Scientia Africana, Vol. 14 (No.2), December 2015. Pp 33-49
© College of Natural and Applied Sciences, University of Port Harcourt, Printed in Nigeria ISSN 1118 – 1931

IMPACT OF LITHOLOGIC HETEROGENEITY ON ACOUSTIC VELOCITIES IN THE BORNU BASIN, NIGERIA

C. N. Nwankwo and S. A. Akpan

Department of Physics, University of Port Harcourt, Nigeria

Received: 01-07-15
Accepted: 22-09-15

ABSTRACT

Six exploratory wells were analyzed and interpreted with the aim of determining the effect of lithologic heterogeneity on acoustic velocities using the petrophysical properties calculated from the logs. The wells include Murshe-1, Tuma-1, Ziye-1, Krumpta-1, Gubio SW-1 and Herwa-1. Gamma ray logs were used for the lithological delineation; the computation of porosity and compressional (acoustic) wave velocity was achieved utilizing sonic logs while the sediments bulk density was determined from density log. The analysis of compressional wave velocity with depth confirms a general trend of non-linear increase in velocity with depth across the wells, and there exists a marked lithological variation between 3000 m and 3200 m depth across the wells in the basin. Also, analyses of the results depict a non-linear increase in density with depth. The relationship between permeability and depth showed permeability increasing in high porosity areas. Permeability range value of 116 to 9238 MD and porosity of 1to 60% computed in this study is an indication that the reservoir sand in Bornu Basin has the potential to accumulate significant amount of extractable hydrocarbon. In general, the trends of relationship amongst acoustic wave velocity, porosity, density and permeability with depth have produced positive but non-linear variation. Ideally, if the formation is isotropic and homogeneous the trends would have been linear. The non-linearity which exists amongst these parameters could be as a result of the presence of a geologic structure, especially at the southern part of the basin.

Key words: Heterogeneity, Acoustic velocity, compressional wave, Bornu basin

INTRODUCTION

With crude oil reserves said to have declined in recent times, the need for Nigeria to ramp up exploration activity continue to grow. Though the country aims to grow its reserves but according to the Department of Petroleum Resource (DPR), Nigeria has seen its reserve base decline from 37 billion barrels to 35 billion barrels (George, 2014). This decline has been attributed to the fact that little or no significant investment had been recorded in oil exploration in the recent few years.

It is thus, from the need to grow Nigeria reserve base that the Nigerian National Petroleum Corporation (NNPC) have made desperate attempt to explore hydrocarbon in other sedimentary basins of the country, giving more attention to the Bornu basin, but so far no success has been achieved. As a result of this, several research works are being done to aid in a successful exploration of hydrocarbon in this basin. From available literatures however, little or no data have been presented on the influence of lithologic dependent parameters on acoustic velocity.

Heterogeneity in a reservoir is referred to as non uniform, non linear spatial distribution of rock properties. It is the property of the medium that causes the boundary between the displacing and displaced fluids to distort and spread as the displacement proceeds; or the condition of being heterogeneous (Jensen et al., 2000; Fitch et al., 2015). Reservoir heterogeneity is a function of the porosity/permeability distribution due to the lithologic variation during sedimentary deposition.

The heterogeneous lithologic characteristics of subsurface formations do not only show vertical variation of velocity but also show strong lateral velocity variations, which are associated with complex overburden structures. It is also associated with voids and dipping strata (Plona and Johnson, 1984).

The complex relationship between acoustic properties and the texture, composition and facies of sedimentary rocks strongly influences the geological interpretation of wire-line logs and seismic reflection data. Thus, making it essential to identify and quantify the factors which influence acoustic velocity of sediments that generates seismic waves. Jarot and Samsuri (2003), pointed out that rock characterization and acoustic wave velocity analysis are very important stages in the petroleum reservoir characterization and seismic exploration.

Acoustic velocity is a geophysical parameter that measures the rate of change of displacement as sound wave is propagated through the stratified geology of an area from the source to receiver (Sheriff, 1991). The variation of acoustic velocity with depth is associated with lithologic properties, particles size, density, porosity, confining pressure, pore fluid content, particle orientation etc. Strong velocity variations both vertically and laterally are associated with complex overburden structures; examples are salt diaprism, voids and dipping strata (Judson *et al*., 1980; Plona and Johnson, 1984).

In oil exploration and other geophysical survey, one of the most indispensible parameters used is acoustic velocity. This is based on the fact that acoustic velocity can easily be applied to determine and predict horizons, faults, facies, unconformities, stratigraphic boundaries, geologic structures, fluid contents, effective stress, porosity etc. To dictate reflectors and refractors with plane or dip horizontal bed, it is important to know velocity details at any depth (Tamunobereton-ari et al., 2010). Due to difference in elastic moduli brought about by lithologic heterogeneity, there exists variation in acoustic velocity of different media. Velocity give essential structural and lithological knowledge since it correlates different lithologic features of the earth material (Polymenakos et al., 2005).

Delineation of subsurface heterogeneity is one key factor in reliable reservoir characterization. These heterogeneities occur at various scales and can include variations in lithology, pore fluids, clay content, porosity, pressure, and temperature (Mukerji et al., 2001). It is one critical part of petroleum reservoir characterization which involve careful analysis and understanding of petrophysical properties from well logs and core data.

The lithology of clastic sediments is due to its depositional environment, degree of sorting of sediments, climatic changes, source mineral sediments and other previous geologic activities (Bultman, 1999). Old sediments show little uniformity in velocity function since they are well consolidated. However, in new deposited areas, structural deformation and uplifts depict velocity variation (Tamunobereton-ari et al., 2011).

In describing the lithology of Chad (Bornu) basin, Nwankwo (2007) identified sands, sandy shale (siltstone) and shale as its constituents. Based on the homogeneity of the lithological characteristics of layers, Bornu basin is classified into six (6) distinct formations namely; Chad Formation, Kerri Kerri Formation, Gombe Formation, Fika (Shale) Formation, Gongila Formation, and Bima Sandstone. Within these major formations lie several minor strata of various dimension and unique characteristics.

The aim of this study is to delineate the lithologic heterogeneity by estimating the percentage of sand and shale volume; and to establish how density and acoustic velocity are related within the delineated lithologies.

GEOLOGY OF CHAD BASIN

Chad basin, the largest intracratonic basin and the largest area of inland drainage in Africa covers an area of about 2,500,000km^2 and straddles five countries namely; Nigeria, Chad Republic, Niger Republic, Cameroon and Central African Republic at an elevation of 200m and 500m above sea level (Nwankwo, 2007). Its western margin is marked by the watershed between the River Niger and River Chad drainage systems, and approximately one-tenth of the surface area of the Chad basin is in NE Nigeria (Bornu Basin). The basin is bounded to the east by the Northern Massif (Mandara Mountains) and the south by the Benue Trough and Biu Plateau (Olugbemiro et al., 1997). Bornu basin covers about 152,000km^2 of territory in Bornu, Bauchi, Plateau and Kano States and falls between longitude 11°45' E and 14°45' E and latitude 9°30' N and 13°45' N (Fig. 1).

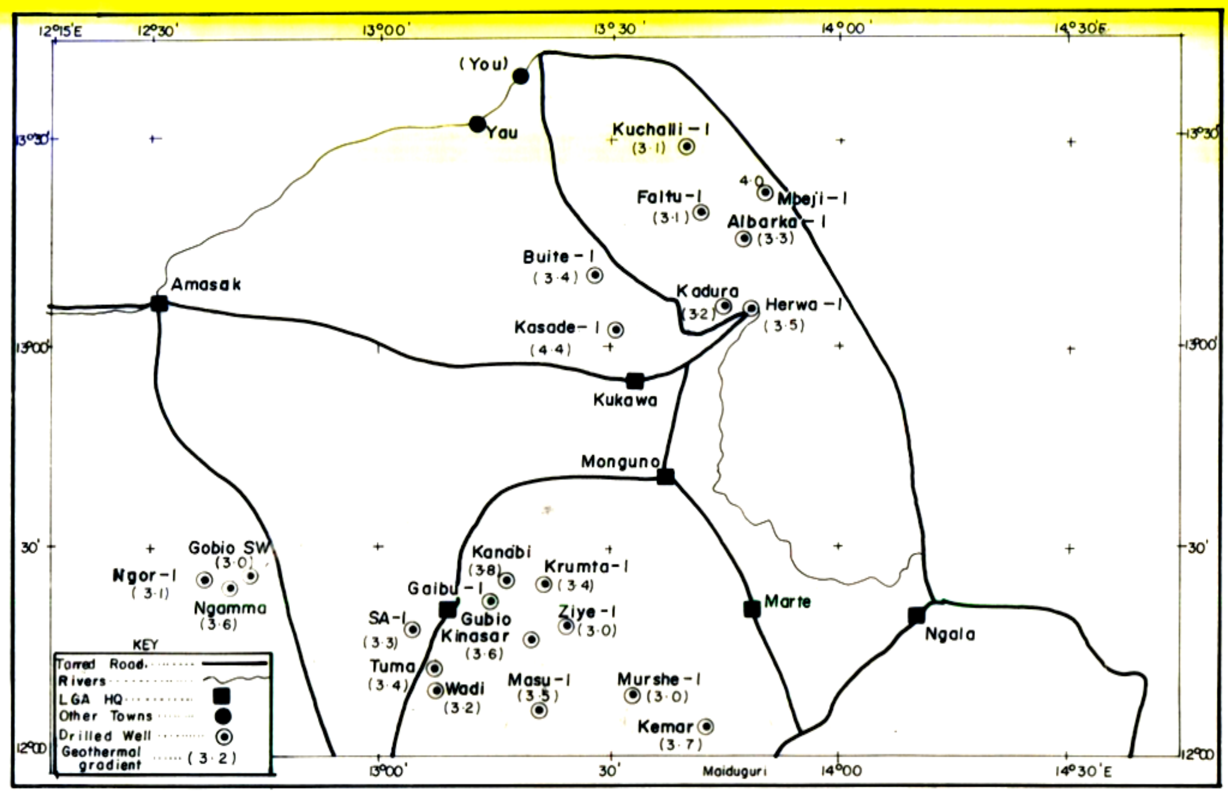


Fig.1: Map of Bornu Basin showing the Location of Oil wells (Nwankwo and Ekine, 2009).

Various mechanisms have been proposed to explain the evolution of the basin. Lees (1952), Carter et al. (1963) and Burke et al. (1970) maintained that the Benue-Chad Trough is believed to be the third and “failed arm” of a triple junction rift-system that preceded the opening of the South Atlantic during the early Cretaceous, and the subsequent separation of Africa and South American Continents. Cratchley and Jones (1965) and Ajakaiye and Burke (1973) have shown from geophysical evidence that the Benue trough’s structural alignment and that of the Manga area may pass into one another in Bornu basin.

The basin is thus genetically linked with Benue Trough. A mid-Cretaceous phase of active seafloor spreading in the Atlantic resulted in subsidence of the West African intracratonic basins, which lead to widespread of Cenomanian-Turorian marine transgression into the Chad basin (Furon, 1963; Franks and Nairn, 1973).

Sediments of the basin are mainly continental, sparsely fossiliferous, poorly sorted, and medium to coarse-grained, feldspathic sandstones called the Bima Sandstone. A transitional calcerous deposited Gongila Formation that accompanied the onset of marine incursions into the basin overlies the Bima Formation. These are overlain by graptolitic shales (Fika Formation). The Kerri-Kerri Formation, which is of Paleocene age makes contact with the Fika Formation at the top. The youngest stratigraphic sequence of Bornu Basin is the Chad Formation. Detail stratigraphic sequence of Bornu Basin has been given by Matheis (1976), Petters (1981), and Okosun (1995).

MATERIALS AND METHOD

Geophysical well logs from six exploratory wells namely, Murshe-1, Tuma-1, Ziye-1, Krumpta-1, Gubio SW-1 and Herwa-1 from the Southern part of Chad Basin (Bornu Basin) were utilized in this study. The logs are composite logs and comprise of gamma-ray, SP, Caliper, Resistivity, Neutron, bulk Density, and Sonic logs. These wells were selected based on completeness, penetrated depth and coverage of the explored area. Well logs provide information on the nature of the strata penetrated, the size and shape of the structures, the depth at which the rocks are encountered, porosity and permeability of the rock unit, as well as type of fluids contained therein and depth of fluid interfaces of the subsurface formations penetrated in the area.

The well logs used in this study were provided in hard copy which made the use of any geophysical software for the analysis difficult. Thus, manual log digitization and interpretation was employed based on the principle of each logging method. Lithostratigraphic units for the various wells were inferred from Gamma ray logs for the six wells. The sedimentary sequences considered are sands and shale beds. The Gamma ray log is measured in API unit ranging from (0-150) API. Clean sand formations were delineated based on the GR signatures increasing towards the sand line and GR signatures moving towards shale line from the cutoff line depicts shale formation. This was accompanied by the determination of the corresponding transit time of the delineated lithology unit from sonic logs. Compressional wave velocity was estimated from sonic log by employing the relationship between total transit times of the traversed acoustic wave with velocity given as:

$$\Delta t_{log} = \frac{1}{V_P}\,(\mu s/ft) \qquad 1$$

$$V_P = \left(\frac{1}{\Delta t_{log}}\right)\left(\frac{304800}{1}\right)(m/s) \qquad 2$$

Where V_P is the compressional wave velocity.

The interval transit time from sonic log for a given rock depends upon its lithology and porosity, the same way compressional wave velocity is influenced by the rock matrix as well as the fluids filling the pore space. Thus, the total time it takes for an acoustic pulse to travel through a rock complex is proportional to the amount of fluid in the pore space multiplied by the time it takes to travel through the rock matrix. Based on this relationship, the transit time from sonic log was used to compute porosities of the formations at various depths employing the Willie *et al.* (1958) time average equation:

$$\phi = \frac{\Delta \mathrm{t}_{\log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \qquad 3$$

where $\Delta \mathrm{t}_{\log}$ is the transit time reading on the log, Δt_{ma} is transit time due to rock matrix, Δt_f is transit time of the formation and ϕ is the porosity.

Rock density is dependent on minerologic compositions, formation lithology and the degree of compaction. The bulk density logs were used to determine the formation densities for the three wells. The bulk density log is measured in gram per cubic centimeter (g/cm^3) and ranges from (1.95 to 2.95) and increase from left to right. The densities of the sand and shale formations encountered at each depth were digitized for each well.

For wells without bulk density log, the formation densities were estimated using the empirical relation of compressional wave velocity and bulk density given by Gardner et al. (1974):

$$\rho = 0.23V_P^{\,0.25}$$

where ρ is bulk density in g/cm^3 and V_P is compressional wave velocity in ft/s.

Equation 4 was employed in estimating the bulk densities for Tuma-1 and Herwa-1 well while bulk densities for Krumpta-1, Murshe-1, Ziye-1 and Gubio SW-1 well were determined from their respective bulk density logs.

RESULTS AND DISCUSSION

The analyses of results show that shallow beds generally depict low acoustic velocities than deeply buried beds as a result of compaction of the buried beds with time. Some of the delineated shallow beds which have high velocities than deeper beds may be as a result of well sorted grains at shallow depth.

A non-linear variation in acoustic velocity and porosity is observed for the sand and shale beds (Figs. 2 and 3). Velocity dropped below the normal trend of the relationship in zone A (Murshe-1 Well), due likely to less compaction which may have resulted from increase in pore spaces. This lowest acoustic velocity existed at approximately the same depth range, in the relationship between the two lithologies of interest in all the other wells. This zone of low acoustic velocity is most probably connected with the period of stratigraphic breaks (unconformity) which has some significance to the evolutionary history of the basin, as identified by Ejedawe et al. (1985) and Okosun (1995). Thus, in oil exploration and other geophysical survey, acoustic velocity can be used to predict horizons, faults facies, unconformities, stratigraphic boundaries, porosities etc.

Figure 3 exhibit an inverse of the trend of figure 2, porosity decreasing with increase in depth of burial which is indication of the occurrence of more sedimentation and cementation of the grains. This scenario suggests the continuation of well sorted grains down the lithologies. At zone B of figure 3 which corresponds to zone A in figure 2, high porosity is observed in both lithologies, with much increase occurring in sand beds. This area of reduced compaction is also evident in the trend of density with depth marked zone C in figure 4. The general trend of porosity with depth for sand and shale beds is heterogeneous.

In figure 4 shallow zones have low densities across the lithologies and the bulk density constantly increase slightly with depth. However, around zone C, the bulk density values decreased in both sand and shale beds. The variation of bulk density with depth depict an inverse of the trend in porosity and depth; bulk density increase non-linearly with depth but deviates as it gets to zone C, an area earlier noted with high porosity.

More sand beds were delineated in Tuma-1 well with the variation of acoustic velocity and depth depicting a non-linear increase (Fig. 2b). The variation starts with a low velocity which corresponds to an area of high porosity in the trend of porosity and depth for the same well (Fig. 3b). This denotes a region of unlithified sediments. Blangy *et* al. (1993), pointed out that for high porosity sediments lithification affects the propagation of acoustic velocities. Around 1300m depth marked zone E (Fig. 2b), acoustic velocity increases more in sand bed while it decreased in shale. Within this zone, the sand bed is much compacted than shale lithology. This also ties with the trend of porosity and depth (Fig. 3b) whereby the variation of porosity with depth in the zone is high for the shale bed but decreased in sand bed.

More shale lithologies were encountered in Gubio SW-1 well which suggests that the south-northern part of the basin probably contains more radioactive elements. This may have resulted from the presence of intrusive rocks. The trend in relationship between bulk density and depth (Fig. 4) is such that shallow beds in high porous area (zone G) are less dense above which bulk density trend increases non-linearly with depth to another high porosity zone (J) of unlithified sediments where the density trend drops before increasing again as depth of burial increases.

Similar variations are observed in Ziye-1, Krumpta-1, and Herwa-1 well, with lithologic variations influencing the propagation of acoustic velocities. But in general, the velocity values obtained across the wells depicts more increase in sand bed than in shale bed and around depth range of 3000m and 3200m, acoustic velocity tends to decrease more in all the wells considered in this study. A non linear increase in acoustic velocity with depth in shale beds as

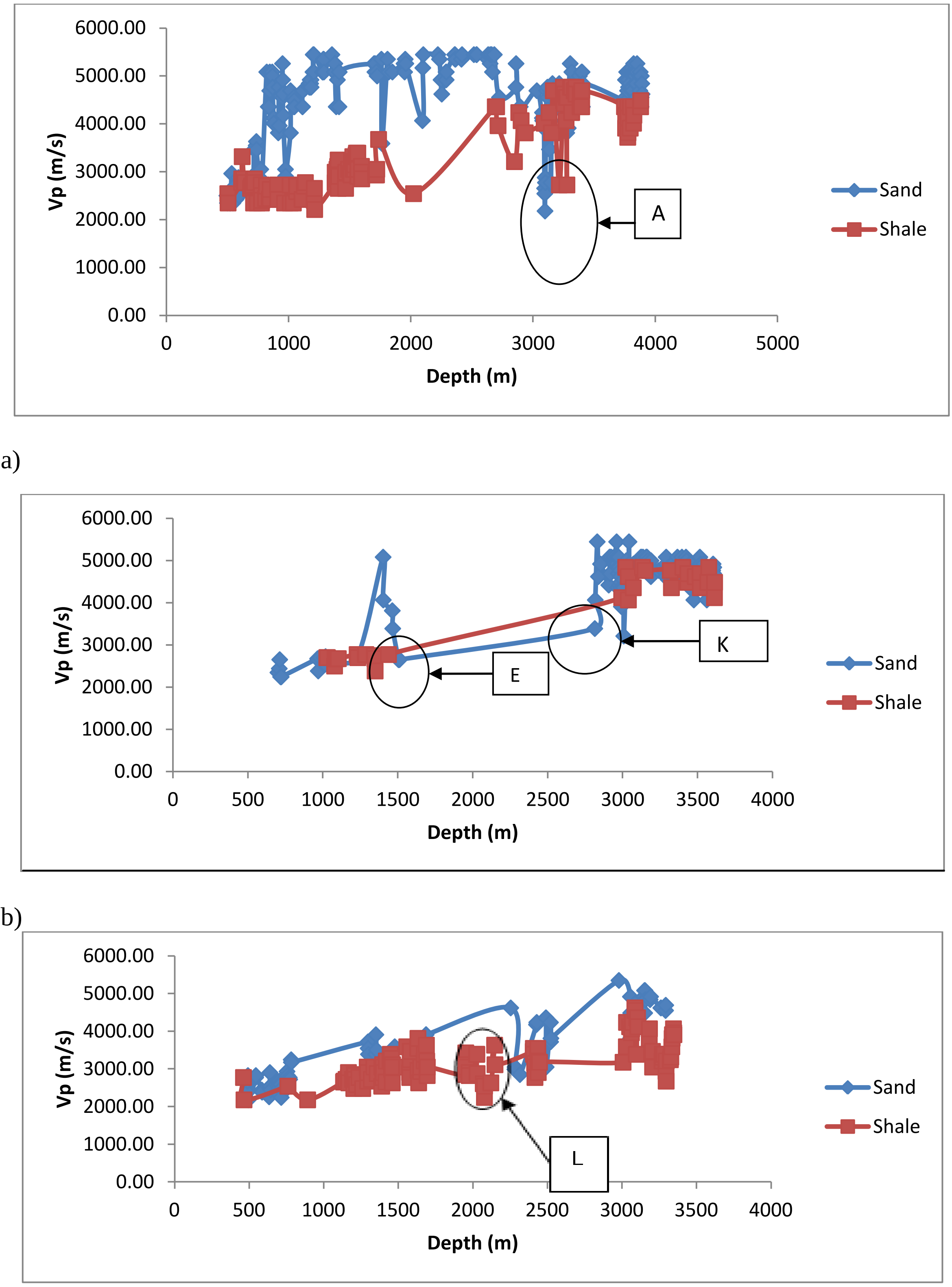
Scientia Africana, Vol. 14 (No.2), December 2015. Pp 33-49
© College of Natural and Applied Sciences, University of Port Harcourt, Printed in Nigeria ISSN 1118 – 1931

obtained by Tamunoberaton-ari et al. (2010) for Niger Delta was observed in the study.

A good reservoir rock generally is one with porosity and permeability that favours accumulation of significant amount of extractable hydrocarbon. Rock porosity and fluid saturations are the principal factor involved in determining the amount of oil and gas originally in place while permeability is a measure of the ease with which fluid flows through the pore spaces of rock material (Abdolla, 2010). An average porosity range values of 1 – 60% and permeability of 116 – 9238mD computed for sand lithology across the wells shows that Bornu Basin has very good quality petrophysical properties for hydrocarbon accumulation. The study has also established that porosity, density and velocity of signals are strongly affected by the material properties of rocks at different media.

This study has investigated the impact of lithologic heterogeneity on acoustic velocities in Bornu basin. Analysis and interpretation of the result obtained suggests that variation in lithology affect the propagation of acoustic waves. Trends in the relationship between bulk densities with depth, acoustic velocities with depth, and porosities with depth across the wells revealed zones of deviation in the trends. Generally, the trend in acoustic velocities versus depth shows velocities increasing non-linearly with depth up to some zones where the velocities decreases at different points across the wells and above which the non-linear increase sets in. The trends of bulk densities with depth also depict non-linear increasing trends but deviates on reaching the point acoustic velocities and porosities deviated with depth. Bulk densities values in these sections are more than the normal trend values which could be as a result of increase in pore volume. This is because rocks get compacted as depth of burial increases. During deposition of sediments excess pressure is built up and the weight squeezes the trapped fluid causing compaction disequilibrium. This occurs most commonly when low permeable shale prevent pore fluid from escaping as rapidly as the pore spaces tries to compact.

The trend in relationship between porosities with depth and acoustic velocities with porosities is such that, as porosities decrease non-linearly with depth across the wells, acoustic velocities increase in less porous areas. As with the trends of acoustic velocities with depth and bulk densities, zones of porosity deviation were also encountered at different points across the wells; all of which is an indication that diversity in lithology affects the propagation of acoustic velocities as the wave travel through alternating beds.



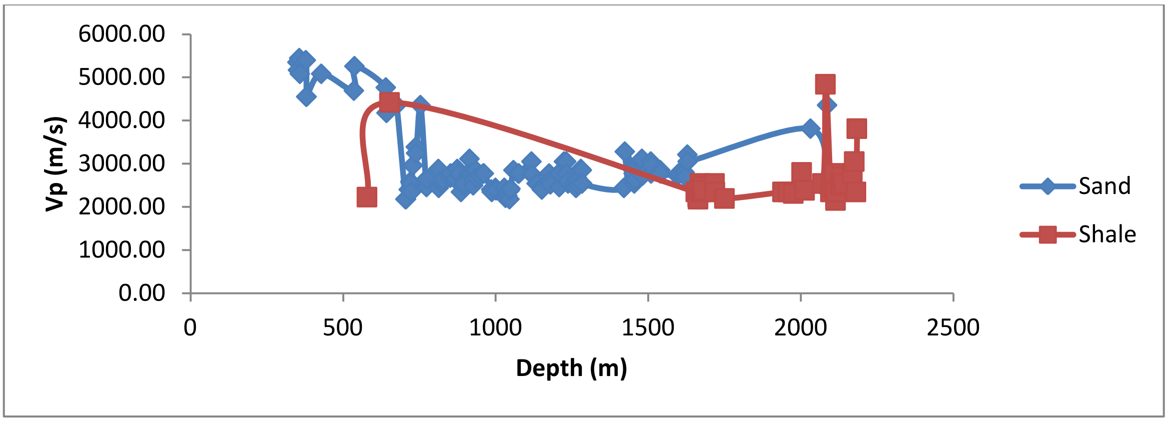
(a)

(b)

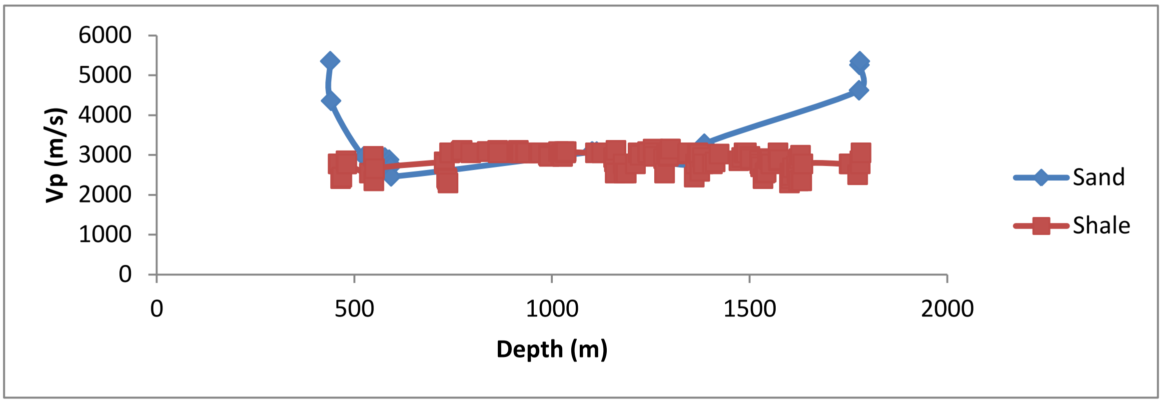
(c)

Fig. 2: Variation of Compressional wave velocity (V_P) with Depth: (a) Murshe-1 (b) Tuma-1 (c) Ziye-1 Wells.

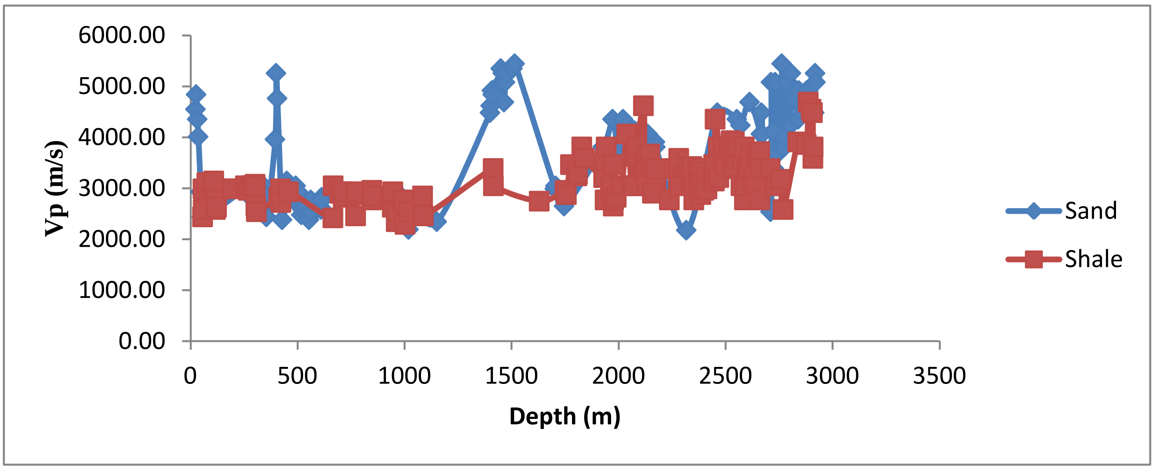
Scientia Africana, Vol. 14 (No.2), December 2015. Pp 33-49
© College of Natural and Applied Sciences, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*



(d)

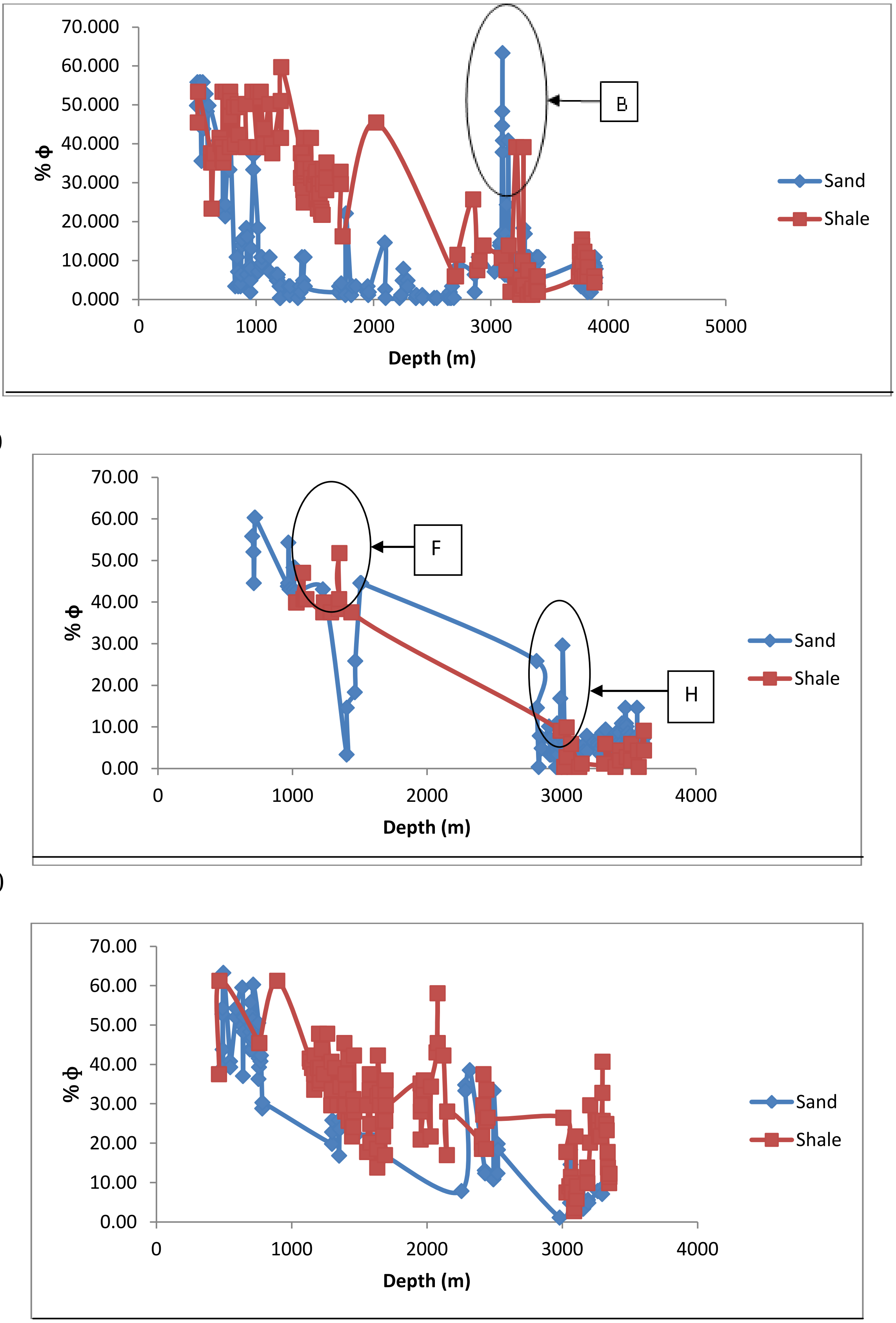


(e)



(f)

Fig. 2: Variation of Compressional wave velocity (V_P) with Depth: (d) Herwa-1 (e) Gubio SW-1 (f) Krumpta-1 Wells.



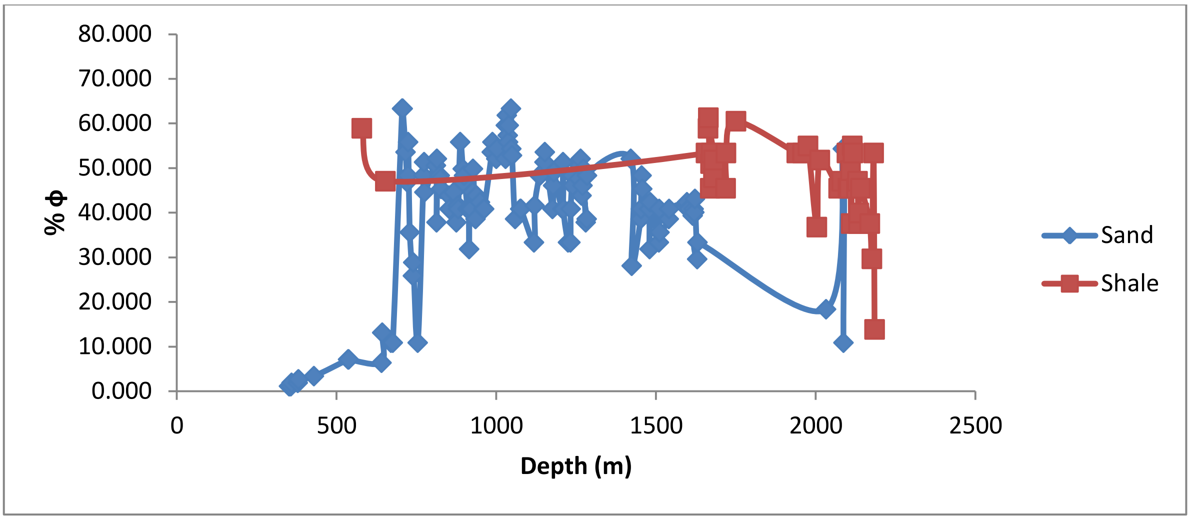
(a)

(b)

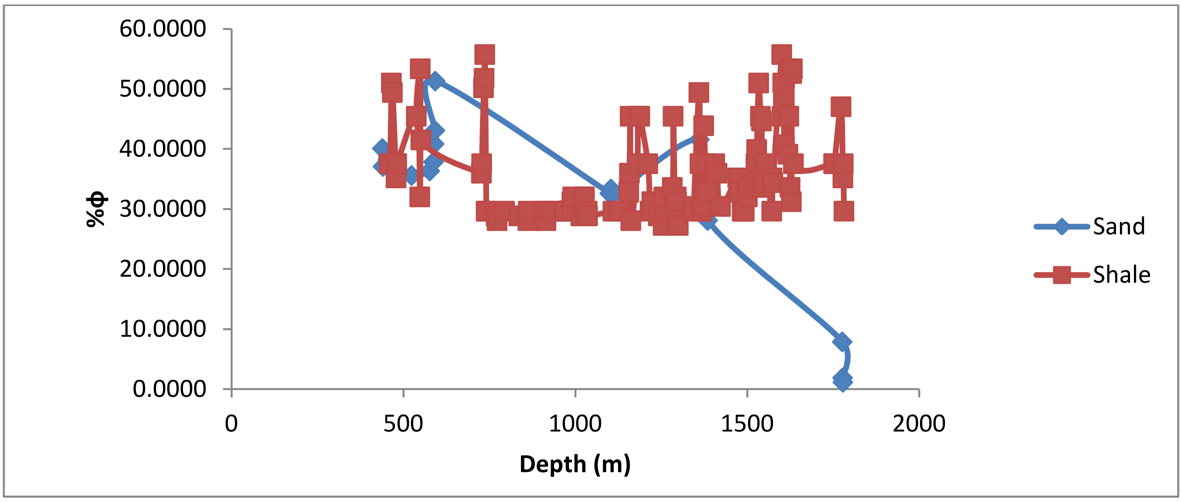
(c)

Fig. 3: Porosity variation with Depth: (a) Murshe-1, (b) Tuma-1 (c) Ziye-1 Well.

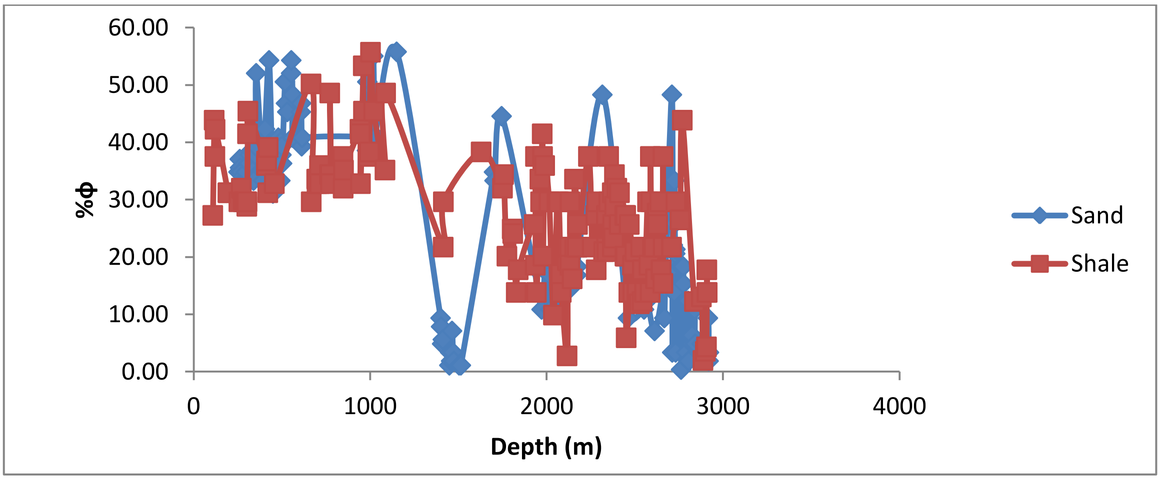
Scientia Africana, Vol. 14 (No.2), December 2015. Pp 33-49
© College of Natural and Applied Sciences, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*



(d)

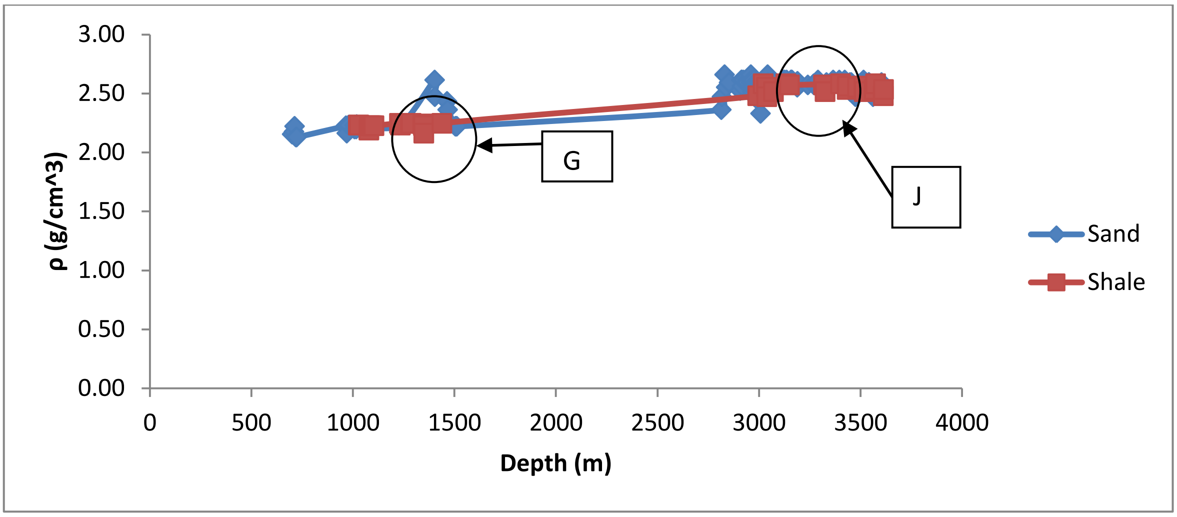


(e)

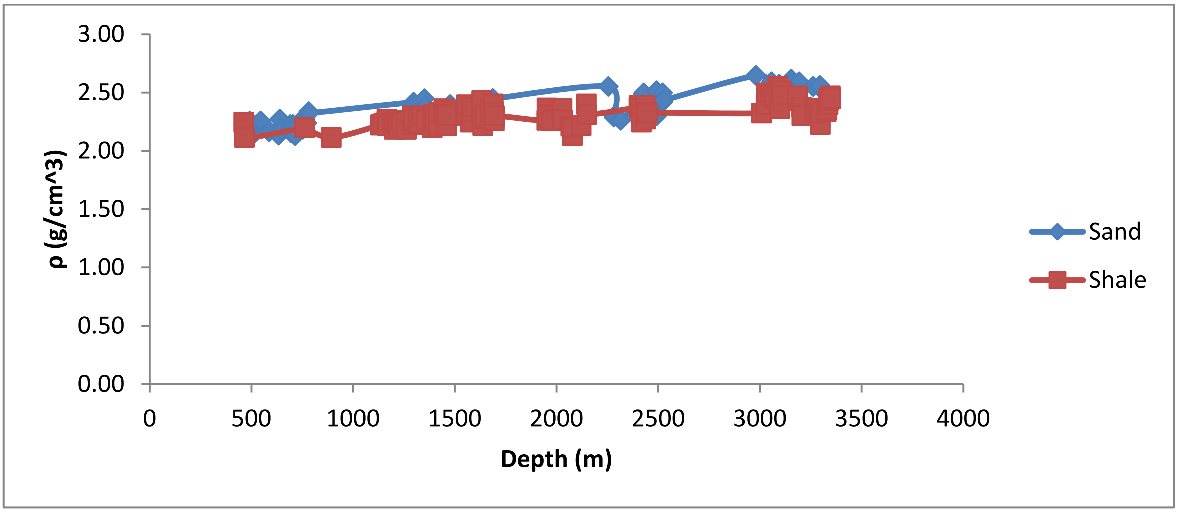


(f)

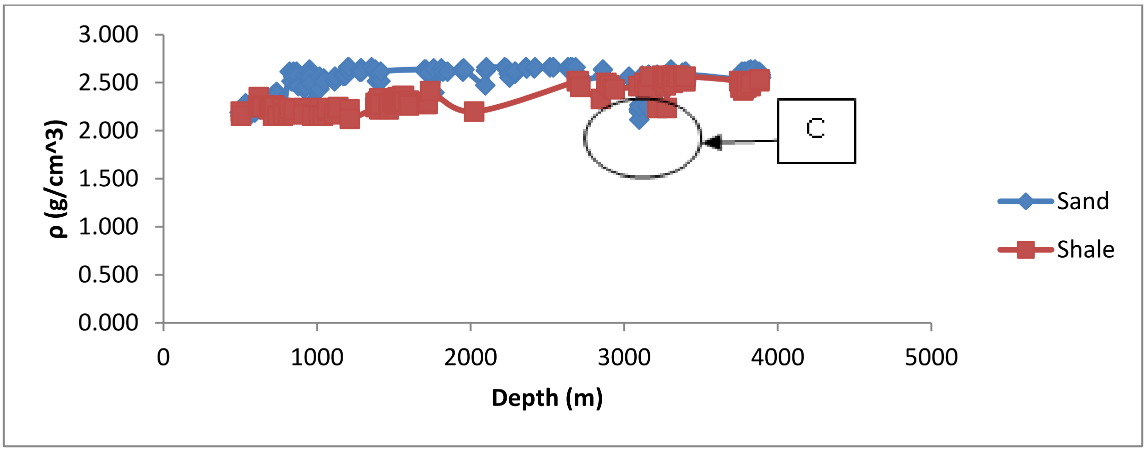
Fig. 3: Porosity variation with Depth: (d) Herwa-1 (e) Gubio SW-1 (f) Krumpta-1 Well.



(a)



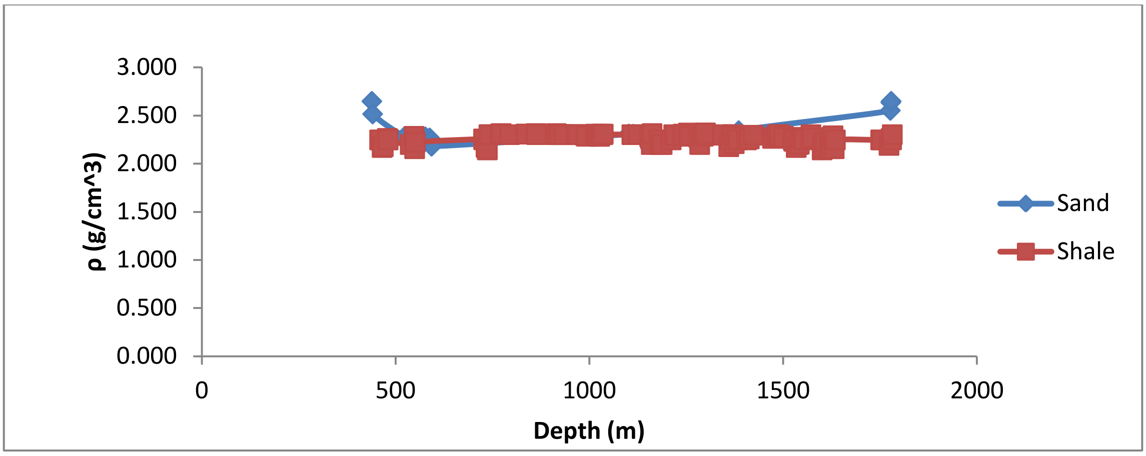
(b)



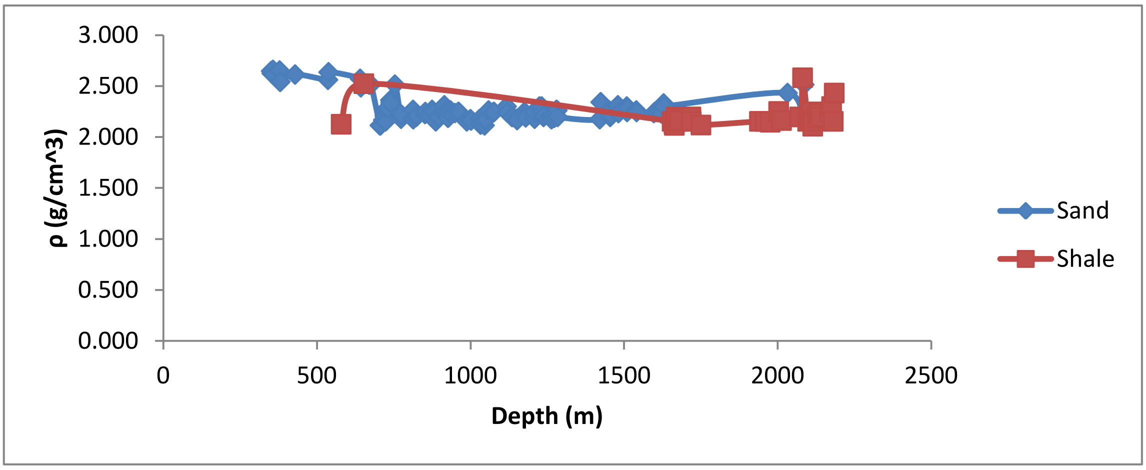
(c)

Fig. 4: Density variation with Depth: (a) Tuma-1 (b) Ziye-1 (c) Murshe-1 Well.

Scientia Africana, Vol. 14 (No.2), December 2015. Pp 33-49
© College of Natural and Applied Sciences, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

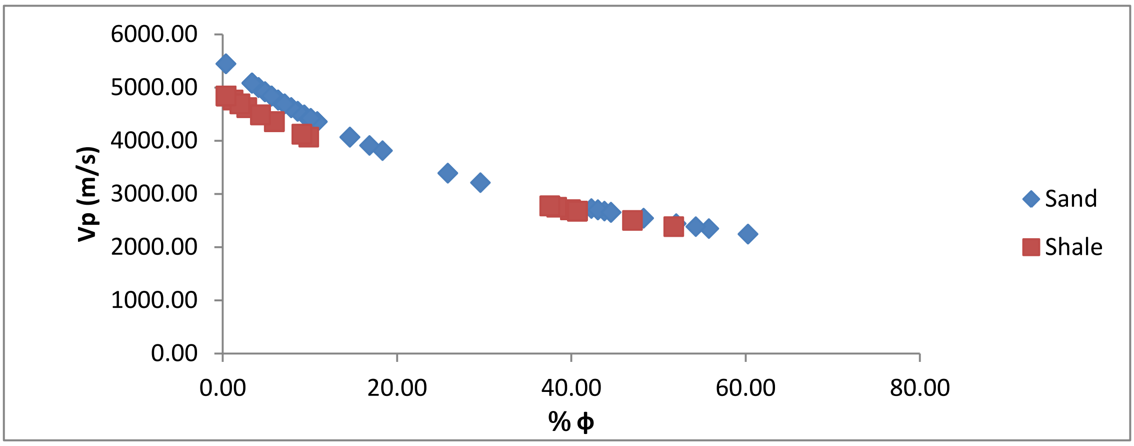


(d)

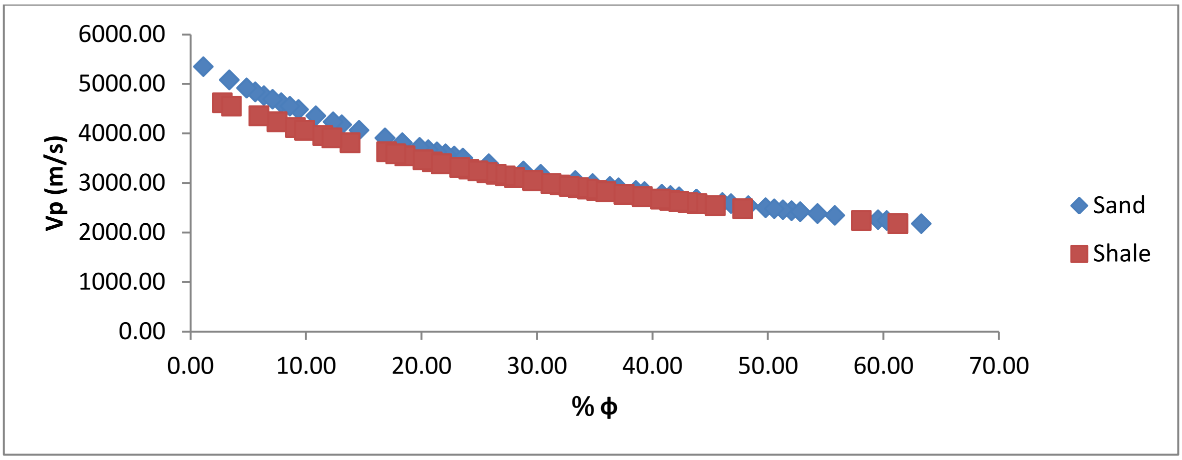


(e)

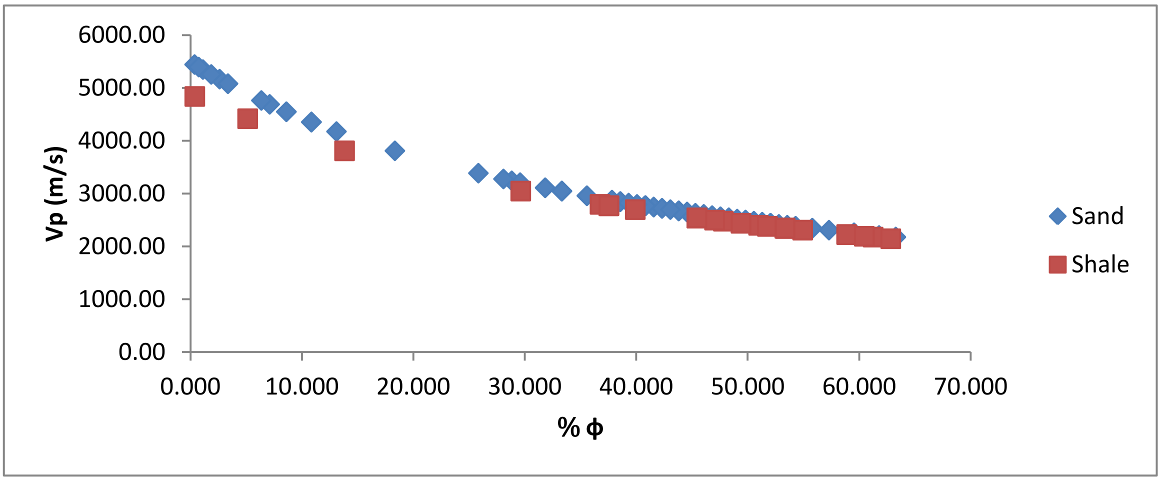
Fig. 4: Density variation with Depth: (d) Gubio SW-1 (e) Herwa-1 Well.



(a)

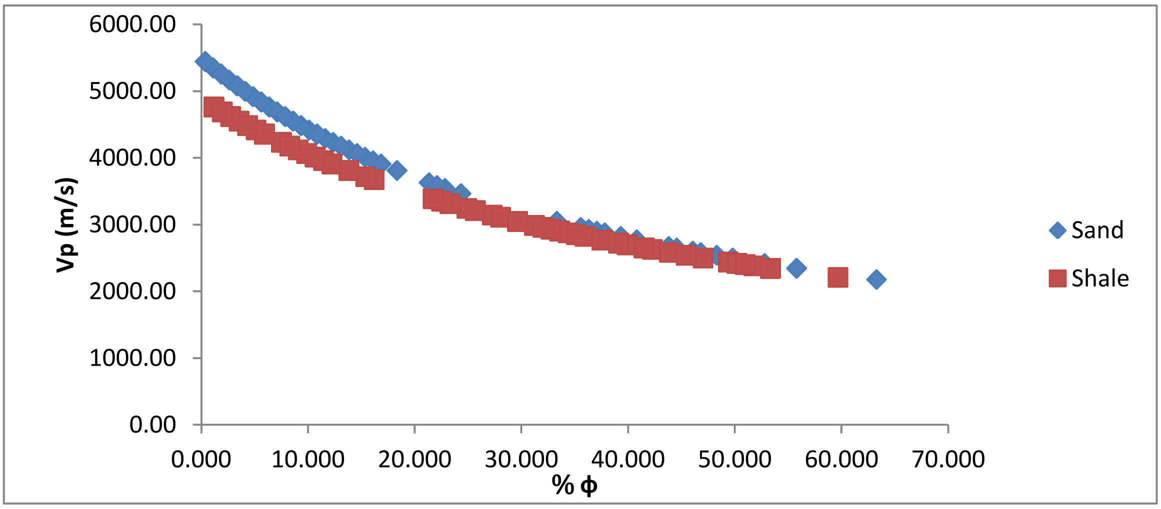


(b)



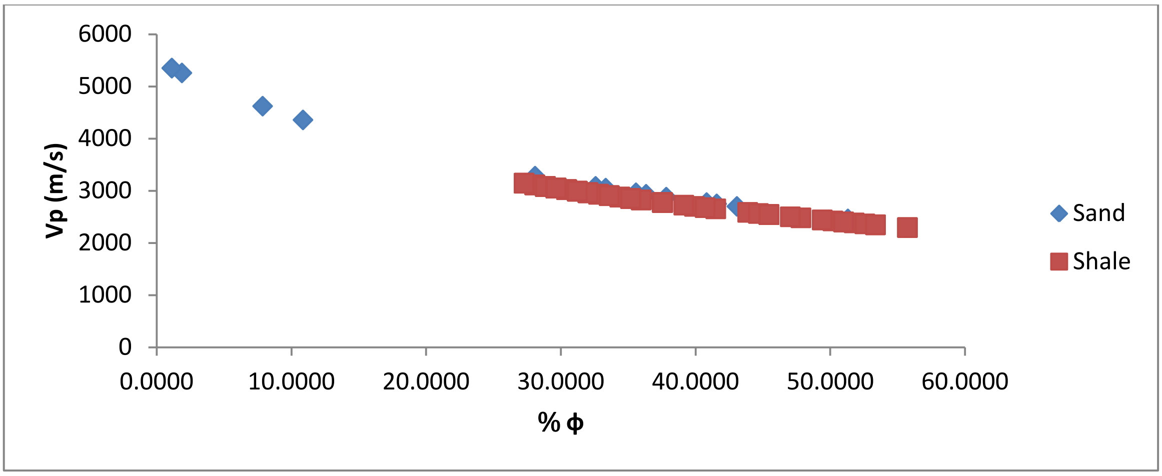
(c)

Fig. 5: Variation of Compressional wave velocity (V_P) with Porosity: (a) Tuma-1 (b) Ziye-1 (c) Herwa-1 Well.

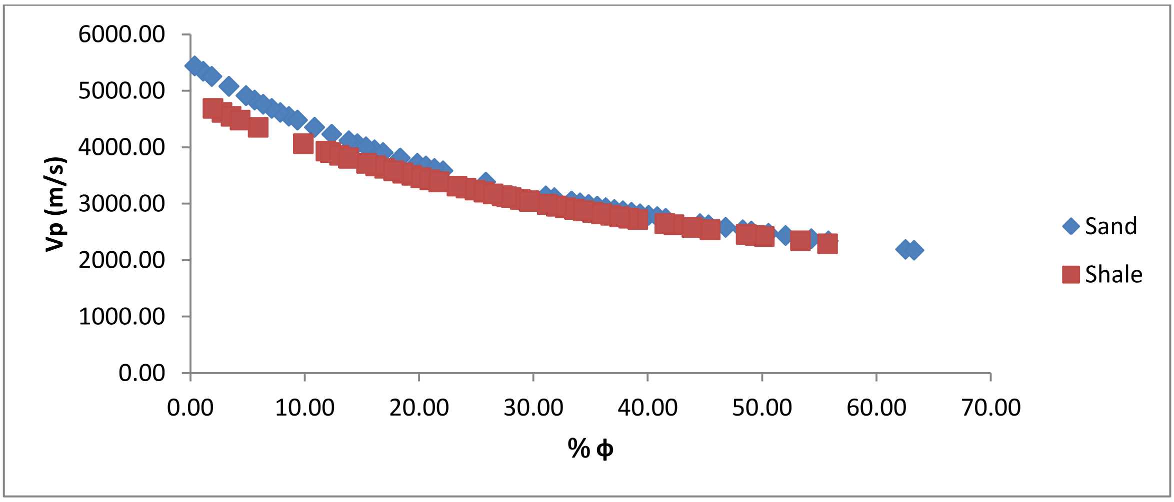


(d)

Scientia Africana, Vol. 14 (No.2), December 2015. Pp 33-49
© College of Natural and Applied Sciences, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*



(e)



(f)

Fig. 5: Variation of Compressional wave velocity (V_P) with Porosity: (d) Murshe-1 (e) Gubio SW-1 (f) Krumpta-1 Well.

REFERENCES

Abdolla E. (2010): Evaluation of Petrophysical Properties of an Oil Field and their effects on production after gas Injection, 1st International Applied Geological Congress, Department of Geology, Islamic Azad University – Mashad Branch, Iran, pp.26-28.

Ajakaiye D. E and Burke K. (1973): A bouguer Gravity map of Nigeria: Tectonophysics, 16, 103-115.

Blangy J. P., Strandeness S., Moos D and Nur A. (1993): Ultrasonic Velocities in sands-revisited. *Geophysics*,58:344-356.

Boboye O. A. (2012): Late Albian - Eocene palynological biostratigraphy of three wells in the Nigerian sector of Chad (Bornu) Basin. Journal of Mining and Geology, 48(2):127–157.

Brigaud F., Chapman D. S and Le Douaran S. (1990): Estimating Thermal Conductivity in Sedimentary Basin using Lithological data and Geophysical well logs: AAPG Bulletin 74(9):1459-1477.=

Bultman M. W. (1999): Geometry, Structure, and Concealed Lithology of the San Rafael Basin, South Eastern Arizona.

Burke K. C., Dessauvagie T. F. J. and Whiteman A. J. (1970): Geological History of the Benue Valley and adjacent areas, in T. F. J. Dessauvagie, and A. J. Whiteman, eds. African geology, Cretaceous rocks of Nigeria and Adjacent areas: Ibadan, Nigeria. University of Ibadan press, 187- 205.

Carter J.O., Barber W., Tait E. A. and Jones G. P. (1963): The Geology of Parts of Adamawa, Bauchi and Bornu Provinces in Northeastern Nigeria. Geol. Survey. Nigeria Bull., 30, 1-108.

Cratchley C. R. and G. P. Jones (1965): An interpretation of the geology and gravity anomalies of the Benue Valley, Nigeria; Overseas Geological Survey, Geophysical Paper. 1, 26.

Ejedawe, J.E. , Coker, J.L., Lambert-Aikhiowhare, D.O. 1985. Evolution of the oil Generative window (OGW) in sedimentary basins. NAPE continuing Education Course series 1.

Fitch P.J.R, Lovell M.A, Davies S.J, Pritchard T and Harvey P.K (2015). An integrated and quantitative approach to petrophysical heterogeneity. Marine and Petroleum Geology, 63, 82-96.

Franks S. and Nairn A. E. M. (1973): The equatorial marginal basins of West Africa. In Nairn, A. and Stehli, F. (Eds), the ocean basins and margins. The South Atlantic Plenum press, 301- 350.

Furon R. (1963): Geology of Africa. Oliver and Boyd, London. 377

George O. (2014): Nigeria's Oil Reserve Depletes to 35 Billion Barrels. The Sun News Paper, Retrieved from http://sunnewsonline.com/new/? p = 56870.

Jarot S. and Samsuri A. (2003): Characterization, Pressure and Temperature Influence on the Compressional and Shear Wave Velocity in Carbonate Rock. International Journal of Engineering & Technology IJET, 9(10): 80-93.

Jenson J.J, Lake L.W, Corbett P.W.M, Goggin D.J (2000). Statistics for Petroleum Engineers and Geoscientists in: Handbook of Petroleum Exploration and Production, second ed. Vol 2, Elseview Science B.V, Amsterdam.

Judson D.R., Lin J., Schultz P. S., and Sherwood J. W. C. (1980): Depth Migration after Stack: Geophysics, 45, 376 - 393.

Lees G. M. (1952): Foreland Folding: Quarterly Journal of Geology Society, London, 108.

Matheis G. (1976): Short review of the geology of the Chad Basin in Nigeria. C.A. Kogbe (Ed), Geology of Nigeria, Elizabethan Publishing Nigeria, 289-294.

Mukerji T., Avseth P., Mavko G., Takahashi I. and González E. (2001): Statistical rock physics: Combining rock physics, information theory, and geostatistics to reduce uncertainty in seismic reservoir characterization, The Leading Edge,20(3), 313 – 319.

Nwankwo C. N (2007): Heat flow studies and hydrocarbon maturation modeling in the Chad basin, Nigeria.

Unpublished Ph. D. Thesis, University of Port Harcourt, Port Harcourt.

Nwankwo C.N and Ekine A.S (2009). Geothermal gradients in the Chad Basin Nigeria from bottom hole temperature logs, Int. journ of physical Sci., 4(12): 777-783.

Okosun, E.A. (1995): Review of the geology of Bornu basin. Journal.Mining and Geol, 31 (2): 113-120.

Olugbemiro R. O., Ligouis B. and Abaa S. I. (1997): The Cretaceous Series in the Chad basin, NE, Nigeria: source rock potential and thermal maturity. Journal of Mining and Geology, 20(1), 51- 68.

Petters S.W. (1981): Stratigraphy of Chad and Illumeden Basin (West Africa). Eclogae Geology Helvetate. 74: 39-159.

Plona T. J. and Johnson D. L. (1984): Acoustic properties of porous systems: I. Phenomenological description: In Physics and Chemistry of Porous media, edited by D. L.

Polymenakos L., Papamarinopoulos S., Miltiadou A. and Charkidakis N. (2005): Investigation of the Foundation of a Byzantine Church by Three Dimensional Seismic Tomography: Journal of Applied Geophysics, 57, 81 - 93.

Plummer C. C. and McGeary D. (1993): Physical Geology 6th Edition. Wm. C. Brown Publishers, England.

Selley R. C. (1998): Concept and methods of subsurface facies Analysis: Imperial College University press, London.

Sheriff, R.E; (1991): "Encyclopaedic Dictionary of Exploration Geophysics", 3rd Ed. Society of ExplorationGeophysicists, USA.

Tamunobereton-ari I., Omubo-Pepple V.B. and E.D. Uko. (2010): The Influence of Lithology and Depth on Acoustic Velocities in South-east Niger Delta, Nigeria. American Journal of Scientific and Industrial research.1 (2), 279 -292.

Tamunobereton-ari I., Omubo-Pebble V. B. and Uko, E. D. (2011) Determination of the Variability Seismic velocity with Lithology in the South-Western part of Niger Delta Basin Nigeria using well logs. Journal of Basic and Applied Scientific 1(7), 700-705.

Wyllie M.R., Gregory A.R. and Gardner G.H.F. (1958): An experimental investigation of factors affecting elastic wave velocities in porous media. Geophysics, 23:400.