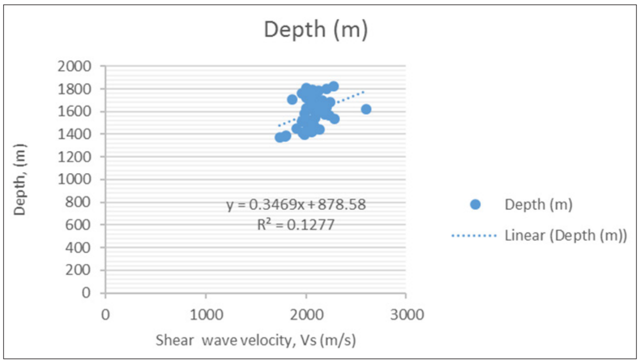

Figure 15: Depth versus Shear Wave Velocity (Vs) for Well OKO 7

Discussion

Seismic Wave Velocity

Seismic wave velocity is simply the rate at which seismic waves (acoustic or sound waves) travel through the subsurface materials (like rocks and fluids). It can also be said to mean the rate at which elastic waves propagate through the earth material, it could be body or surface waves. Seismic wave velocity is affected or controlled by numerous geologic factors like material composition, porosity, temperature, pressure, pore geometry, pore fluid, density etc [16].

Compressional Wave Velocity (Vp) versus Percentage Volume of Shale (% Shale)

There is a gradual decrease in compressional wave velocity (Vp) as percentage volume of shale (%shale) increases in the two wells (OKO 5 and OKO 7).

Compressional Wave Velocity (Vp) versus Percentage Volume of Sand (%Sand)

There is a linear increase in both compressional wave velocity (Vp) and percentage volume of sand (%sand) in the two wells.

Shear Wave Velocity Vs versus Percentage Volume of Shale (%Shale)

There is a progressive decrease in shear wave velocity (Vs) as percentage volume of shale (%shale) increases in the two wells.

Shear Wave Velocity (Vs) versus Percentage Volume of Sand (%Sand)

Shear wave velocity (Vs) increases gradually as the percentage volume of sand (%sand) increases in all the wells.

Depth versus Seismic Wave Velocity

There is a general increase in both compressional wave velocity (Vp) and shear wave velocity (Vs) with depth in the two wells.

Conclusion

Under ideal situation in a homogeneous and isotropic formation, seismic wave velocity increases with depth of burial or age of rocks it was observed from the results of this study that

i. Seismic wave velocities (compressional and shear wave velocities) increases with depth but varies at some points due to the change in lithology, inhomogeneity and anisotropicity of the earth materials (rocks and fluids).
ii. Compressional wave velocity (Vp) is greater or higher than shear wave velocity in shale lithology.
iii. Compressional wave velocity is greater or higher than shear wave velocity in sand lithology.
iv. Compressional wave velocity moves faster than shear wave velocity.
v. In conclusion, from the results of and observations made from this study, there is lithological influence on seismic wave velocity (compressional and shear waves velocities) and this can give useful information about different earth or subsurface materials and, their physical properties as well as during the design and construction of high rise buildings, bridges, roads etc.

References

1. Selley RC (1978) Concept and methods of substance facies Analysis. Imperial college University Press, London.
2. Sheriff RE (1991) Encyclopacdic Dictionary of Exploration Geophysics. 3rd Edition. Society of Exploration Geophysics, USA.
3. Plummer CC, McGreary D (1993) Physical Geology. 6th Ed. Wm. C. Brown Publishers, England.
4. Tamunobereton-ari I, Omubo-Pepple VB, Uko ED (2011) Determination of the variability of seismic velocity with lithology in the South-Western part of Niger Delta Basin of Nigeria using Well Logs. Journal of Basic Applied Science Research 7: 700-705.
5. Telford W, Geldart L, Sheriff R, Keys D (1986) Applied Geophysics, Cambridge University Press, New York.
6. Kearey P, Brooks M, Hill I (2002) An Introduction to Geophysical Exploration. Third Edition. Blackwell Science Ltd.
7. Plona TJ, Johnson DL (1984) Acoustic Properties of porous systems phenomenological description in Physics and Chemistry of Porous medium. Edited by D. L.
8. Judson DR, Lin J, Schultz PS, Scherwood JWC (1980) Depth Migration after stack. Geophysics 45: 376-393.
9. Short KC, Stauble AJ (1967) Outline of Geology of Niger Delta. Association of American Petroleum Geologist Bulletin 51: 761-779.
10. Doust H, Omatsola E (1989) Niger Delta, in Divergent Passive Margin Basins, J.D. Edwards and P.A. Santogrossi, (eds.), American Association of Petroleum Geologists Memoir 48: 201-238.
11. Doust H, Omatsola E (1990) Niger Delta, in, Edwards, J. D. and Santogrossi, P.A. (eds.), Divergent/Passive Margin Basins, AAPG Memoir Tulas. American Association of Petroleum Geologists 48: 239-248.
12. Avbovbo AA (1978) Tertiary Lithostratigraphy of the Niger Delta. American Association of Petroleum Geologists Bulletin, 62: 295-306.
13. Schlumberger (2000) Basic Well Log Interpretation. Schlumberger Educational Services.
14. El-Werr A, Shebl A, El-Rawy A, Al-Gundor N (2017) Pre-drill pore pressure prediction using seismic velocities for prospect areas at BeniSuef Oil Field, Western Desert, Egypt. Journal of Petroleum Exploration and Production Technology 7: 1011-1021.
15. Castagna JP, Greenberg ML (1993) Shear Wave Velocity Estimation in Porous Rocks. Theoretical Formulation, Preliminary Verification and Applications. Geophysics Prospecting. 40: 195-209.
16. McCormack MD, Dunbar JA, Sharp WW (1985) A case study of stratigraphic interpretation using shear and compressional seismic data. Geophysics. 49: 509-520.