Asian Journal of Environment & Ecology
2(1): 1-10, 2017; Article no.AJEE.31667

SCIENCEDOMAIN *international*
www.sciencedomain.org

Prediction of Compressional Wave Velocity and Formation Bulk Density from Electrical Resistivity in the Sub-surface of South-East and South-South Nigeria

U. K. Afegbua[1*], F. O. Ezomo[2], O. D. Osahon[2], J. Braimoh[3], M. S. Tsalha[1], H. T. Sanni[1], D. Duncan[1], E. S. Usifoh[1], O. S. Abimaje[1] and A. O. Biose[4]

[1]Centre for Geodesy and Geodynamics, Toro, Bauchi State, Nigeria.
[2]Department of Physics, University of Benin, Benin City, Edo State, Nigeria.
[3]Department of Science Laboratory Technology, Auchi Polytechnic, Auchi, Edo State, Nigeria.
[4]Energy Commission of Nigeria, Energy Centre, University of Benin, Benin City, Edo State, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author UKA designed the study. Authors UKA, FOE, ODO, JB, HTS, DD, ESU and AOB participated in the field investigations and data collections. Authors UKA, FOE, ODO, JB, HTS, ESU and AOB performed the data processing and analysis. Authors FOE, ODO, UKA, JB, DD and AOB were involved in sites selections and setting up of field instruments. Author UKA wrote the protocol and the first draft of the manuscript. Authors UKA and FOE managed the analyses of the study. Authors UKA, HTS, ESU, JB and AOB managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEE/2017/31667
Editor(s):
(1) Sylwia Myszograj, Department of Water Technology, Sewage and Wastes, University of Zielona Gora, Poland.
Reviewers:
(1) A. Rahmouni, Mohammed V University, Rabat, Morocco.
(2) Nordiana Mohd Muztaza, Universiti Sains Malaysia, Pulau Pinanag, Malaysia.
Complete Peer review History: http://www.sciencedomain.org/review-history/17813

Original Research Article

Received 19th January 2017
Accepted 7th February 2017
Published 13th February 2017

ABSTRACT

The aim of this study is essentially to predict compressional wave velocity (Vp) from electrical resistivity (R) observations in parts of the South-South and South-East Nigeria; and also to compute the formation density (*p*) of consolidated layers in the subsurface and subsequently establish a relationship between *p* and Vp for the entire region covered. The known formation and observed

**Corresponding author: E-mail: umakad@yahoo.com;*

resistivity from field surveys formed the baseline data for this study. The methodology involved the collection of known and observed values of electrical resistivity in the study area. Using relevant empirical equations as initial models, the Vp and *p* were computed and a relationship between Vp and R was established using regression analysis. The predicted Vp and the corresponding *p* were correlated with results obtained from earlier studies in the area. The model linking the density (*p)* and compressional velocity (Vp) developed in this study would be useful for future Vp prediction and density computation in the South-South and South-East regions given resistivity values of interest. Findings from this research would also be useful for the estimation of some petrophysical parameters especially in the South-South region.

Keywords: Electrical resistivity; P-wave velocity; formation density; South-East and South-South Nigeria; petrophysical parameters.

1. INTRODUCTION

At different points on the Earth sub-surface, there exist different electrical properties relative to different geological materials or rocks. The different geological foundations are a function of a number of factors, which include variations in water contents, dissolved ions in water and material make-up [1]. It is therefore, possible to acquire and classify zones with different electrical properties using resistivity investigations. The science of rock physics accounts for the link between geophysical observations and the core physical properties of rocks such as composition, porosity, and pore fluid content [2]. Petrophysics deals with the technical evaluation of laboratory data and downhole measurements for reservoir properties such as shale-volume fraction, porosity φ, permeability k, etc.

Several Resistivity investigations have been carried out in the South-East and South-South Nigeria; to explore for Groundwater as in [1,3,4]; for subsurface characterization e.g bedrock in [4,5,6,7,8]; and for foundation studies or/and Engineering site evaluation as in [9,10,11,12,13,10]; and road failue [12], among others.

Evidence abound that electrical resistivity and compressional wave velocity in heterogeneous near-surface materials can be correlated if the both parameters are known [14]. In the case when one of the parameters is unknown, the relationship between them can be used to derive the other [15]. Electrical and seismic relationship in the subsurface as contained in [15], was a subject of debate as correlation between anomalous electrical conductivities and low velocities are increasingly observed in non-invasive deep crustal studies [15]. Resistivity and velocity are both functions of porosity and this is also the unifying assumption in non-invasive experiments focusing on correlating deep crustal data of variable quality from approximately coincident regional studies [14]. The need to study varied near-surface materials for any such relationships especially as this may have implications for improved structural, petrophysical and environmental characterizations and for the development of algorithms for effective joint multidimensional interpretation of electrical and seismic field data [14].

The compressional velocities with geological time and depth of burial of the rock were predicted in [15]. In another study, Gardner introduced relation of density and P-wave velocity [16]. Given the values of velocity and density of the deep or near sub-surface materials therefore, the porosity and other petrophysical parameters of the medium can be estimated. In the same vein, if P-wave velocities are well predicted and knowing the porosity information of the area, shear wave velocities could also be obtained. Both the P and S-waves velocities are important properties for improved local seismic events location and seismic hazard studies. From resistivity data, the synthetic P-wave velocity log can be found using Faust's empirical relation [15]. Synthetic P-wave velocity log used as input data in order to aims estimated density using [16] empirical relationship. Finally, porosity log can be estimated from density. The values of resistivity and depth of consolidated layer from geophysical surveys might be shallow or very deep; depending on the burial of compacted sedimentary rocks.

The aim of this study therefore is to predict the compressional wave velocity and formation density in parts of the South-East and South-South Nigeria, using resistivity values obtained at the consolidated sub-surface layers; establish an empirical model linking the formation bulk density and compressional velocity for the region covered; and subsequently derive some petrophysical parameters in parts of the study area.

1.1 Location and Geology of the Study Area

The study area comprising the South-East and South-South Nigeria, as enclosed by a rectangle in the lower part of Fig. 1. The study area is accessible through network of roads and well developed footpaths. The three major litho-petrological components of Nigeria geology are the Basement Complex that is Precambrian in age, Younger Granites comprise several Jurassic magmatic ring complexes centered on Jos and other parts of north-central Nigeria, and 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, ([18,17]) and as shown in Fig. 1.

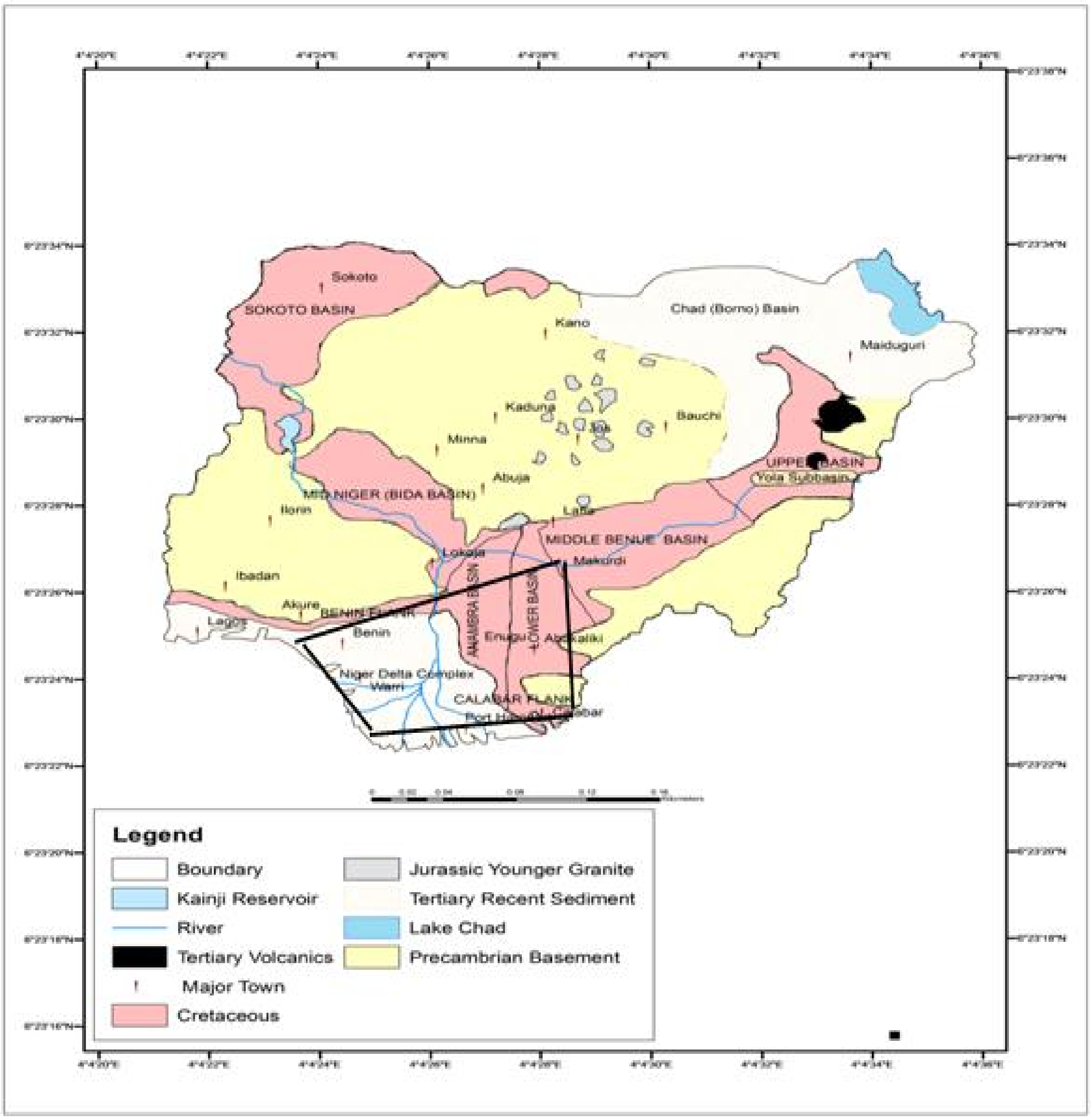

Fig. 1. Geological map of Nigeria (Modified after: [17])

The oldest sedimentary rocks in the south eastern Nigeria is the Asu river group (Albian) which comprise of sandstone, shales and lime stones, and these sediments lay unconformably on the Precambrian basement of granites, and biotite gneisses [19]. Sedimentation in the Anambra Basin commenced with the Early Campanian – Early Maastrichtian of the Enugu and Nkporo Formations (lateral equivalents) which consist of a sequence of bluish to dark grey shale and mudstone locally with sandy shales, thin sandstones and shelly limestone beds [19]. The Asu River Group sediments in the Lower Benue Trough comprises predominantly of shales with localized sandstones, siltstones and limestones [18]. There are also extrusive and intrusive material of the Abakaliki Formation in the Abakaliki area and the Mfamosing Limestone in the Calabar Flank [20]. Down dip, towards the Niger Delta, the Akata Shale and the Agbada Formation constitute the Paleocene equivalents of the Anambra Basin [19].

The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and southwestern Cameroon. The northern boundary is the Benin flank--an east-northeast trending hinge line south of the West Africa basement massif. The northeastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east-south-east by the Calabar flank--a hinge line bordering the adjacent Precambrian. Shallow marine clastics were deposited farther offshore and, in the Anambra basin, are represented by the Albian-Cenomanian Asu River shale, Cenomanian-Santonian Eze-Uku and Awgu shales, and Campanian/Maastrichtian Nkporo shale, among others [21,22]. The distribution of Late Cretaceous shale beneath the Niger Delta is unknown. The Tertiary section of the Niger Delta is divided into three formations, representing prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios. The type sections of these formations are summarized in a variety of papers (e.g. [23,24,25]).

In the Eocene, the coastline shape became convexly curvilinear, the longshore drift cells switched to divergent, and sedimentation changed to being wave-dominated [22]. At this time, deposition of paralic sediments began in the Niger Delta Basin proper and, as the sediments prograded south, the coastline became progressively more convex seaward.

Deposition of the overlying Agbada Formation, the major petroleum-bearing unit, began in the Eocene and continues into the Recent. The formation consists of paralic siliciclastics over 3700 meters thick and represents the actual deltaic portion of the sequence. The clastics accumulated in delta-front, delta-topset, and fluvio-deltaic environments. In the lower Agbada Formation, shale and sandstone beds were deposited in equal proportions, however, the upper portion is mostly sand with only minor shale interbeds. The Agbada Formation is overlain by the third formation, the Benin Formation, a continental latest Eocene to Recent deposit of alluvial and upper coastal plain sands that are up to 2000 m thick [23].

2. MATERIALS AND METHODOLOGY

The bulk of available resistivity data collected from previous studies in the study area formed the baseline data for this study. Resistivity observations were also obtained through geophysical surveys in parts of South-East and South-South, Nigeria. The parameters of interest are the formation resistivity values acquired from the compacted layers in the subsurface, where the P-wave velocity value is expected to be highest.

The resistivity (*p*) of a consolidated layer and the P-wave velocity (*Vp*) are related by some formulae, which include:

$$Log\ 10\ p = mLog10\ \mathrm{Vp} + c \quad (1)$$

with the respective constants *m* and *c* having different signs in unconsolidated and consolidated materials [14]. [15] found an empirical formula for velocity in terms of the depth of burial Z and the formation resistivity R as shown in equation 2:

$$V_p = a(RZ)^{\frac{1}{6}} \quad (2)$$

Here, V_p is the P-wave velocity and R, the resistivity of the consolidated layer at depth Z, while a is a constant which can be neglected or assigned 0.23 value in [16]. For a shallow subsurface investigation, equation 2 could be reduced so that the one sixth power is negligible. There exists two approaches of deriving the density of the layer using the values of P-wave velocity derived from equation 2. One of the approaches is the commonly used Gardner's equation [16]. Gardner's equation empirically derived values from a wide range of sedimentary rocks and written as:

$$\rho = aV_p^b \tag{3}$$

where: ρ = formation density, Vp = P-wave velocity, a = 0.23 and another constant, b = 0.25 ([16]). In this study, the constants 'a' and 'b' were assigned 0.01 and 0.70 values respectively.

Using equation 2, the values of the compressional wave velocities were computed using known values of formation resistivity. The density of the medium was also evaluated using equation 3. With the resistivity and density, and adopting regression analysis, a model was established using equation 1.

The total porosity of a formation is given by equation 4, [26].

$$\phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \tag{4}$$

Where ρ_{ma} is the matrix density; ρ_f is fluid density and ρ_b is the formation bulk density from the study. Porosity is defined as the percentage of voids to the total volume of rock [27].

In order to test the reliability of the predicted P-wave velocities using the known resistivity values, P-wave velocities computed from resistivity data acquired through field work were correlated with some known P-waves velocities in some selected sites of the study area [28,29,30]. The resistivity data were carefully collected cutting across the study area, with different sedimentary rocks. The Vp and density for the States of Edo, Ebonyi, Anambra and Cross Rivers in the study area were at first instance, computed to test the approach adopted for this research. The values of Vp and density for the entire study area were derived. The seismic velocity and density computed at the consolidated layers in the sub-soil were correlated to establish a relationship (model) between them. Using the computed formation bulk density, the porosity of some sites in the South-South region were equally estimated using log data.

3. RESULTS AND DISCUSSION

Results of resistivity observations from surveys in parts of the study area are presented in Tables 1 to 4. The areas covered are Cross Rivers and Akwa Ibom states, Edo and Delta states, Rivers and Bayelsa States, and Anambra States. Constants 'a' and 'b' could be assumed as unity or assigned values using the Gardner's equation [16]. These constants have different values for consolidated and unconsolidated layers. However, the interest in this study was the consolidated layers.

Table 5 presented results of the predicted compressional wave velocities (Vp) and formation densities (*p*) using over 400 values of known electrical resistivity values from literatures and surveys in this study. The log10Vp and Log10 P were used to establish the model (equation 5) for the entire region. Using equation 5, P-wave velocity can be predicted given information of the formation density at the consolidated or unconsolidated layers. Most values of the predicted P-wave velocities for the study area, are well correlated with those obtained in ([31,28,29,30] etc.) in the same region. With the knowledge of P-wave velocity as predicted, the shear wave velocity of an area could also be estimated using the model in [31].

Table 1. Resistivity (R), depth of consolidated layer (Z), predicted P-wave velocity (Vp) for each area and the derived formation density of consolidated layer (*p*) in some selected sites in Cross Rivers and Akwa Ibom States

R (Ωm)	Z (m)	a	Vp (m/s)	b	*p* (kg⁄m3)
4830.9902	17.3	0.01	835.7613	0.7	1.1103441
7314.2151	35.8	0.01	2618.489	0.7	2.4696507
12474.436	22.5	0.01	2806.748	0.7	2.5926411
4344.7	19.1	0.01	829.8377	0.7	1.1048294
8591.6519	15.8	0.01	1357.481	0.7	1.5592424
3894.8472	43.2	0.01	1682.574	0.7	1.812099

Table 2. Resistivity (R), depth of consolidated layer (Z), P-wave velocity (Vp) and formation density of consolidated layer (*p*) in some selected sites in Anambra States

R (Ωm)	Z (m)	a	Vp (m/s)	b	*p* (kg/m3)
2162.7669	14.2	0.01	307.1129	0.7	0.962836
13574.217	5.21	0.01	707.2167	0.7	1.186085
4915.8121	51.1	0.01	2511.98	0.7	3.159562
152798.32	2.5	0.01	3819.958	0.7	0.635269
3578.1995	87.2	0.01	3120.19	0.7	3.333398
3649.1955	89.5	0.01	3266.03	0.7	3.899719
3882.8082	56.3	0.01	2186.021	0.7	2.251696
15414.559	114.5	0.01	17649.67	0.7	3.398152
59008.963	58.8	0.01	34697.27	0.7	3.344245
29232.406	69.4	0.01	20287.29	0.7	3.258516
36542.012	51.7	0.01	18892.22	0.7	2.696489
61314.928	48.7	0.01	29860.37	0.7	3.023442
35835.155	67.9	0.01	24332.07	0.7	2.872583
4937.8827	37.5	0.01	1851.706	0.7	1.919559

Table 3. Resistivity (R), depth of consolidated layer (Z), P-wave velocity (Vp) and formation density of consolidated layer (*p*) in some selected sites in Edo and Delta States

R (Ωm)	Z (m)	a	Vp (m/s)	b	*p* (kg/m3)
3116.8828	51.2	0.01	1595.844	0.7	1.7461973
1251.776	109.8	0.01	1374.45	0.7	1.5728607
3048.3006	67.2	0.01	2048.458	0.7	2.0796916
5312.0725	74.5	0.01	3957.494	0.7	3.2975712
3693.9538	77.9	0.01	2877.59	0.7	2.6382761
6147.5636	47.2	0.01	2901.65	0.7	2.6536981
1269.5149	80.4	0.01	1020.69	0.7	1.2771023
1778.0602	59.8	0.01	1063.28	0.7	1.3141755
3877.9326	97.9	0.01	3796.496	0.7	3.203082
2500.9816	119.4	0.01	2986.172	0.7	2.7075742
879.14809	125.6	0.01	1104.21	0.7	1.3493859
7340.8387	27.9	0.01	2048.094	0.7	2.0794329
4194.8845	30.3	0.01	1271.05	0.7	1.4890656
983.19813	128.2	0.01	1260.46	0.7	1.4803702
694.18363	211.3	0.01	1466.81	0.7	1.6461208

Table 4. Resistivity (R), depth of consolidated layer (Z), P-wave velocity (Vp) and formation density of consolidated layer (*p*) in some selected sites in Rivers and Bayelsa States

R (Ωm)	Z (m)	a	Vp (m/s)	b	*p* (kg/m3)
4285.6667	8.7	0.01	372.853	0.7	0.6310683
3828.3503	17.9	0.01	685.2747	0.7	0.9662851
1810.4838	11.1	0.01	200.9637	0.7	0.4094325
4049.9151	27.1	0.01	1097.527	0.7	1.3436639
4091.7016	30.5	0.01	1247.969	0.7	1.4700857
4041.0997	31.1	0.01	1256.782	0.7	1.4773451
2672.6	28.2	0.01	753.6732	0.7	1.0328284

The density values computed from the predicted compressional velocities are useful for estimating some petrophysical parameters like the porosity, permeability etc, in the South-South region where the oil rich Niger Delta is located. Therefore, porosity values were estimated from the predicted P-wave velocity in Rivers and Bayelsa states of Niger Delta as shown in Table 6. The porosity values are well correlated to those earlier obtained in [32,33,34,27], using different techniques. Fig. 2 is the line fit between log10Vp and log10p, which is the output of linear regression between log of density and log of P-wave velocity.

Table 5. Some known values of resistivity, computed compressional wave velocities and densities covering the entire area of study. A total of 450 resistivity observations were collected

R (Ωm)	Z (m)	a	Vp (m/s)	b	log10Vp	*p* (kg⁄m3)	log10 *p*
11186.667	19.5	0.01	2181.4	0.7	3.338735	2.1732752	0.196412
16978.333	8.1	0.01	1375.245	0.7	3.13838	1.5734975	0.146323
16655	18.2	0.01	3031.21	0.7	3.481616	2.7360953	0.232132
1264.5594	10.6	0.01	134.0433	0.7	2.921189	0.3083696	0.092025
17606.668	26.8	0.01	4718.587	0.7	3.673812	3.7296526	0.280181
4655.2459	30.5	0.01	1419.85	0.7	3.733987	1.6090507	0.295225
7827.9288	30.9	0.01	2418.83	0.7	3.733906	2.3362738	0.295204
11613.335	27.8	0.01	3228.507	0.7	3.509002	2.8595732	0.238978
2301.3765	11.5	0.01	264.6583	0.7	2.984374	0.496455	0.107821
9665	6.3	0.01	608.895	0.7	2.784542	0.8895691	0.057863
2061.2379	55.9	0.01	1152.232	0.7	4.063417	1.3902021	0.377582
961230.14	206.4	0.01	1983979	0.7	6.297537	256.02121	0.936112
11040	34.7	0.01	3830.88	0.7	3.583299	3.2233613	0.257552
8819.4954	53.9	0.01	4753.708	0.7	4.889322	3.7490631	0.584058
3005.7701	54.8	0.01	1647.162	0.7	6.667188	1.7853173	1.028525
18078.335	21.8	0.01	3941.077	0.7	3.595615	3.2879897	0.260632
6433.4191	17.87	0.01	1149.652	0.7	4.058033	1.3880224	0.376236
559.50717	334.8	0.01	1873.23	0.7	6.272604	1.9535016	0.929879
3376.4264	30.11	0.01	1016.642	0.7	4.007178	1.2735548	0.363522
7798.3341	42.2	0.01	3290.897	0.7	3.517314	2.8981443	0.241056
13560	51.2	0.01	6942.72	0.7	3.84153	4.8873198	0.32211
1347.3406	109.8	0.01	1479.38	0.7	5.168171	1.6559828	0.653771
5854.3452	67.2	0.01	3934.12	0.7	4.594847	3.2839257	0.51044
4642.3378	74.43	0.01	3455.292	0.7	4.53864	2.9987436	0.496388
4373.4403	77.9	0.01	3406.91	0.7	5.534289	2.969289	0.7453
4871.7284	97.2	0.01	4735.32	0.7	5.675472	3.7389059	0.780596
2166.0549	80.2	0.01	1737.176	0.7	5.239475	1.8530651	0.671597
4149.1973	59.8	0.01	2481.22	0.7	5.394634	2.3782948	0.710386
2156.626	98.4	0.01	2122.12	0.7	4.328219	2.1317632	0.443783
1079.2977	119.6	0.01	1290.84	0.7	4.110753	1.5052571	0.389416
3234.5842	128.2	0.01	4146.737	0.7	4.685399	3.4071758	0.533078
12569.229	27.9	0.01	3506.815	0.7	4.544772	3.0299747	0.497921
10355.226	30.1	0.01	3116.923	0.7	4.70882	2.790026	0.538933
27142.895	125.4	0.01	34037.19	0.7	5.732424	14.871939	0.794834

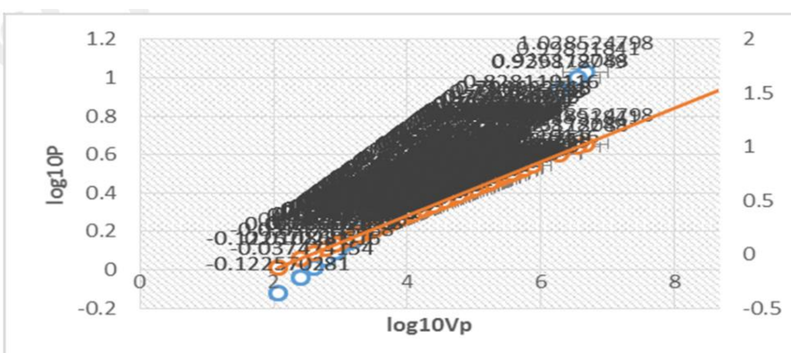

Fig. 2. Output of linear regression between log of density and log of P-wave velocity. Orange rings = data used for regression analysis; Orange straight line = linear forecast for the data; Black clustered rings = data labels; Blue circles = % error

The relationship obtained from the regression analysis using Table 5 and Fig. 2 is presented in equation 5. The minus (-) sign in equation 5 arose from the regression analysis.

$$\log_{10}\rho = 0.3\log_{10} V_p - 0.7 \quad (5)$$

Using the estimated formation density in parts of the South-South region on Table 6, matrix density ρ_{ma} = 2.65g/ cm^3 (sandstone) and fluid density ρ_f = 1.1g/ cm^3, the derived porosity of the formation ϕ, were computed as shown on Table 6, using equation 4.

The values of density for sandstone, limestone, dolomite, and that of fluid density etc are standard and common values of matrix density and fluid density respectively; and are reported in previous studies like ([35,36,31,34] etc.). In this study, matrix density for sandstone was used.

Table 6. Values of total porosity corresponding to formation density. R is the formation resistivity

R (Ωm)	Vp (m/s)	ρ (kg/m3)	Φ
1118	372.853	1.010677	1.057628
998.7	685.2747	1.176777	0.950467
472.3	200.9637	0.865979	1.150981
1056.5	1097.527	1.323828	0.855595
1067.4	1247.969	1.367032	0.827721
1054.2	1256.782	1.369439	0.826168
697.2	753.6732	1.205101	0.932193

4. CONCLUSION

An electrical and seismic relationship in the subsurface in parts of South-East and South-South Nigeria has been established from the predicted compressional wave velocities and formation densities of consolidated layers. The known formation resistivity and observed resistivity from field surveys formed the bulk of the baseline data for this study. The predicted compressional seismic velocities and the corresponding formation densities are well corrected with earlier studies in the area. The model linking density and Vp velocity developed in this study would be useful for future Vp prediction given density values of formation of interest. Findings from this research would be useful for the estimation of some petrophysical parameters especially in the South-South region. The characterization petrophysics and environment and for the advancement of procedures for effective interpretation of electrical and seismic field data is also one of the likely benefits of the study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Imoukhuede M, Idehai A, Egai O. Aspects of geophysical exploration for groundwater using vertical electical sounding (VES) in parts of University of Benin, Benin City, Edo State. J. Appl. Sci. Environ. Management. 2014;18(1):19-25.
2. Mavko G, Mukerji T, Dvorkin J. The rock physics handbook: Tools for seismic analysis of porous media. 2nd Edition: Cambridge University Press, New York. 2009;511.
3. Ezomo FO, Akujieze C. Geophysical investigation of groundwater in Oluku village and its environs of Edo State, Nigeria. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS). 2011;2(4):610-614.
4. Ezomo FO, Aiyohuyin EO. Existence of sandstone deposit in Isihor village area of Edo State, Nigeria. International Journal of Science and Technology. 2012;1(8):405-410.
5. Ezomo FO. Geophysical study of clay attributes in Iruekpen village area of Edo State, Nigeria. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS). 2012;3(3):563-566.
6. Badmus BS, Olatinsu OB. Geophysical characterization of basement rocks and groundwater potentials using electrical sounding data from Odeda Quarry Site, Southern, Nigeria. Asian Journal of Earth Sciences. 2013;5:79-87.
7. Agha SO, Arua AI. Integrated geophysical investigation of sequence of deposition of sedimentary strata in Abakaliki, Nigeria. European Journal of Physical and Agricultural Sciences. 2014;2(1):1-5.
8. Obasi A, Onwe IM, Igwe EO. Geoelectrical subsurface characterization for foundation purposes in the College of Agricultural Sciences (CAS) Campus, Ebonyi State University, Abakaliki, Southeastern Nigeria. Journal of Environment and Earth Science. 2015a;5(18):42-52.

9. Akintorinwa OJ, Adesoji JI. Application of geophysical and geotechnical investigations in engineering site evaluation. International Journal of Physical Sciences. 2009;4(8):443-454.
10. Ozegin KO, Oseghale AO, Audu AL, Ofokotu EJ. An application of the 2-D D.C resistivity method in building site investigation – a case study: South-South Nigeria. Journal of Environment and Earth Science. 2013;3(2):108-112.
11. Aku MO, Gani LI. Geophysical investigation of the subsurface condition of the permanent site of Federal University Lokoja, Kogi State. International Journal of Scientific and Research Publications. 2015;5(6):1-6.
12. Ebhohimen V, Mamah L. Geophysical investigation of road failure the case of Opoji in Nigeria. International Journal of Scientific & Engineering Research. 2014;5(1):1769-1779.
13. Obasi AI, Aghamelu OP, Chukwu CN, Nnabo PN. Engineering geophysical study of the Ebonyi State University permanent site, Abakaliki, South-Eastern Nigeria. British Journal of Applied Science & Technology. 2015b;7(2):168-178.
14. Max MA, Gallardo LA, Mohamed AK. Evidence for correlation of electrical resistivity and seismic velocity in heterogeneous near-surface materials. Geophys. Res. Lett. 2003;30(7):1-4.
15. Faust LY. A velocity function including lithologic variation. Geophysics. 1951;18: 271-288.
16. Gardner GHF. Formation velocity and density – The diagnostic basics for stratigraphic traps. Geophysics. 1974;39: 770-780.
17. Afegbua KU, Ezomo FO. Evaluation of performance of Z-component of Nigerian Seismographic stations from spectral analysis. International Journal of Physical Sciences. 2013a;8(11):428-442.
18. Fatoye FB, Gideon YB. Geology and mineral resources of the lower Benue Trough, Nigeria. Advances in Applied Science Research. 2013;4(6):21-28.
19. Obi DA, Obi EO, Okiwelu AA. Basinal configuration and intrasediment intrusives as revealed by aeromagnetics data of South East Sector of Mamfe Basin, Nigeria. IOSR Journal of Applied Geology and Geophysics. 2013;1(5):01-08.
20. Petters SW. Palaeontographica Abt A. 1982;179:1–104.
21. Nwachukwu SO. The tectonic evolution of the southern portion of the Benue Trough, Nigeria. Geology Magazine. 1972;109: 411-419.
22. Reijers TJA, Petters SW, Nwajide CS. The Niger Delta basin. In Selley RC, ed. African Basins--Sedimentary Basin of the World: Amsterdam. Elsevier Science. 1997;3:151-172.
23. Avbovbo AA. Tertiary lithostratigraphy of Niger Delta. American Association of Petroleum Geologists Bulletin. 1978;62: 295-300.
24. Doust H, Omatsola O. Niger Delta: In Divergent and passive margin basin (Edwards JD, Santoyrossi PA, Eds.) American Association of Petroleum Geologists. Memoir. 1990;48:191-248.
25. Kulke H. Regional petroleum geology of the world. Part II: Africa, America, Australia and Antarctica: Berlin, Gebrüder Borntraeger. 1995;143-172.
26. Rider M. The geological interpretation of well logs. Blackie, Glasgow. 1986;151-165.
27. Adewoye O, Amigun JO, Okwoli E, Cyril AG. Petrophysical and structural analysis of maiti field, Niger Delta, using well logs and 3-d seismic data. Petroleum and Coal. 2013;55(4):302-310.
28. Horsfall OI, Omubo-Pepple VB, Tamunobereton-ari I. Estimation of shear wave velocity for lithological variation in the NorthWestern Part of the Niger Delta Basin of Nigeria. Am. J. Sci. Ind. Res. 2014;5(1):13-22.
29. Essien UE, Akankpo AO. Compressional and shear-wave velocity measurements in unconsolidated top soil in Eket, South-eastern Nigeria. The Pacific Journal of Science and Technology. 2013;14(1):476-491.
30. Essien UE, Akankpo AO, Igboekwe MU. Poisson’s ratio of surface soils and shallow sediments determined from seismic compressional and shear wave velocities. International Journal of Geosciences. 2014;5:1540-1546.
31. Tamunosiki D, Ming GH, Wang L, Uko ED, Tamunonengiyeofori W. Petrophysical characteristics of coastal swamp depobelt reservoir in the Niger Delta using well-log data. Journal of Applied Geology and Geophysics. 2014;2(2,I):2321–0982.
32. Amigun JO, Olisa B, Fadeyi OO. Petrophysical analysis of well logs for reservoir evaluation: A case study of ‘Laja’ oil field, Niger Delta. Journal of Petroleum

and Gas Exploration Research. 2012;2(10):181-187.
33. Eshimokhai S, Akhirevbulu OE. Reservoir characterization using seismic and well logs data a case study of Niger Delta. Ethiopian Journal of Environmental Studies and Management (EJESM). 2012;5(4): 597-603.
34. Horsfall OI, Davies DH, Davies OA. Hydrocarbon reservoir characterization using well log in Niger Delta basin of Nigeria. International Journal of Applied and Natural Sciences (IJANS). 2015;4(5):55-64
35. Gluyas J, Swarbrick R. Petroleum geoscience. Publ. Blackwell Publishing. 2004;32.
36. Myers G. Nuclear logging, Chapter 3D, in E.D. Holstein, (ed.), Reservoir Engineering and Petrophysics. Petroleum Engineering Handbook for Neutron Logs. 2007;V(A):267-287.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/17813