ELASTIC-WAVE AND RELATED PROPERTIES OF CLASTIC ROCKS FROM A PART OF NIGER DELTA, NIGERIA

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Abstract: Elastic-wave velocities of drill-core specimens with mineral compositions and textures of elastic rocks at Niger Delta, Nigeria, can be useful for identifying large zones of high porosity or high clay content (such as some fault zones, or the clay-rich haloes surrounding known uranium ore bodies). The overall objective of this study is to identify zones of high porosity and high clay contents using elastic-wave velocities V_p and V_s, and the ratio V_p/V_s. Thin sections were studied, and measurement of V_p, V_s, and porosity were made from cylindrical core specimens representing the Niger Delta Agbada Formation. Multiple linear regression has been employed to determine $1\backslash V_p$ and $1\backslash V_s$, and the ratio V_p/V_s as a function of porosity (ϕ) and clay fraction (Fc) for all specimen from the study area. The seismic velocities V_p and V_s, and the ratio V_p/V_s for Agbada sediment are found to be influenced by changes in porosity more strongly than by changes in clay content by a factor of approximately four. For clay fractions less than 0.15, simple linear relationships appear to exist between the reciprocal velocities $1/V_p$ and $1/V_s$, and the ratio V_p/V_s, and porosity.

Keywords: Compressional, shear velocity, porosity, permeability, clastic rock

1. INTRODUCTION

In addition to conventional compressional-wave surveys, widespread use is now being made of shear-wave velocities in seismic surveys. A number of workers in recent years have described methods for obtaining such data. They have demonstrated the importance of the ratio of compressional- to shear-wave velocity V_p / V_s in interpreting field data in terms of lithology and texture, and as an indicator of the presence of hydrocarbons in oil exploration. Field methods for obtaining shear-wave as well as compressional-wave data for the purposes of lithological identification have been described by a number of authors like [1-3]. [4] studied means for determining rock lithology and porosity from Vp and Vs laboratory measurements.

[5] applied geostatistical techniques to relate transit times from surface seismic reflection to porosity measurements from wells, and compared the results to those derived from linear regression by [6-11]. [12] investigated the effect of changes in clay content on Vp/Vs in clastic silicate rocks.

[13] presented work-relating petrophysics to porosity and velocity. They developed a petrophysical classification of siliciclastics to predict lithology and porosity from seismic velocity. They presented results for Vp/Vs vs porosity. In their work they fit linear and polynomial trends to the laboratory data; their results show an increase of Vp/Vs with porosity.

Thin sections were studied, and measurement of Vp,Vs and porosity were made for 40 core samples representing both the Niger Delta clastic rocks and the underlying basement material. Permeability measurements were made on 10 samples from two of the boreholes.

The dominant lithostratigraphic succession in the area discussed by [14] is a marine and monotonous marine shale (Akata Formation), followed by interbedded shallow-marine and fluvial sands, silts and clays (Agbada Formation, and a continental sand section, Benin Formation (Figure 1).

The degrees of compaction and cementation of the Agbada Formation, according to [15], is made up of deposit of five sub-environments: fluviatile; backswamp and lagoonal sediments; barrier bar sand; barrier foot (interbedded sand, silt and clay); marine clay and transgressive deposits.

2. MATERIALS AND METHODS

Geophysical Measurement

The well information used for this study describing the Agbada Formation is an area of 6 km by 5 km, slightly larger than the 3D seismic data set. The area contains 20 Vertical Seismic Profiling

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(VSP) points, including core samples, porosity-permeability measurements and wireline logs (Figure 2).

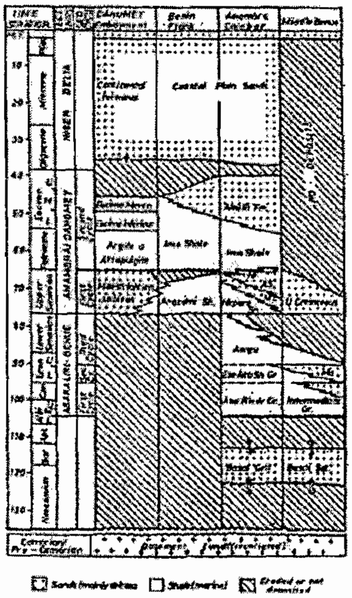

Fig. 1: Niger Delta Stratigraphic Synopsis (Murat. 1970)

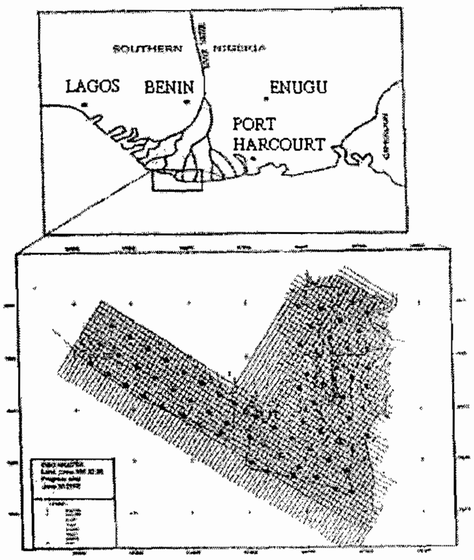

Fig. 2. Map of Niger Delta showing the location of study area within the limit of survey and well control points

A total of three wells were selected for petrophysical measurements. All of these wells are located inside the well control area for the study. The core samples were 50 mm in diameter and approximately 75mm in length.

The bulk densities of water-saturated specimens were calculated after they were weighed. The specimens were dried for 24 hours in a vacuum at a constant temperature of 800C. They were again weighed and the densities calculated. The volume of water removed during drying was used in calculating the porosity of each sample. The accuracy in measuring the fractional porosity is estimated to be approximately 0.002.

The compressional- and shear-wave velocities were recorded from the conventional seismic reflection data technology. The compressional and shear data set were used to show how these properties are distributed through the reservoir interval.

3. RESULTS AND DISCUSSION

Preliminary studies

The lithological factors that might be expected to affect elastic-wave velocities in rocks from the Niger Delta are clay content, porosity and permeability. Petrophysical measurements of porosity, density, Vp, permeability, and clay content are plotted as function of depth for the three Wells numbered A, B and C. Their detailed variations are shown in Figures 3,4 and 5.

Density

The densities of the layers studied vary between 2434 and 2508 kg/m3, although there are significant local deviations from these values. In general, the values of density show little significant depth or stratigraphic variations. Changes in the clay contents also appear to have no observable effect on the values of measured density, but an increase in clay usually occurs with a concomitant increase in porosity.

Clay content

Clay fractions vary mainly between 0.05 and 0.15 but range from nearly 0 to 0.40. In general, the correlation between clay fraction and Vp shows that an increase in clay content results in a marked decrease in Vp. It should be noted that as the clay fraction increases, the porosity appears to increase by only a small amount. Figures 3,4 and 5 indicate a general but slight increase in clay content with depth in the upper part of each well, with little overall change in the lower portion.

Grain size

The various stratigraphic units at study area are delineated mainly by grain size (Figure 1). There is no difference in Vp with stratigraphic position as shown in Figures 3,4 and 5. Also, Figure 7 shows no differential clustering from plots of Vp vs porosity for various grain sizes indicating that grain-size variation has little to no effect on Vp in the Agbada Formation

Porosity and Permeability

The calculated porosities are between 0.05 and 0.10. Figures 3,4 and 5 do reveal a slight variation of porosity with depth, and a direct relationship between Vp and porosity. Figure 6 demonstrates clearly that Vp decreases as porosity increases.

The permeability is locally highly variable but, in general, appears to decrease with depth despite the uniform porosity (Figures 4 and 5).

Linear regression analyses of the preliminary results for layers from each of the wells are shown in Table1. The overall changes in these parameter -density, porosity and

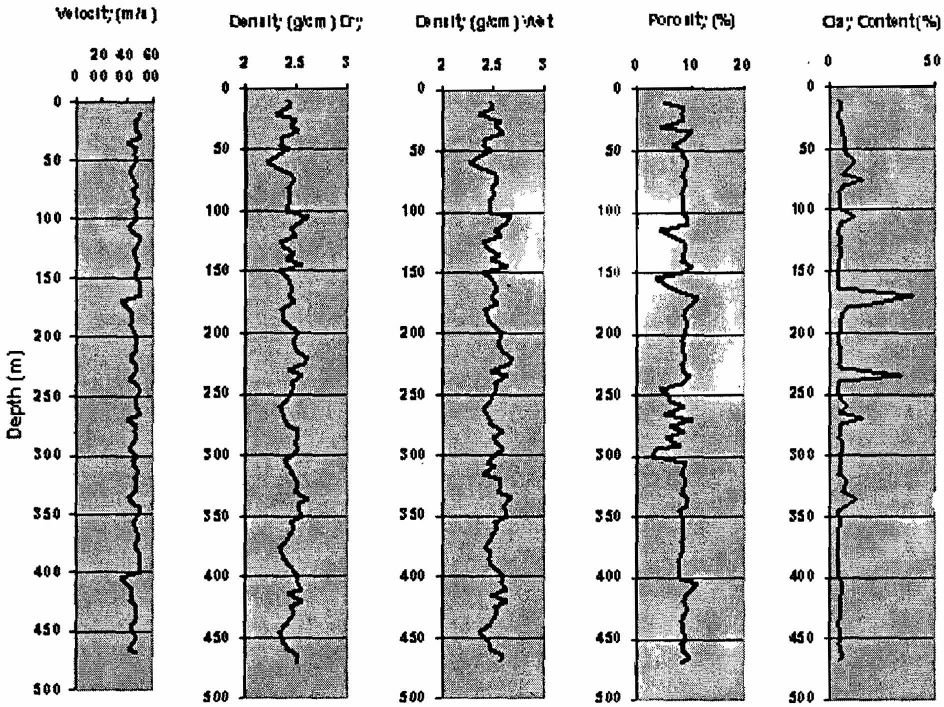

Fig. 3: P-wave velocity, Water-saturated density for dry and wet samples, Porosity and Clay Content for Core samples from Well A.

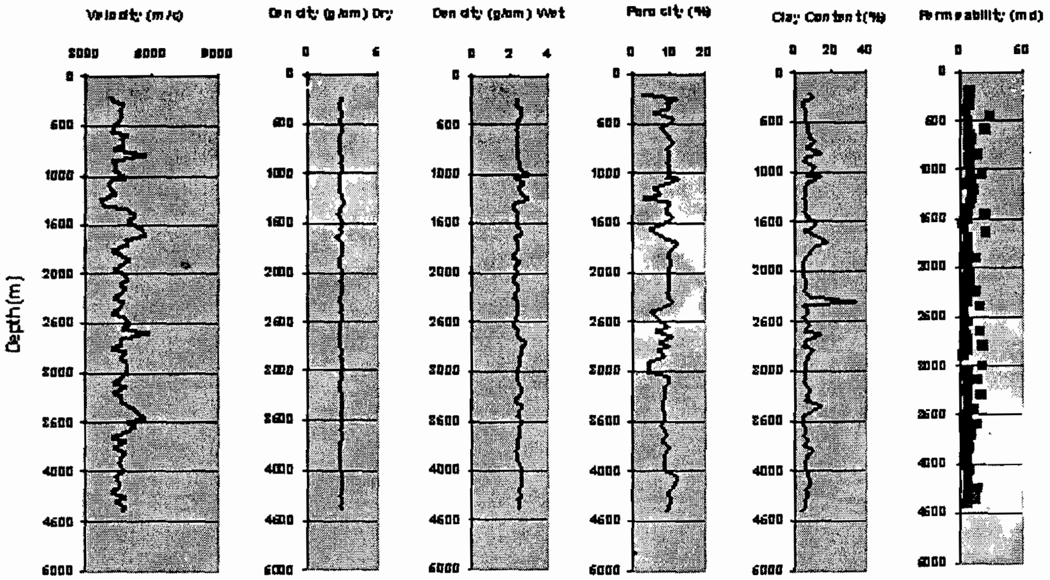

Fig. 4: P-wave velocity, Water-saturated density for dry and wet samples, Porosity, Clay Content and permeability for Core samples from Well B.

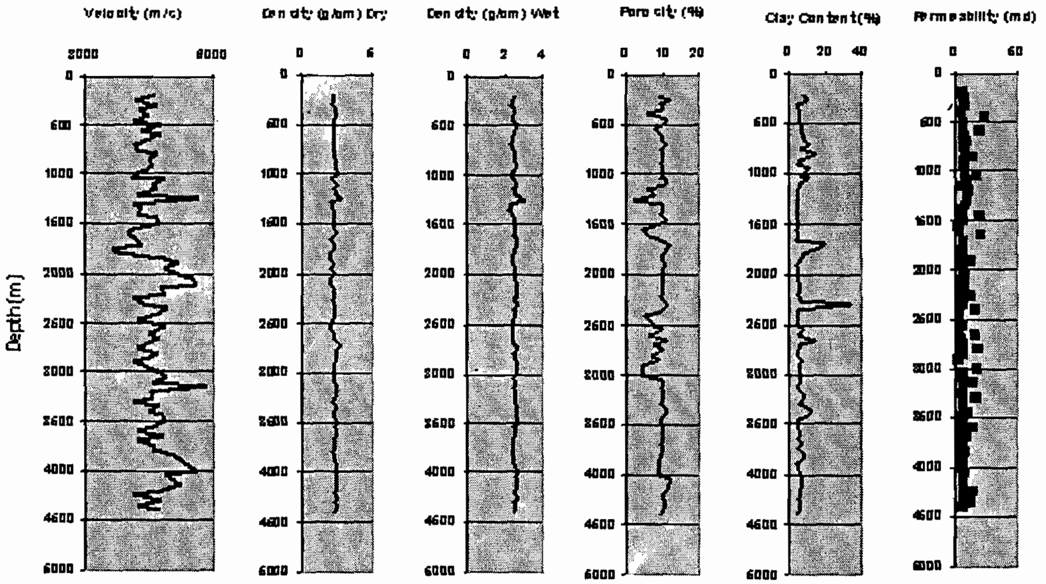

Fig. 5: P-wave velocity, Water-saturated density for dry and wet samples, Porosity, Clay Content and permeability for Core samples from Well C.

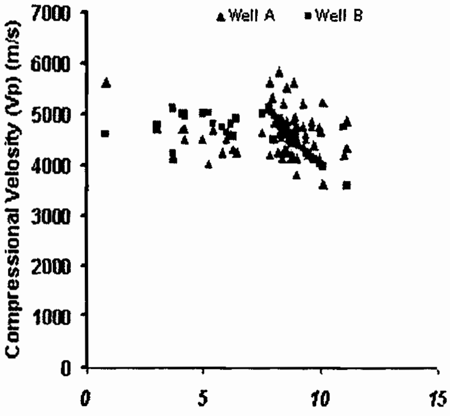

Fig. 6a: Plot of Vp against Porosity for Well A and B.

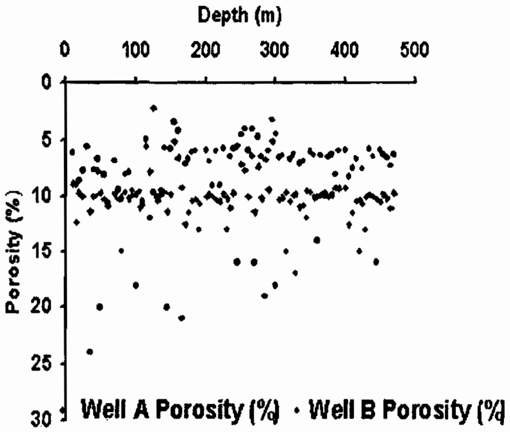

Fig. 6b: Plot of Porosity against depth for Well A and Well B

Table 1. Table showing the relationship between seismic properties, porosity and net overburden pressure.

Net Overburden Pressure (psi)	**50**	**100**	**150**	**200**	**250**	**300**	**50**	**100**	**150**	**200**	**250**	**300**
Porosity %	**V_p (m/s)**						**V_s (m/s)**					
3	**2450**	**2458**	**1268**	**2365**	**2255**	**2230**	**1155**	**1150**	**1140**	**1135**	**1120**	**1100**
6	**2380**	**2360**	**2345**	**2285**	**2265**	**2250**	**1115**	**1120**	**1090**	**1080**	**1075**	**1070**
9	**2205**	**2200**	**2190**	**2150**	**2080**	**2065**	**1050**	**1043**	**1035**	**1020**	**1015**	**1005**
12	**2195**	**2180**	**2175**	**2150**	**2130**	**2090**	**1045**	**1043**	**1030**	**1036**	**1007**	**990**
14	**2080**	**2060**	**2050**	2040	**1960**	**1950**	**1025**	**1016**	**1000**	**995**	**980**	**975**
16	**1950**	**1955**	**1925**	1928	1825	**1924**	**1045**	**1040**	**959**	**956**	**950**	**930**

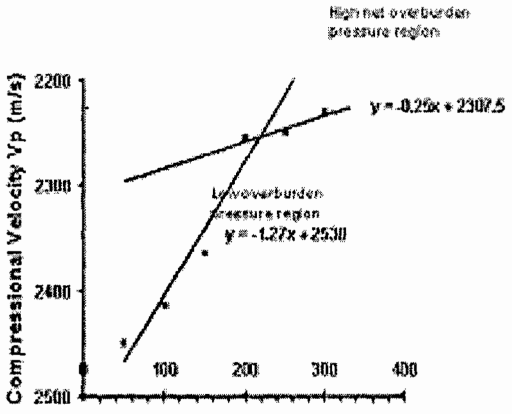

Fig. 7a: Graph showing the relationship between Compressional wave velocity Vp and Net Overburden Pressure

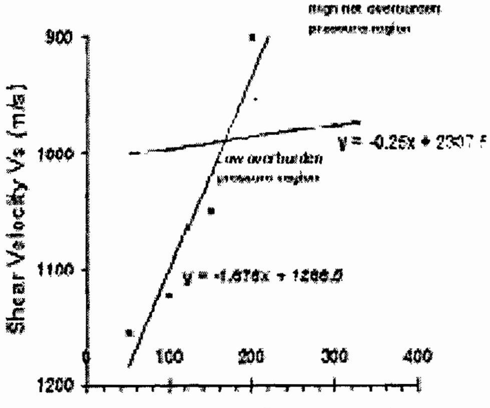

Fig. 7b: Graph showing the relationship between Shear wave velocity Vs and Net Overburden Pressure

Vp with depth are not dramatic, as it is evident from the low magnitude of the slopes from the regression. Grain size has little to no effect on Vp. Porosity and clay content, however, serve as important controls on the rocks' seismic velocities.

Elastic-wave velocities

Vp and Vs for typical water-saturated Agbada Formation of the Niger Delta specimens are plotted as functions of net overburden pressure from 50 to 300 psi in Figure 7 for sample porosities in the range 0.03 to 0.16. The pronounced changes in slope for Vp and Vs at low net overburden pressure probably result from the closure of microcracks of small aspect ratios at these stresses. A statistical analysis of Vp / Vs ratio for all specimens tested (Fig. 8) indicates that in the range of net overburden pressure from 50 to 300 psi there is only a small increase in Vp / Vs. This overall change (an increase of 0.07 percent) is considerably less than the 0.8 percent uncertainty based on the precision of the experimental results. [1] showed in their study that once the microcracks of small aspect ratios in a porous sandstone are closed, Vp / Vs is relatively insensitive to further changes in net overburden pressure (as might be caused by an increase in net overburden pressure 50 to 300 psi.

[6] predicts a linear relationship for Vp / Vs as a function of porosity proposed for water-saturated porous rocks from his empirical time-average relationship. Multiple linear regression as functions of porosity (ϕ) and clay fraction (Fc) for a total of 40 rock samples from the Agbada Formation are determined. .The velocities used are those measured at net overburden pressure of 300 psi (to avoid the effects of the presence of microcracks). The regressions determined for 1/ V_p, 1/ V_s and V_p / V_s are shown in Table 2. The standard deviations of the regression coefficients for ϕ and Fc and multiple correlation coefficient r, are as listed in Table 2. These regression coefficients are significant at the 0.1 percent level and that regression of the dependent variable in each case ϕ and Fc accounts for a significant amount of the variation in the dependent variable.

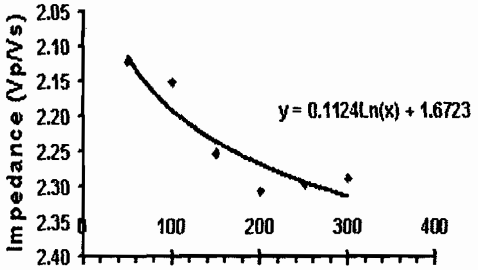

Fig. 8: Graph showing the relationship between Impedance (Vp/Vs) and Net Overburden Pressure (psi)

Table 2: Regression table for Parameters 1/ V_p, 1/ V_s and V_p / V_s as a function of Porosity

Parameter y	Slope a_0	Intercept a_1	Regression Coefficient R^2
1/ V_p	0.034	4.00	0.95
1/ V_s	0.002	4.00	0.93
V_p / V_s	0.015	2.10	0.85

The relationships are shown in Table 3 for 1/ V_p, 1/ V_s and V_p / V_s in the porosity range 0 to 0.15 and for clay fractions from 0 to 0.3. It is seen that increases in ϕ and F_c result in increases in magnitude of all three parameters 1/ V_p, 1/ V_s and V_p / V_s. It is clear also that these parameters are more sensitive to changes in porosity than to those in clay content by a factor of approximately four. This conclusion is similar to those of [16] and [12].

Table 3: The relationships for 1/ V_p, 1/ V_s and V_p / V_s in the porosity range 0 to 0.15 and for clay fractions from 0 to 0.3.

Porosity (%)	Clay Fraction (%)	1/Vp	1/Vs
3	5	4.1	8.7
6	10	4.1	8.9
9	15	4.2	9.5
12	20	4.4	11.1
14	25	4.4	10.2
16	30	4.5	10.3

A study of the relationships for 1/ V_p, 1/ V_s and V_p / V_s have been ploted in Figures 9 and 10 as functions of porosity for the samples having a clay fraction less than 0.15. The correlation coefficients shown in Figures 9 and 10 indicate that each of the regressions is significant at better than the 1 percent level. The increases in 1/ V_p, 1/ V_s and V_p / V_s with increasing porosity are similar in magnitude to those reported by [4].

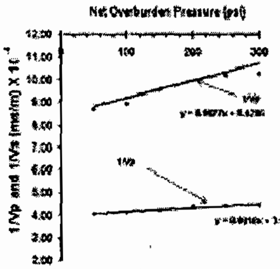

Fig.9: Graph of 1/Vp and 1/Vs against Net Overburden Pressure (psi)

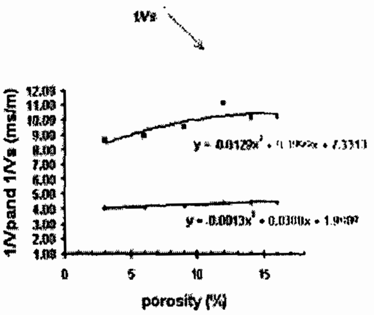

Fig. 10a: 1/Vp and 1/Vs) versus Porosity for Net Overburden Pressure of 300 psi

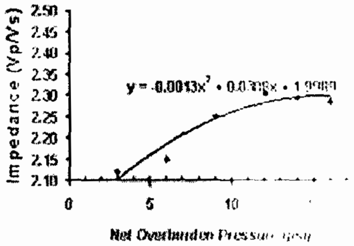

Fig. 10b: Impedance (Vp/Vs) versus Poros for Net Overburden Pressure 300 p

4. CONCLUSION

The main feature of the Agbada Formation of the Niger Delta is variation in grain size along with considerable variation in clay content. However, neither of these features appears to affect seismic velocities.

Marked variations in velocities V_p and V_s and the ratio for V_p / V_s of the Agbada Formation of the Niger Delta are functions of changes in porosity and clay content. Increases in both clay and porosity cause reductions in Vp / Vs, but clay has only about one quarter the effect of porosity in the range of porosities 0 to 0.03 and clay fraction 0 to 0.4. For clay fractions less than 0.2, simple linear relationships appear to exist between the reciprocal velocities 1/ Vp and Vs / and the ratio / and porosity. The relationships between seismic velocities and net overburden pressure show that it is linear; seismic properties increase faster (high slope) in low net overburden pressure regions and slower (low slope) in high net overburden region.

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