Rock Physics Analysis and Templates for an Unconsolidated Sand Reservoir in Aka Field Offshore Niger Delta

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Abstract
Rock Physics analysis and templates of an unconsolidated segments of wells from Aka field in the Niger Delta, have been performed for lithology and fluid classification. The analysis was based on the assumption that if well log data points fall close to a theoretical line in velocity-porosity planes, then the internal structure of a rock is similar to the idealized structure predicted by the theoretical model. Three suite of well logs containing: gamma ray, spontaneous potential, deep and shallow resistivity, density, neutron-porosity, compressional sonic log and one dipole sonic data; check shot and base map of the studied area were used. The fairly unconsolidated oil sands and their close shale zones were mapped for petrophysical analysis of the well logs. Several models of friable sand model, contact cement model and constant cement model, with varying degree of diagenetic process; were built to define the contents of the reservoirs. Hertz-Mindlin theory, combined with modified Hashin-Shtrikman lower bound and Gassmann fluid substitution were applied to create a rock physics framework for the quantitative analysis along with some established constants for fluids and reservoir lithologies typical of Niger Delta. The oil sands unconsolidated sessions have depth ranges from 4158 – 4167 m, 3876 – 3891 m and 3560 – 3592 m for well-1, well-2 and well-3 respectively. The values of water saturation, density, P-velocity and S-velocity of the oil sand unconsolidated sessions range from 21 - 22%, 2.25 - 2.35 g/cc, 2800 – 2950 m/s and 2251 - 2372 m/s respectively. The Greenberg-Castagna equations predicted for the field are: \( V_s = 0.8043V_p - 0.8561 \) and \( V_s = 0.7724V_p - 0.8668 \) for sand reservoirs and shales respectively. The crossplots of shear velocity against porosity show the porosity value of oil sand that range from 24 - 26%, within 2 - 3% degree of diagenetic process of constant cement model. The crossplots of shear impedance \( V_p/V_s \) against acoustic impedance also show similar distinct classification of fluid and lithology that was in agreement with the estimated oil sand porosity range.

Key words: Rock Physics, lithology, reservoir, P-velocity, constant cement model.

INTRODUCTION
Conventional seismic interpretation implies picking and tracking of laterally consistent seismic reflectors for the purpose of mapping geologic structures, stratigraphy and reservoir architecture. His traditional seismic reservoir characterization puts emphasis on finding the geographical meaning
Rock Physics is the link between rock properties and seismic interpretation; it is the fundamental constituent to the quantitative integration of surface seismic data, well logs and core information. It allows point-by-point translations of elastic properties to reservoir properties. Rock Physics is a point-based relationship and seismic data is band-limited. Seismic reservoir characterization requires linking this point-based Rock Physics relationships to band limited seismic data and statistical methods to account for the ambiguous relationships between elastic and reservoir properties. The needed relations between acoustic and elastic impedance and reservoir properties can be determined from well log and core data where the rock characteristics are measured simultaneously on the same rock sample.

Rock Physics analysis is the key to relating the seismic properties to reservoir properties and high quality seismic reservoir characterization requires well log data that are consistent between formations and wells over the entire vertical interval of interest and represent the true undisturbed rock properties. Rock Physics relates reservoir parameters such as porosity, permeability, fluid and lithology to depositional and diagenetic trends of sands, shales and shaly sands which are the characteristics of the geology of Niger Delta. One of the most powerful uses of Rock Physics is for extrapolation. Cuttings, coring and logging tell us about the lithology, porosity, permeability and fluids of the reservoir. Using rock physics, we can extrapolate to geologically plausible conditions that might exist away from the well, exploring how the seismic signatures might change. This is particularly useful when we wish to understand the seismic signatures of fluids and facies that are not represented in the well. Simulation-based quantitative interpretation is one of the main messages of statistical rock physics.

The elastic properties of reservoir such as velocity, density, impedance and $V_p/V_s$ ratio take an important role in reservoir characterization because they are related to the reservoir properties. To analyze these elastic properties, Rock Physics knowledge is a bridge that links the elastic properties to the reservoir properties such as water saturation, porosity and shale volume. The most significant properties of reservoir rocks are porosity and permeability, because they control the volume and

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production of fluids in the reservoir. However, reservoir porosity estimation is essential and needs to be determined for flow simulation and reservoir management\(^8\).

Reservoir characterization based on impedance estimates from seismic inversion as well as porosity-impedance relationships from well-log data will allow identification of additional areas of potentially good reservoir quality \(^8\). Rock Physics modelling, which quantifies the elastic properties of rocks and fluids by reflection signatures, can help us understand the behaviour of the reservoir and non-reservoir zones and correct for some of the problems encountered in well log data\(^9\). Rock Physics relationships are the essential element in the evaluation and modelling of seismic attributes for hydrocarbon exploration and appraisal, as Rock Physics templates provide great utility as calibration method and a visual, multiscale integration platform\(^10\).

Furthermore, the exploration and exploitation of hydrocarbons involve finding the right depth and in the correct container with the ability to lift them without disturbing the environment; rock physics is the glue that bonds these processes together\(^11\).

Rock Physics Templates are geologically constrained rock physics models that serve as tools for lithology and fluid prediction\(^1\). It creates dynamic graphical overlays of one or more rock physics models, including the effect of variations in model constraints and reservoir properties such as porosity and water saturation. Rock Physics Templates reduce some complexity and detail of Rock Physics modelling by bringing calibrated model templates to the larger geoscience and interpretation community\(^10\).

The present exploration in Niger Delta focuses mainly on deep offshore whose reservoirs are mainly turbidite sands. These contain a lot of shales/clays which must be classified from seismic data before drilling operation. Since Aka field is an offshore field of Niger Delta, Rock Physics template would provide the needed link between the reservoir properties and seismic properties, thus making reservoir properties to be inferred directly from inverted seismic data.

To forestall the miseries following a dry well aiming at a perfect bright spot and an unquestionable AVO response; necessitates the use of a method which link the seismic properties (P-velocity, S-velocity and acoustic impedance) directly to reservoir properties (porosity, lithology and fluid content). Thus, Rock Physics template would reduce uncertainty in seismic interpretation.

Recent experiences in a number of global basins have demonstrated the value of an integrated approach to developing rock and fluid acoustic properties for the quantitative interpretation of seismic data.


The direct link of subsurface elastic properties with reservoir properties necessitated the building of Rock Physics templates for a Niger Delta oilfield that would serve as a guide for quantitative seismic interpretation, thus reducing risk in seismic interpretation. The selection of a suitable rock physics model depends mainly on the mineralogy and porosity of the region.

**Rock Physics Models**

**Friable Sand Model**

The elastic moduli at the critical porosity end point \((\psi_c)\) are given by Hertz-Mindlin (HM) theory and the zero porosity point represents the mineral point. These two points are connected by the unconsolidated line represented mathematically by the Modified Lower Hashin-Shtrikman (MLHS) bound expressed and shown in equations (1) and (2).

\[
K_{dry} = \left[ \frac{\psi/\psi_c}{K_{HM} + (4/3)\mu_{HM}} + \frac{1-\psi/\psi_c}{K + (4/3)\mu_{HM}} \right]^{-1} - \frac{4\mu_{HM}}{3} \tag{1}
\]

\[
\mu_{dry} = \left[ \frac{\psi/\psi_c}{\mu_{HM} + \mu_{HM} (9K_{HM} + 8\mu_{HM})} + \frac{1-\psi/\psi_c}{\mu_{HM} + \mu_{HM} (9K_{HM} + 8\mu_{HM})} \right]^{-1} - \frac{\mu_{HM}}{6} \left( \frac{9K_{HM} + 8\mu_{HM}}{K_{HM} + 2\mu_{HM}} \right) \tag{2}
\]

\(\psi =\) porosity, \(K_{dry}, \mu_{dry}\) = effective “dry” bulk and shear modulus respectively.

**Contact Cement Model**

The contact cement dramatically increases the stiffness of the sand by reinforcing the grain contacts. In this model, the effective bulk \((K_{dry})\) and shear \((\mu_{dry})\) moduli of dry rock are re-expressed as shown in equations (3) and (4).

\[
K_{dry} = \frac{n(1-\psi_c)\mu_c S_n}{6} \tag{3}
\]

\[
\mu_{dry} = \frac{3K_{dry}}{5} + \frac{3n(1-\psi_c)\mu_c S_n}{20} \tag{4}
\]

**Constant Cement Model**

This model is a combination of the contact cement model and friable-sand model. The equations for dry-rock bulk and shear moduli at a smaller porosity \((\psi)\) are represented in equations (5) and (6).

\[
K_{dry} = \left[ \frac{\psi/\psi_b}{K_b + (4/3)\mu_b} + \frac{1-\psi/\psi_b}{K + (4/3)\mu_b} \right]^{-1} - \frac{4\mu_b}{3} \tag{5}
\]

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$\varnothing_b =$ porosity of the well-sorted end-member; $K_b, \mu_b =$ dry-rock bulk and shear moduli at this porosity respectively; $K_{dry}, \mu_{dry} =$ dry-rock bulk and shear moduli at a smaller porosity respectively.

$$\mu_{dry} = \left[ \frac{\varnothing_b}{\mu_b + z} + \frac{1-\varnothing_b}{\mu + z} \right]^{-1} - \frac{\mu_b}{6} \left( \frac{9K_b+8\mu_b}{K_b+2\mu_b} \right) \tag{6}$$

**Gassmann Fluid Substitution**

Fluid substitution is a prediction of fluid saturation effects on seismic properties. It uses Gassmann’s equation to calculate elastic properties at the desired saturation, from either the dry rock or a rock saturated with another fluid\(^{16}\). It is remarkably accurate and robust for porosities greater than 10%\(^ {17}\). Fluid substitution is an important part of the seismic Rock Physics analysis (e.g., AVO, 4D analysis), which provides a tool for fluid identification and quantification in reservoir\(^ {18}\). The Gassmann fluid substitution of saturated rock compressibility($K_{sat}$) in a reservoir (clean sands, shaly sand, etc.) with uniform water saturation for different saturation values and for porosities from zero to initial/critical porosity is expressed in equations (7) and (8).

$$K_{sat} = K_{frame} + \frac{\varnothing}{K_{fl}} \left( \frac{1-K_{frame}}{K_{matrix}} \right)^2 \left( \frac{K_{frame}}{K_{matrix}} \right) \tag{7}$$

$$\mu_{sat} = \mu_{frame} \tag{8}$$

$K_{frame}$ and $K_{sat} =$ effective bulk modulus of dry rock and rock with pore fluid respectively; $K_{fl}$ and $K_{matrix} =$ effective bulk modulus of pore fluid and mineral material making the rock respectively; $\mu_{frame}$ and $\mu_{sat} =$ effective shear modulus of dry rock and rock with pore fluid respectively; $\varnothing =$porosity. These dry and saturated moduli are related to P-wave velocity ($V_p$) and S-wave velocity ($V_s$); alongwith the rock bulk density($\rho_b$) given by equation (9), (10) and (11) respectively.

$$V_p = \sqrt{\frac{K + 4/3\mu}{\rho_b}} \tag{9}$$

$$V_s = \sqrt{\frac{\mu}{\rho_b}} \tag{10}$$

$$\rho_b = \varnothing \rho_{fluid} + (1 - \varnothing) \rho_{mineral} \tag{11}$$

$\varnothing =$ porosity, $\rho_{fluid} =$ fluid density and $\rho_{mineral} =$ mineral density


\(^{19}\) F. Gassmann, 1951. Über die elastizität poröser medien: Vierteljahrsschrift der
Estimating Average Mineral and Fluid Properties

Gassmann equations are applicable for monomineralic rocks but known reservoirs in Niger Delta are not monomineralic in nature and their constituent fluids are mixtures of oil, gas and water.

**Shaly Sand**

We assume the bulk \( (K) \) and shear \( (\mu) \) moduli of the zero-porosity composite mineral to be given by the Voigt average equations (12) and (13) below:

\[
K_{avg} = f_{qz}K_{qz} + f_{clay}K_{clay} \tag{12}
\]

\[
\mu_{avg} = \mu_{qz}f_{qz} + \mu_{clay}f_{clay} \tag{13}
\]

\( f_{qz} \) and \( f_{clay} \) are the quartz and clay fractions in the solid phase; \( K_{qz} \) and \( \mu_{qz} \) are the bulk and shear mineral modulus of quartz and; \( K_{clay} \) and \( \mu_{clay} \) are the bulk and shear mineral modulus of clay, respectively.

**Shale**

Assume that all silt grains are quartz and that they are suspended in the clay matrix even at the zero-porosity end-member. This results in a soft effective mineral moduli, which can be calculated using the Reuss average equations given by equations (14) and (15) below:

\[
\frac{1}{K_{avg}} = \frac{f_{qz}}{K_{qz}} + \frac{f_{clay}}{K_{clay}} \tag{14}
\]

\[
\frac{1}{\mu_{avg}} = \frac{f_{qz}}{\mu_{qz}} + \frac{f_{clay}}{\mu_{clay}} \tag{15}
\]

Where the input parameters are the same as given for the shaly sands effective mineral moduli.

**Mixed Fluids**

\(^{20}\) Domenico\(^{20}\) suggested that mixed gas-oil-brine saturations can also be modelled with Gassmann’s relations, if the mixture of phases is replaced by an effective fluid with average bulk modulus \( (K_{fluid\_avg}) \) and density\( (\rho_{fluid\_avg}) \) given by equations (16) and (17) below:

\[
\frac{1}{K_{fluid\_avg}} = S_{brine}\frac{1}{K_{brine}} + S_{oil}\frac{1}{K_{oil}} + S_{gas}\frac{1}{K_{gas}} \tag{16}
\]

\[
\rho_{fluid\_avg} = S_{brine}\rho_{brine} + S_{oil}\rho_{oil} + S_{gas}\rho_{gas} \tag{17}
\]

\( S_{brine}, S_{oil}, S_{gas} \) and \( K_{brine}, K_{oil}, K_{gas} \) are the saturations and densities for brine, oil and gas phases respectively. The fluid properties at the reservoir conditions are calculated using the Batzle-Wang relations\(^{21}\).

**Niger Delta Petroleum Basin**

The 12 km thick Niger Delta clastic wedge spans a 75,000 km\(^2\) area in Southern Nigeria and the Gulf of Guinea offshore Nigeria. This clastic wedge contains the 12\(^{th}\) largest known accumulation


of recoverable hydrocarbons, with reserves exceeding 34 billion barrels of oil and 93 trillion cubic feet of gas. These deposits have been divided into three large-scale lithostratigraphic units:

i. The basal Paleocene to Recent pro-delta facies of the Akata Formation,

ii. Eocene to Recent, paralic facies of the Agbada Formation, and

iii. Oligocene-Recent, fluvial facies of the Benin Formation.

These formations become progressively younger farther into the basin, recording the long-term progradation of depositional environments of the Niger Delta onto the Atlantic Ocean passive margin. Figure 1 shows the geological map of Niger Delta Basin. The stratigraphy of Niger Delta is complicated by the syndepositional collapse of the clastic wedge as shale of the Akata Formation mobilized under the load of prograding deltaic Agbada and fluvial Benin Formation deposits. A series of large-scale, basinward-dipping listric normal faults formed as underlying shales diapered upward. Blocks down dropped across these faults filled with growth strata, changed local depositional slopes, and complicated sediment transport paths into the Basin.

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METHODOLOGY

Data

The data used in this study consists of a suite of well logs (from three wells), base map and check shot. The suite of logs comprises of gamma ray, deep and shallow resistivity, density, neutron-porosity, compressional sonic log and one dipole sonic data from Well-1. The relative positions of the wells are shown in Figure 2.
Data Processing and Interpretation

Petrophysical Analysis

The density data were corrected for mud filtrate invasion using Rasolovoahangy porosity upper and lower bound case\(^\text{25}\), while the sonic data were calibrated with the check shot data. Finally, the data was copied to Excel spreadsheet to view missing data points which were filled with the average of the data points before and after such missing point. All these were done before loading the data in Petrel software for petrophysical interpretation. The determination of fluids and reservoir parameters were carried out with emphasis on the unconsolidated reservoir zones and the closest non-reservoir zones were mapped. P-velocity \((V_p)\), S-velocity \((V_s)\) and density \((\rho)\), were then obtained from these zones respectively, which were used in the rock physics analysis.

The formation water saturation \((S_w)\) of all the mapped reservoir zones, were determined by the Indonesian equation (18).

\[
\frac{1}{\sqrt{R_t}} = \left( \frac{V_sh^{1-0.5V_sh}}{\sqrt{R_sh}} + \frac{\phi^{m/2}}{\sqrt{aR_w}} \right) * S_w^{n/2}
\]

(18)

\(R_t\) = true resistivity (usually deep resistivity reading), \(\phi\) = porosity, \(R_{sh}\) = resistivity of shale; \(R_w\) = resistivity of water; \(S_w\) = water saturation; \(V_{sh}\) = volume of shale; \(a\) = cementation factor; \(m\) = cementation exponent; \(n\) = saturation exponent. Constants used: \(n = 2\), \(a = 1\) and \(m = 2\).

**Rock Physics Diagnosis**

The initial step in creating a Rock Physics template is determining the appropriate Rock Physics model, of which friable sand, contact cement and constant cement model were considered in this study. Figure 3 shows the workflow of the processes involved. The bulk and shear moduli for the constituent grains (quartz) and cements (quartz/clay) minerals of the reservoirs and non-reservoir zones values were assumed, which are consistent with Niger Delta clastic reservoirs. Derive the dry bulk moduli and shear moduli for porosity range 0 - 40%, using friable sand, contact cement and constant cement model respectively: using Excel Spreadsheet /MatLab Software. Gassmann’s fluid substitution is performed for water saturation \((S_w)\) range of 0 - 100% (from oil to brine); on the dry bulk \((K_{frame})\) and shear moduli \((\mu_{frame})\) to obtain saturated bulk \((K_{sat})\) and shear moduli \((\mu_{sat})\); hence, P- and S-velocities are estimated. The fluid properties calculated using the Batzle–Wang relations and; the estimated properties of the reservoirs are given in Table 1.

**Table 1: Estimated properties of reservoirs**\(^{26}\).

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Temperature = 77°C  Effective pressure = 30Mpa

<table>
<thead>
<tr>
<th></th>
<th>Brine properties</th>
<th>Oil properties</th>
<th>Mineral properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Clay</td>
</tr>
<tr>
<td>Salinity (ppm)</td>
<td>80,000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Density (g/cc)</td>
<td>1.06</td>
<td>0.8</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.65</td>
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<tr>
<td>Bulk Modulus (GPa)</td>
<td>2.48</td>
<td>0.93</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36.60</td>
</tr>
<tr>
<td>Shear Modulus (GPa)</td>
<td>-</td>
<td>-</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>45.00</td>
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<td>Oil Gravity</td>
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<td>32.00</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Gas Gravity</td>
<td>-</td>
<td>0.60</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Oil-Gas ratio</td>
<td>-</td>
<td>64.00</td>
<td>-</td>
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</tbody>
</table>

The sedimentology of the reservoir rocks in the wells were inferred from S-velocity ($V_s$) against porosity ($\emptyset$) crossplot in order to minimize pore fluid effects\(^{27}\).

The following rock physics models were chosen for generating templates for the three wells:

i. well 1: 3% Constant Cement Model

ii. well 2: 2.5% Constant Cement Model

iii. well 3: 2% Constant Cement Model

The non-reservoir zone which is mainly shale is modelled after the friable model, because the shales of soft clay minerals that are normally not cemented\(^1\). These theoretical Rock Physics models are calibrated and validated to local geology and well log data.

Rock Physics diagnosis is done by superimposing the theoretical rock physics curves of Shear velocity versus porosity plot, $V_p/V_s$ versus acoustic impedance ($I_p$) plot and Shear Impedances versus Acoustic Impedance plots on the well log data of respective cross plots.

Thus, the models behaviour is investigated through cross-plotting different physical parameters: “$V_s$ versus $\emptyset$”, “$I_p$ versus $I_s$”, “$V_p/V_s$ versus $I_p$”. It is convenience to correlate the plots with seismic inversion results; thus, preferred crossplots are “$I_p$ versus $I_s$” and “$V_p/V_s$ versus $I_p$”.


RESULTS AND DISCUSSION

Petrophysical Analysis

Figure 4[1, 2 and 3] shows the interpretation of the fairly unconsolidated sand reservoir of well-1, -2 and -3; mapped at a depth range of 4158 – 4167 m, 3876 – 3891 m and 3560 – 3592 m Measured Depth (MD) respectively; the shale zones have a depth range of 4185 – 4205 m, 3848 – 3874 m and 3518 – 3559 m (MD) respectively. The estimated reservoir resistivity for well-1, -2 and -3 are 160, 200 and 160 Ωm respectively; their net pay are 4.12 m, 15 m and 7.27 m respectively, as shown in the interpretation panel. The estimated water saturation for the three wells range from 21 – 22%.
Castagna Equation for the Field

Figure 5[1 and 2] shows the crossplot of P-velocity ($V_p$) against S-velocity ($V_s$) from various reservoir sand zones and shale zones, as mapped by petrophysical analysis in Well-1 which has both sonic and dipolar logs that, were harmonized to produce a resultant crossplot with emphasis on the unconsolidated zone. The P-velocity and S-velocity data from these zones are linearly correlated whose regression line gives the Castagna equation of the zones. The Castagna equations for the reservoir sand zone and shale zone are given in equations (19) and (20) respectively.

Sand zone: \[ V_s = 0.8043V_p - 0.8561 \]  
(19)

Shale zone: \[ V_s = 0.7724V_p - 0.8668 \]  
(20)

Figure 5: $V_p$ versus $V_s$ crossplot in regression derivation for sand [1] and shale [2] zones respectively.
Elastic Properties for the Wells
Figure 6[1, 2 and 3] shows the crossplot of gamma, P-velocity, S-velocity and density with depth for the reservoir zone as mapped out from petrophysical interpretation of well-1, -2 and -3. The reservoir sand zones considered were the unconsolidated region of low P-velocity, low S-velocity and low density. The S-velocity was derived from the P-velocity using the derived Castagna equations (19) and (20). The lowest P-velocity is approximately 2950 m/s, 2900 m/s and 2800 m/s respectively; the density is approximately 2.35 g/cc, 2.25 g/cc and 2.25 g/cc respectively for the oil sand in these zones.

Figure 6: Depth plots of elastic properties from zone of interest in well -1, 2 and 3 respectively.

Rock Physics Analysis
Figure 6[1, 2 and 3] shows the crossplots of $V_s$ versus porosity for oil sand and shale zones as mapped by petrophysical analysis in Well-1, -2 and -3, with the Rock Physics models. The red points and blue crosses represent the oil sand and shale plots respectively. The models of contact cement, constant cement and friable sand are colour coded grey, green and pink respectively; with 3%, 2.5% and 2% diagenetic process of the constant cement model line, give the average forward modelling with high concentration of oil sand data plots within the average porosity of 24%, 25% and 26% for Well-1, -2 and -3 respectively. There is clear distinction between the oil sand and the shale cluster points which show lithology discrimination as the crossplot of $V_s$ versus porosity minimize pore fluid effects.
Figure 7: $V_S$ versus density porosity superimposed on the rock physics models to quantify the cement volume in the reservoir rocks, from well-1, 2, and 3 respectively.

Rock Physics Templates

The Rock Physics template of Well-1, 2 and 3 are shown in Figure 8[1, 2 and 3] with a crossplot of acoustic impedance versus shear impedance calculated from the well log data. The red points and blue crosses are the oil sand and shale plotted points respectively, while the green and pink lines represent the shale and brine sand model respectively. There is a clear distinction between oil sand and shale cluster points which show lithology discrimination, with full concentration of the sand clusters at average porosity of 24%, 25% and 26% for Well-1, -2 and -3 respectively. For the oil sand plots (red dots), the points with low acoustic impedance show high porosity and oil saturation. The points between the porosity trend of sand and the porosity trend of shale show the shaly sand and sandy shale. Slight increase in acoustic impedance at these porosities (24 – 26%) for the three wells which that the reservoirs are shaly.

The Rock Physics template posted as the crossplot of $V_p/V_S$ ratio versus acoustic impedance calculated from well log data at Well-1, -2 and -3 is shown in Figure 8[4, 5 and 6]. The red dots and blue crosses are the oil sand and shale plotted points respectively, while the green and pink lines represent the shale and brine sand model respectively. There is a clear distinction between oil sand and shale cluster points which shows lithology discrimination, with full concentration of the sand clusters at estimated porosity value of 24%, 25% and 26% for Well-1,-2 and -3 respectively. The points with low acoustic impedance show high oil saturation and high porosity as shown by the cluster points.
Figure 8: Crossplots of shear impedance versus acoustic impedance [1, 2, and 3] and of Vp/Vs versus acoustic impedance [4, 5 and 6] calculated from well log data at well-1, 2 and 3 respectively.

CONCLUSION

A model has been built for an unconsolidated reservoir in a Niger Delta oilfield on the assumption that if well log data points fall close to a theoretical line in velocity-porosity plane, then the internal structure of a rock is similar to the idealized structure predicted by theoretical model. Several models have been compared: friable sand model, contact cement model and constant cement models of different degree of cementation.

The oil sands water saturation of the range 21 – 22%, density of the range 2.25 – 2.35 g/cc, with P-velocity and S-velocity of the range 2800 – 2950 m/s and 2251 – 2372 m/s respectively inferred that the reservoir rocks are unconsolidated; and the Greenberg-Castagna equations predicted for the field are: $V_s = 0.8043V_p - 0.8561$ and $V_s = 0.7724V_p - 0.8668$ for sand reservoirs and shales respectively.

Through extensive crossplots analysis of various rock properties, lithology and fluid discrimination was achieved with: shear velocity versus porosity, shear impedance and Vp/Vs versus acoustic impedance crossplots, in agreement with the estimated water saturation and oil sand porosity. The shear velocity versus porosity crossplots estimated oil sand porosities range from 24 – 26%, with 2 – 3% degree of diagenetic process of constant cement model, alongside clear lithology distinction between oil sands and shales. These templates could be correlated with the seismic inverted results from the same field or deposition environment to predict lithology and fluid content of undrilled areas.
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