RESEARCH ARTICLE OPEN ACCESS

Effect of Porosity on Acoustic Impedance: A Case Study of South-Eastern Niger Delta, Nigeria.

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Abstract:

One major challenge encountered during geophysical exploration for oil and gas is identifying reservoir rock types. One useful tool for tackling this challenge is to identify the relation between porosity and acoustic impedance in the reservoir rock of interest. Therefore, this study was carried out to estimate the effect of porosity on acoustic impedance for a given Oil field in part of Niger Delta using wireline log data from 4 wells (A, B, C and D). This was done to characterize the relationship between porosity and acoustic impedance in the Niger Delta region at large. The wireline data used for this study consist of Sonic Log, Density, Gamma ray, Resistivity and Caliper log. The data were analysed using Hampson Rusell software. The reservoir evaluation was carried out on the well to determine the reservoir of interest in the wells. Log transforms were done in which rock attributes that were not existing were generated using the eLog in the Hampson Russell Software. Crossplots of estimated values acoustic impedance against porosity were done for the 4 study wells. Estimated values of acoustic impedance and porosity for the 4 study wells had ranges between 1500-47000ft/s*g/cc and 5-66% respectively. Analysing the crossplots showed that porosity and acoustic impedance have an inverse relationship in reservoir rocks of the Niger Delta, with regions of high acoustic impedance and low porosity indicates that the rock matrix is predominantly shaley while regions of low acoustic impedance and high porosity indicates that the rock matrix is predominantly sandy. The reservoir rocks of the Niger Delta are thus said to be made of shaley-sandstones. Additionally, these findings also show that seismic waves are more impeded in rock matrices that are predominantly shaley, relative to rock matrices that are predominantly sandy.

Keywords — **Acoustic Impedance, Porosity, P-Impedance, Well Logs, Intercalation.**

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I. INTRODUCTION

In petroleum exploration, the first step towards a successful hydrocarbon discovery is in obtaining a good subsurface image of the reservoir properties [1]. Such subsurface properties include porosity, i.e. the pore fraction of the rock, and acoustic impedance, i.e. the measure of how much resistance is experienced by seismic waves as they propagate through rock matrix.

Porosity and acoustic impedance are some of the most challenging properties to determine in subsurface reservoir characterization with the complexity of assessing them originating from the fact that porosity and acoustic impedance may vary essentially over a sedimentary basin [2], such as in the Niger Delta Basin. However, porosity have the most im-pact on reserves and production forecast, and consequently on the economy of a prospect [3, 4].

On a global scale, hydrocarbon resources are finite and the rate at which new hydrocarbon discoveries are found is in a decline, particularly during the period when the urgent need for oil and gas continuously increases [5]. The production rate in many areas supersedes that of reserves substitute. On the other hand, in several mature hydrocarbon provinces, the reserves are there; but they need to be located or extracted more resourcefully [6]. A robust combination of reservoir characterization techniques and the latest software packages yields top-notch advancements to production in existing fields. The ultimate objective therefore of a petroleum geoscientist is to define reservoirs in terms of its porosity, permeability, fluid content, lateral and vertical heterogeneity and net-to-gross prior to drilling and during production [7]. Much work is done to include as many sources of information as possible into reservoir characterization. Information is re-quired from well logs, cores and cuttings, seismic and pro-duction data and geotechnical input.

Additionally, the oil industry is moving to "earth-model-centric" roadmap in which the geological model is continuously updated throughout the life cycle of the field adding any new data to the already existing pile, with the updated model essential for future field development decisions [8, 9].

Many geological processes are significantly impacted by porosity of the rocks involved. This is especially valid in the case of sedimentary basin like the Niger delta. Porosity virtually influences the compaction and consolidation of sediments; and these processes are important in connection with oil reservoirs. Conversely, porosity and acoustic impedance of sediments are liable to checked changes sediments experience geological evolution [10].

In this study, well log data from four (4) oil wells in parts of South-Eastern Niger Delta were analysed to characterize the effect of porosity on acoustic impedance in the reservoir rocks of the Niger Delta region.

II. LOCATION OF STUDY AREA

The four (4) well logs used in this study were from ‘Arkwo Creek, situated in the seaside Swamp depobelt of south-eastern Niger Delta (Fig. 1), with base map in Fig. 2 showing the locations of the four (4) study wells. The field is situated between latitude 40°N and 60°N and longitude 30°E and 90°E and sited on the West African continental margin, at the apex of the gulf of Guinea, which shaped the site of a triple intersection amid mainland separating in the cretaceous age [11].

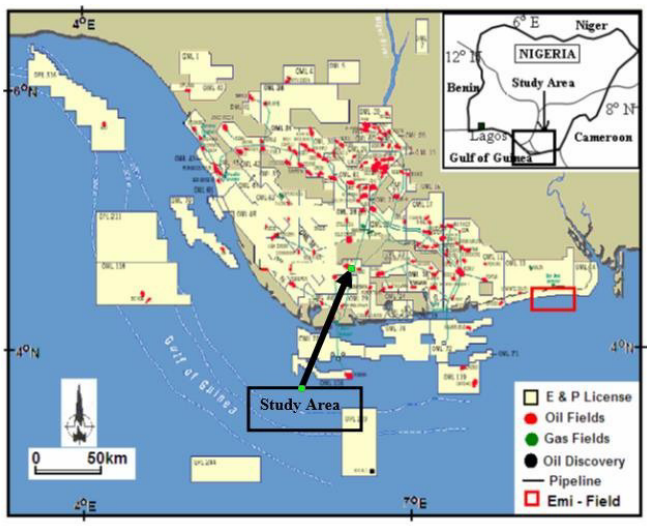

Fig. 1: Map of Niger Delta Showing the Study Area [12]

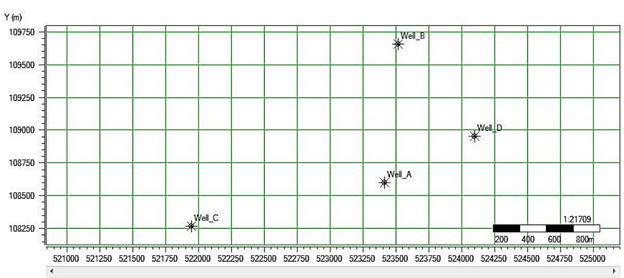

Fig. 2: Base Map Representing the Grid View of the Well Location

The Niger Delta is one of the world’s biggest tertiary Delta framework, and to a great degree, productive hydrocarbon region [13]. It is perhaps the most critical sedimentary basin in sub-Sahara Africa concerning Petroleum product [14]. Its present morphology is that of wave dominated delta with a smoothly seaward – convex coastline traversed by distributaries. From peak to coast the aerial portion extend more than 300km [13], covering a zone of 75,000km^2 [15, 16]

III. METHODOLOGY

The data available in this study consist of digital well log data which include Header information, Derrick Floor elevation (DFE), Checkshot Survey from the Niger Delta. The data consists of suites of Four Wells (A, B, C and D) which was analysed using HAMPSON RUSSELL Software (HRS).

The selection of well log data include: Sonic log, Density log, Caliper log, Porosity log, Gamma Ray log, and Resistivity log. The inverse of the interval transit times of the sonic logs were used to generate the compressional velocities for each well. Shear log data are not available but were generated from Castagna´s relation.

The well logs, each with a basic petrophysical log suite, was loaded and compiled in a new project. Also, other data imported include checkshot, directional survey and well markers. The purpose of the checkshot is for time to depth conversion, which enables a view of the logs in time and as well as in depth. The directional survey gives the trajectory of the wells that is if the well is straight or deviated. The well markers are used in identifying the probable reservoir within the well logs. The markers also give information on reservoir properties such as porosity, water saturation and thicknesses, hydrocarbon water content and gas oil content.

In practice, well logs contain several inherent problems especially problems of inversion [17, 18]. Efforts are thus made to check the data for quality control. The logs are de-spiked, filtered, altered to get rid of false result and up-scaled utilizing blocking schedules to diminish the spread in the lithology, fluid and cross plot examinations.

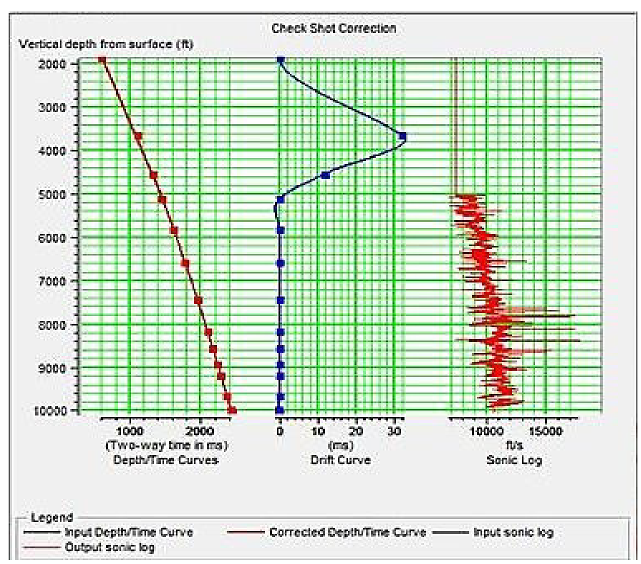

Fig. 3: Check Shot analysis window (Applicable to all the wells)

This first phase of the pre-interpretation process undertaken during this work was to edit the well logs. The log editing operations applied in this work include mainly median filtering and checkshot reticulation. This can be performed using the LOG MATH Function of the Hampson Russell eLOG apparatus. A median filter is applied with the goal to decrease the spurious effect caused by high frequency noise appearing as an abnormal spike in the log curves. Check shot correction shown in Fig. 3 was applied to the sonic log to correlate well log data with seismic data. The check shot correction operation modifies the depth-time curve associated with a sonic log to improve the tie between a synthetic and real seismic data [19].

The P-impedance (Acoustic impedance) curve is not among the available logs. Since acoustic impedance is the product of a porous media's density through which the sound wave travels and the velocity of the sound wave, the P-impedance curve is thus created from the product of P-Wave velocity and density, as estimated from density logs.

The Porosity of the formations were obtained density log. The porosity value is calculated from the relation embedded in the HRS (Hampson Rusellel Software) as shown in equation 1;

$$\Phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad (1)$$

Where;

$\Phi =$ Density log-derived porosity

$\rho_{ma} =$ Matrix density ($2.69gcm^{-3}$, Density of sandstone)

$\rho_b =$ Formation bulk density from density log (in gcm^{-3})

$\rho_{fl} =$ Fluid density ($0.75gcm^{-3}$, Density of oil contained in the drilling mud)

Crossplots were then employed to investigate how the acoustic impedance within the reservoir rocks identified within the study area is influenced by the porosity of the reservoir rocks.

IV. RESULTS

Crossplots of acoustic impedance and porosity impedance estimated from the reservoir rocks identified from the four (4) study wells are show in Figs. 4 to 7.

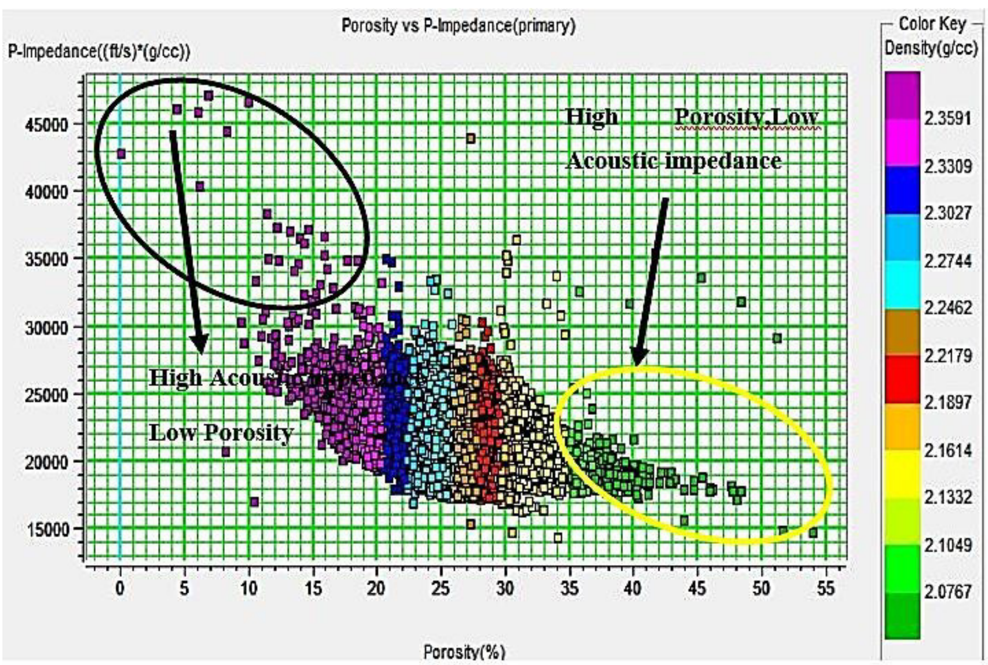

Fig. 4: Crossplot of Acoustic Impedance against Porosity in Reservoir Rocks of Well A

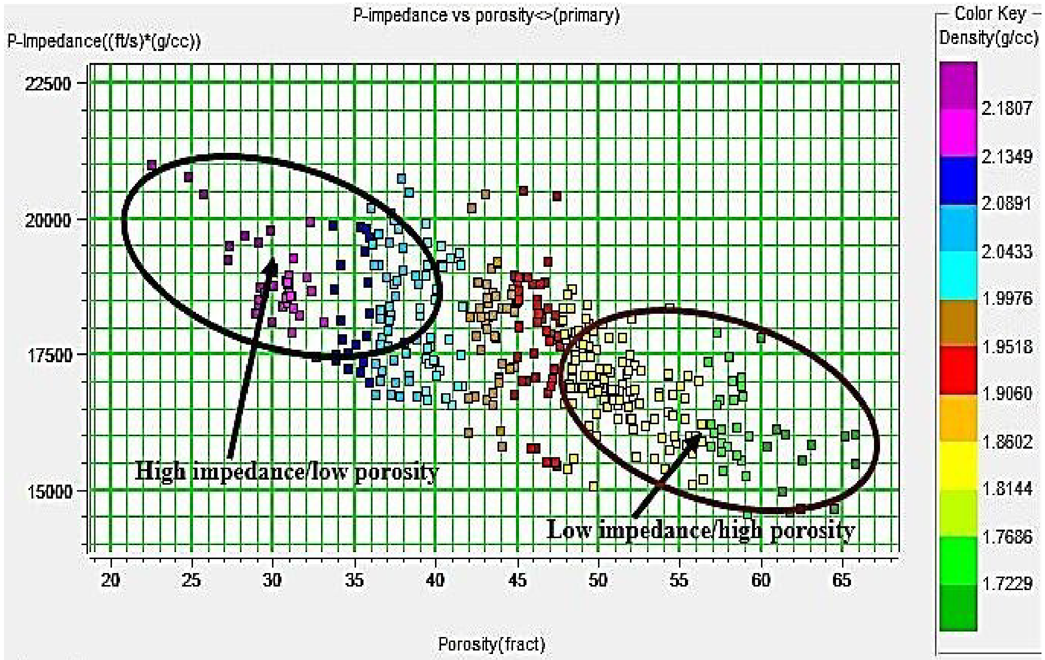

Fig. 5: Crossplot of Acoustic Impedance against Porosity in Reservoir Rocks of Well B

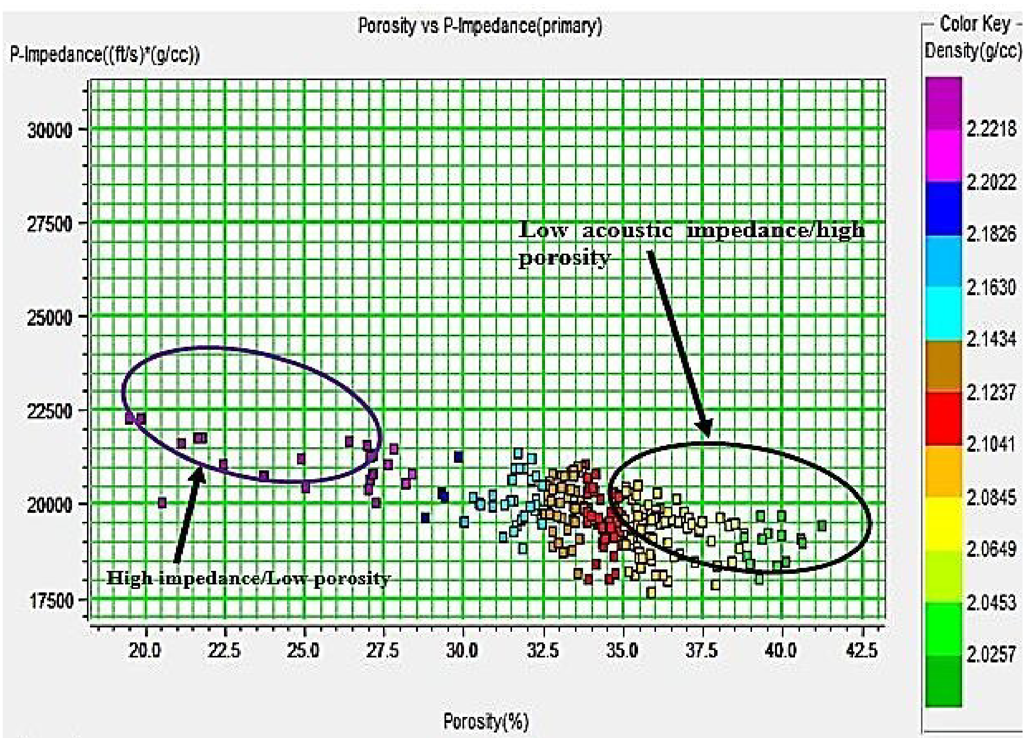

Fig. 6: Crossplot of Acoustic Impedance against Porosity in Reservoir Rocks of Well C

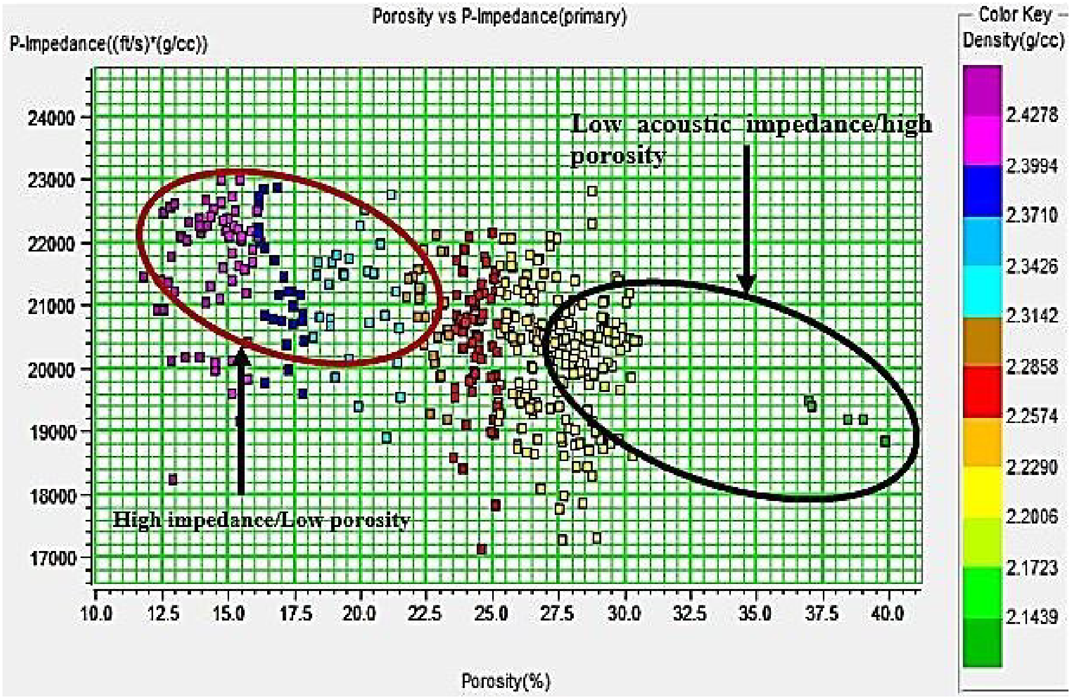

Fig. 7: Crossplot of Acoustic Impedance against Porosity in Reservoir Rocks of Well D

V. DISCUSSION

As shown in Fig. 4, a crossplot of porosity versus acoustic impedance shows that acoustic impedance increases from 15000 ft/s*g/cc to 47000 ft/s*g/cc as porosity decreased from 55% to 5%. However, it was observed that reservoir rocks in Well A are characterized by zones of high acoustic impedance (30000-47000ft/s*g/cc) with low porosity (17-0%) and zones of relatively low acoustic impedance (25000-15000ft/s*g/cc) with high porosity (35-55%).

For Well B, Fig. 5, it is observed that there are regions within the reservoir rock where acoustic impedance and porosity have inverse relationships. As shown in the figure 5, the black oval shape indicates region of high acoustic impedance which increases from 17500ft/s*g/cc to 21500ft/s*g/cc with low porosity values that decreases from 20% to 45%. Also mapped out by the dark red oval shape is a region of relatively low acoustic impedance, decreasing from 18000ft/s*g/cc to 14500ft*g/cc, and high porosity values, ranging from 50% to 60%.

For well C, as seen in Fig. 6, analysis of the crossplot reveals a progressive inverse relationship between acoustic impedance and porosity. It is observed that as the Acoustic impedance increases, the porosity decreases. The purple oval shape in Fig. 6 shows region of high acoustic impedance value which increases from 2000ft/s*g/cc to 4500ft*g/cc and low porosity value which decreases from 15% to 5%. Additionally, regions of low Acoustic impedance, decreasing form 2000ft/s*g/cc to 1500ft/s*g/cc, and increasing porosity values, 35% to 42%, as mapped out by the black oval shape.

Similar trend where the Acoustic Impedance decreases as the porosity values increases is shown in Fig. 7 for well-D. The dark red oval shows region of high acoustic impedance value ranging from 2000ft/s*g/cc to 2300ft/s*g/cc with porosity range of 12.5 % to 22.5% and black oval show the region of low acoustic impedance value ranging from 2100ft/s*g/cc to 1800ft*g/cc with porosity increase range of 27 % to 40%.

Generally, it is evident that within the reservoir rocks of interest, porosity and acoustic impedance have an inverse relationship as increasing porosity leads to a decreasing acoustic impedance and vice versa. This could be attributed to the fact that as porosity increases, the density of the in-situ rock decreases, leading to a decrease in seismic wave velocity through the rock and consequently reduction in acoustic impedance [20]. Previous research [21, 22] has shown that shales are characterized by high acoustic impedance and low porosity while sandstones are characterized by relatively low acoustic impedance and high porosity. Therefore, the presence regions of high acoustic impedance and low porosity and low acoustic impedance and high porosity within the same reservoir rock could be indicative of the intercalation of shale and sand. This is quite typical of reservoir rocks of the Niger Delta Region [23, 24].

Furthermore, these results show that seismic waves are more impeded in shaley rock matrix relative to sandstone rock matrix, even though shales are denser compared to sandstones. This could be attributed to the fact that clays have the tendency of significantly reducing a rock's tendency to shear, thereby reducing its shear modulus [25].

VI. CONCLUSION

From the result on the analysis, the following conclusions are drawn:

i. Estimates of acoustic impedance within the study area had a range of 1500-47000ft/s*g/cc.
ii. Estimates of porosity in the study area had a range of 5-66%.
iii. The crossplot of Porosity versus Acoustic impedance revealed that there exists an inverse proportionality relationship between Acoustic impedance and porosity for the reservoir rocks in the field of interest.
iv. There is an intercalation of sand/shale formations within the reservoir rocks of the field of interest, and consequently the reservoir rocks of the Niger Delta.
v. Shales offer more resistance to propagation of seismic waves relative to sandstones.

ACKNOWLEDGEMENT

The authors are very appreciative of Shell Petroleum Development Company, Nigeria, for providing the data used for this study. Also, we would like to thank Mrs. Blessing O. Davies for her insight and encouragement while this research lasted.

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