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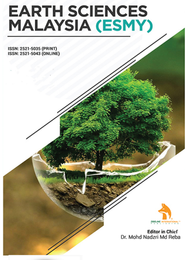

RESEARCH ARTICLE

DETERMINATION OF GEOMECHANICAL ROCK PROPERTY IN THE ESTIMATION OF SANDING IN FIELD "A" IN CENTRAL NIGER DELTA

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ABSTRACT

Well logs data from four wells were analysed for determining the petrophysical and geomechanical properties of two reservoirs in the study area. The parameters derived from these properties were used to predict the likelihood of the occurrence of sanding in the reservoirs of interest. Five sand production methods were used in predicting sanding in the reservoirs of interest. The results obtained from these sand prediction methods all showed that the reservoirs were not likely to produce sanding during drilling exploration and production. Reservoir geomechanical study has a significant role that cannot be neglected in the development of various hydrocarbon exploitation procedures, such as in the exploration and production, drilling and field development phase. The role of geomechanical properties have great impact on the drill bit selection, optimization of well trajectory placement, casing design, wellbore stability analysis, safe mud weight window (SMWW) prediction and sand production. Sand production is a serious problem widely existing in oil/gas production. The problems resulting from sand influx include abrasion of downhole tubular/casing, subsurface safety valve and surface equipment, casing/tubing buckling, failure of casing or liners from removal of surrounding formation, compaction and erosion; and loss of production caused by sand bridging in tubing and/or flow lines.

KEYWORDS

Sanding, Geomechanical, Well log, Reservoir, Modulus.

1. INTRODUCTION

In the oil industry, the drilling of hydrocarbon is capital intensive, as such Geologist and Geophysicists are always on their toes to interpret seismic data so as to ascertain the actual depth these pools of hydrocarbon lie on the subsurface. Once the actual depth is ascertained, the drillers can go ahead to drill. Pending on the strength of the formation, the drilling phase can be fast or slow.

After the drilling phase, comes the well completions and production stage. The production of hydrocarbon most often comes with challenges pending on the compaction or strength of the reservoir. When hydrocarbon is being produced from a weak or uncompacted reservoir (an unconsolidated reservoir or a young reservoir), sand particles are always produced along with the hydrocarbon. These sand particles always have negative effects on the equipment used in the production of hydrocarbon, be it Expandable Sand Screen (ESS) or Perforated Liners.

To avoid the production of hydrocarbon along with unconsolidated sand particles, it is important to determine the geomechanical properties of the reservoir of interest, since the geomechanical properties of a reservoir can foretell a reservoir that is properly compacted or consolidated from the one that is weakly compacted, which in turn can be used to predict a consolidated reservoir from unconsolidated reservoir, ie matured from unmatured reservoir that produces sand.

Sanding usually occurs when a weak reservoir breaks down and sands with small grain particles are produced with the oil during production. This production of the sand particles along with the hydrocarbon usually make the equipment in the oil production to wear off and to a large extent partly reduce production or hydrocarbon flow due to plugging of production equipment by sand particles. In most cases, sand production in hydrocarbon reservoir rock result if hydrocarbon flow surpasses an undoubtful magnitude or intensity control by factors such as reservoir rock strength, stress state, flow velocity among other factors and the well completion techniques deployed in the well. This happens when the reservoir pressure exceeds hydrostatic pressure. The volume of sand grains around the wellbore gradually and continually disaggregated and dislodged with continue flow and accumulate on production equipment, thus overtime, causes plug and thus decreases hydrocarbon production. To estimate the incipience or threshold of sanding, particularly in calculating sanding rate, most time if total amount of sands flow can be less than a few grams per cubic meter of hydrocarbon fluid, then dictate a minor thread to the Well production, but if a significant amount flow crop-up over a compressed period of time during production, it fills and plug the wellbore, erode downhole and surface equipment, and increase operating expenses. 'Excess flow of sand from the reservoir can significantly deteriorate the production of hydrocarbon (Mahmood *et al.*, 2007). Sand production depends on some factors such as the strength of the formation among others. To predict sanding in a reservoir, the

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awareness of the compressive strength of the reservoir is paramount. This gives a total idea of strength properties of reservoir rocks which play an important role in oil drilling and production.

The production of sand along with oil and gas is a formidable problem in many younger, unconsolidated rocks. The purpose of estimating formation strength on the basis of elastic constants is to determine whether the formation is strong enough to produce at high flow rates without sand. If the formation cannot sustain high flow rates without sand, it is beneficial to determine the optimum production rate which can be sustained without producing sand. There is considerable evidence that a good correlation exists between the intrinsic strength of the rock and its elastic constants (Eyinola and Oladunjoye, 2014).

2. STUDY AREA AND GEOLOGY OF NIGER DELTA

2.1 Study Area

The Niger Delta as shown in figure 1 is interpreted as being a river dominated Delta, the post Oligocene delta is a typical wave dominated delta with well developed shore face sands, beach ridges, tidal channels, mangrove and fresh water swamps. It is one of the world's largest Deltas and shows overall upward transition from marine shales (Akata Formation) through a sand/shale paralic interval (Agbada Formation) to continental sands of the Benin Formation (Asadu *et al*., 2015).

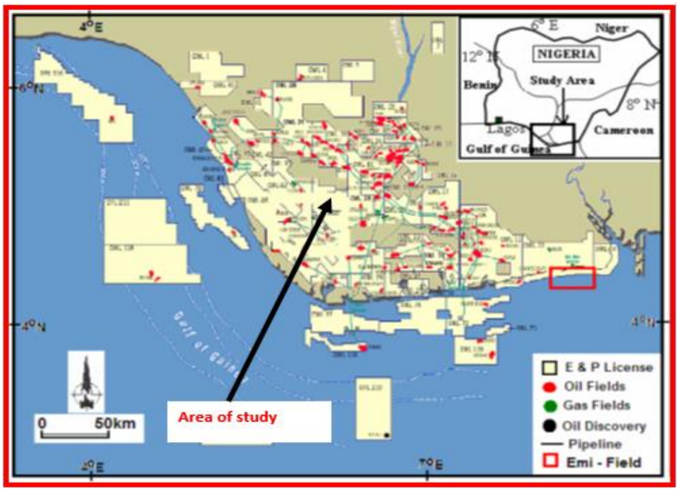

Figure 1: Map Showing the Study Area (Doust and Omatsola, 1990)

2.2 Geology of Niger Delta

Lithostratigraphically, the Niger Delta is divided into three units, this includes

1. Benin Formation
2. Agbada Formation
3. Akata Formation

The three lithostratigraphic units are aged from early Tertiary to Recent and spread across the entire delta. They are seen in the present outcrops and depositional environments. The Hydrocarbons in the Niger Delta are found in the Agbada Formation (Doust and Omatsola, 1990). Figure 2 shows the three lithostratigraphic unit of the Niger Delta.

1. The Benin Formation is the topmost sequence of the Niger Delta clastic wedge, and has been described as the Coastal Plain Sands which outcrop in Benin, Onitsha and Owerri provinces and elsewhere in the delta area. It consists of massive continental (non-marine) sands and gravels considered to have been deposited in the alluvial or upper coastal plain environment. Very little oil has been found in the Benin Formation (mainly minor oil shows). The formation is generally water bearing, thus the main source of portable ground water in the Niger Delta (Asadu *et al.,* 2015).

2. The Agbada Formation overlies the Akata Formation and forms the second of the three strongly diachronous Niger Delta Complex formations. This forms the hydrocarbon-prospective sequence in the Niger Delta. As the principal reservoir of Niger Delta oil, the formation has been studied in some detail. The Agbada Formation is represented by an alternation of sands (fluviatile, coastal, fluviomarine), silts, clays, and marine shales (shale percentage increasing with depth) in various proportion and thicknesses, representing cyclic sequences of offlap units. These paralic clastics are the truly deltaic portion of the sequence and were deposited in a number of delta-front, delta-topset, and fluvio-deltaic environments and range in age from Eocene to Pleistocene.

3. The Akata Formation is the basal unit of the Tertiary delta complex. This lithofacies is composed of shales, clays, and silts at the base of the known delta sequence. They contain a few streaks of sand, possibly of turbiditic origin (Asadu *et al*., 2015, Doust and Omatsola, 1989), and were deposited in holomarine (delta front to deeper marine) environments. The thickness of this sequence is not known for certain but may reach 7000m in the central part of the delta. Marine shales form the base of the sequence in each depo-belt and range from Paleocene to Holocene in age (Asadu *et al*., 2015).

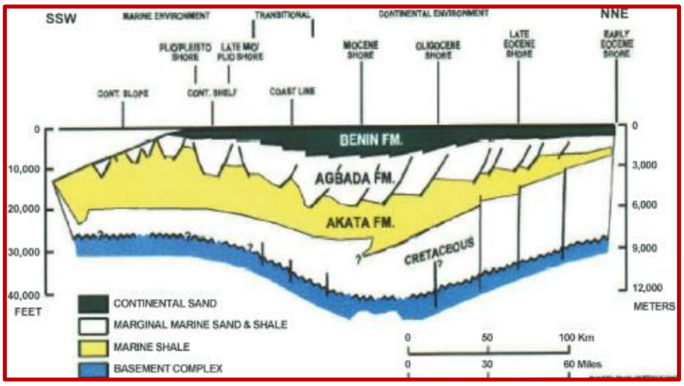

Figure 2: Akata, Agbada and Benin Formations (Doust and Omatsola, 1990)

3. MATERIALS AND METHODS

3.1 Materials

A suite of geophysical well log comprising of sonic log, resistivity log, density log, neutron log and gamma ray log, petrel software and secondary data acquired from Shell Petroleum Development Company(SPDC) were used in this study. Petrel was used specifically for well correlation, petrophysical calculations and rock geomechanical calculations.

3.2 Methods

The study was carried out in six stages as shown in figure 3:

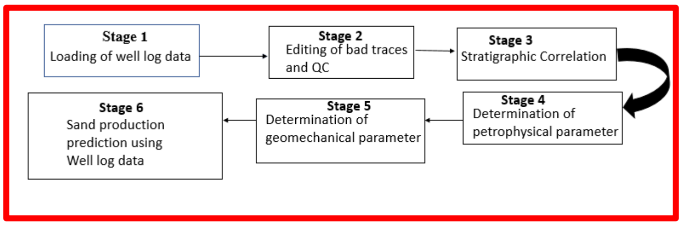

Figure 3: Workflow for the stages of the method used.

In the first stage, the data were gathered and loaded into the software used in the study.

In the second stage the data were quality checked and edited, bad traces were removed so as to delineate the effects of error during analyzing the data. Cycle skipping, caused by spiky sonic logs often result in artificial events that can be mistaken for real reflectors where corrected before they were used to calculate petrophysical and geomechanical parameters'.

In the third stage, stratigraphic correlation was carried out, this was done so as to pick our formation tops, and to delineate the reservoirs for the study.

In the fourth and fifth stages, petrophysical and geomechanical properties of the reservoirs were estimated using various empirical formulas.

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3.2.1 Determination of Petrophysical Parameters

3.2.1.1 P-Wave velocity and S- Wave velocity

To determine compressional velocity or P-wave velocity (v_p), the sonic interval time from sonic log was used. Sonic log data comprised the interval transit time, which is defined as the time necessary for elastic waves (compressional) to travel 1ft of the formation. The log data were recorded in µsec/ft. The interval transit times were transformed to compressional velocity in m/s, using the equation below (Ogagarue, 2008).

$$v_p = \frac{1000000*0.305}{\Delta t_p} \qquad (1)$$

where Δt_p is the interval transit times recorded by the compressional sonic logs respectively, in µsec/ft. Empirical relationship was used to calculate the shear velocity or S-wave velocity (v_s) from v_p as shown in equation 2.

$$v_s = \frac{V_P - 1279.08}{1.11702} \qquad (2)$$

3.2.1.2 Gamma Ray Index

Gamma ray logs measure natural radioactivity in formations and because of this measurement, they can be used for identifying lithologies and for correlating zones. Shale-free sandstones and carbonates have low concentrations of radioactive material, and give low gamma ray readings. As the shale content in a formation increases, the gamma ray log response increases because of the high concentration of radioactive material in shale. However, clean sandstone (i.e. low shale content) may also produce a high gamma ray response if the sandstone contains potassium feldspars, micas, glauconite, or uranium-rich waters (Schlumberger, 1989). Gamma ray index was calculated using the equation below:

$$IGR = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \qquad (3)$$

Where GR_{log}= measured gamma ray log reading at depth (z), GR_{min}= minimum gamma ray log reading in clean sand GR_{max}= maximum gamma ray log reading in clean shale. IGR= Gamma ray index

3.2.1.3 Volume of shale

The volume of shale was calculated mathematically from the gamma ray index (IGR) using Dresser Atlas (1979) formula:

$$Vsh = 0.083\left[2^{\,(3.7\times IGR)} - 1.0\right] \qquad (4)$$

Where: Vsh = volume of shale IGR = gamma ray index

3.2.1.4 Porosity

The total porosity was determined from density log data which was weighted average density of the rock and pore fluid using the equation below

$$\theta_D = \frac{(\rho_{ma} - \rho_b)}{(\rho_{ma} - \rho_{fl})} \qquad (5)$$

Where θ_D = total density porosity, ρ_{ma} = density of rock matrix, ρ_b = measured density and ρ_{fl} = density of fluid.

3.2.2 Determination of geomechanical Parameters

Geomechanical properties were determined using the given well log data. The geomechanical properties include Poisons ratio (v), Young's Modulus (E), Shear Modulus (G), Bulk Modulus (K), Bulk Compressibility (C_b) and Unconfined Compressive Strength (UCS).

3.2.2.1 Determination of Poisons ratio (v)

The log derived Poisson ratio was calculated using v_p and v_s relationship given in equation

$$v = 0.5 \times \frac{\left[\left(\frac{v_p}{v_s}\right)^2 - 1\right]}{\left[\left(\frac{v_p}{v_s}\right) - 1\right]} \qquad (6)$$

Where v_p is the p-wave velocity and v_s is shear wave velocity. The theoretical maximum value of $v = 0.5$

3.2.2.2 Determination of Young's Modulus (E)

The log derived Young's Modulus (E) was calculated using v_p and v_s relationship expressed as:

$$E = \frac{(\rho \times v_s \times (3{v_p}^2 - 4{v_s}^2))}{({v_p}^2 - {v_s}^2)} \qquad (7)$$

Where ρ = bulk density, v_p = p-wave velocity, v_s = S - wave velocity

3.2.2.3 Determination of Shear Modulus (G)

The shear modulus of the reservoir was calculated using the equation below;

$$G = \frac{a\rho_b}{v\Delta T_s} \qquad (8)$$

Where coefficient $a = 13464$, ρ_b = bulk density, v = poisson's ratio and ΔT_s = shear sonic transit time

3.2.2.4 Determination of Bulk Modulus (K)

Bulk modulus was calculated using the relationship between shear modulus and Young's modulus. The equation for Young's modulus is shown below;

$$K = \frac{(3E - 4G)}{3} \qquad (9)$$

3.2.2.5 Determination Bulk Compressibility (C_b)

Bulk compressibility was determined using the equation below

$$\mathrm{C_b} = \frac{1}{\mathrm{K}} \qquad (10)$$

3.2.2.6 Unconfined Compressive Strength (USC)

The equation below was used to calculate the USC of the reservoir.

$$UCS = 2.28 + 4.1089E \qquad (11)$$

In the sixth stage, sand production prediction was carried out using the methods are listed below:

1. Shear Modulus to Bulk Modulus Ratio (G/C_b)

The value for this method was calculated from G/C_b (12)

Where G is the Shear modulus and C_b is the Bulk compressibility

2. Sand Production Index Method (B)

Using this method to predicting sand production in a reservoir, the equation given below was used, using Young's modulus and Poisson's ratio.

$$B = \frac{E}{3(1-2v)} + \frac{4}{3} \times \frac{E}{2(1+v)} \qquad (13)$$

Where B is the sand production index method, E is the Young's modulus and v is the Poisson's ratio.

3. Schlumberger Sand Production Index Method (SI)

The Schlumberger sand production index method was calculated using the equation below

$$\mathrm{SI} = \mathrm{K} \times \mathrm{G} \qquad (14)$$

Where K is the bulk modulus and G is the Shear modulus.

4. RESULTS AND DISCUSSION

4.1 Results

4.1.1 Display of Well Log

The study area consists of four wells which are OWO 11, OWO 10, OWO 7 and OWO 5. The logs in these wells are shown in Table 1. OWO 11 and OWO 10 are good enough to carry out sand prediction, this is because they have good sonic readings. OWO 7 does not have sonic log while the sonic log range of OWO 5 is too short, and it is outside the range of the reservoir of interest.

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Table 1: Log Types Present in each Well

Well	Density Log	Neutron Log	Sonic Log	Gamma Ray Log	SP Log
OWO 11	Yes	Yes	Yes	Yes	Yes
OWO 10	Yes	Yes	Yes	Yes	Yes
OWO 7	Yes	Yes	No	Yes	Yes
OWO 5	Yes	Yes	No	Yes	Yes

4.1.2 Stratigraphic Correlation

Figure 4 shows the stratigraphic correlation of the reservoirs. Two reservoirs of interest (which are OWO 11 and OWO 10) were correlated for effective sand prediction

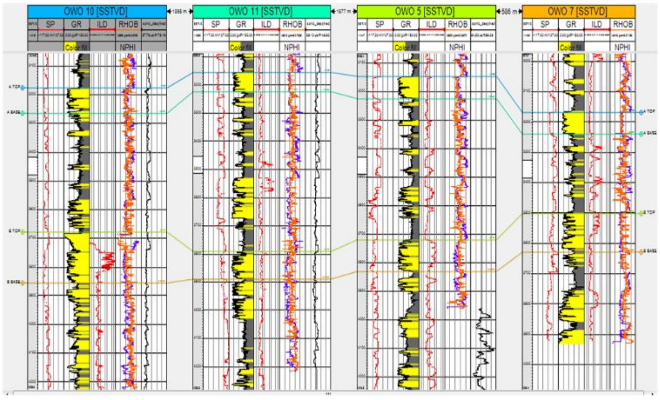


Figure 4: Correlation of the various Wells in the Study Area

4.1.3 Petrophysical Display

Figure 5 – 8 shows the petrophysical log of the reservoirs in all the wells. The calculated petrophysical properties are as follows;

1. Gamma ray index
2. Volume of shale
3. Total porosity
4. Effective porosity
5. Water saturation
6. Permeability
7. Net-gross ratio

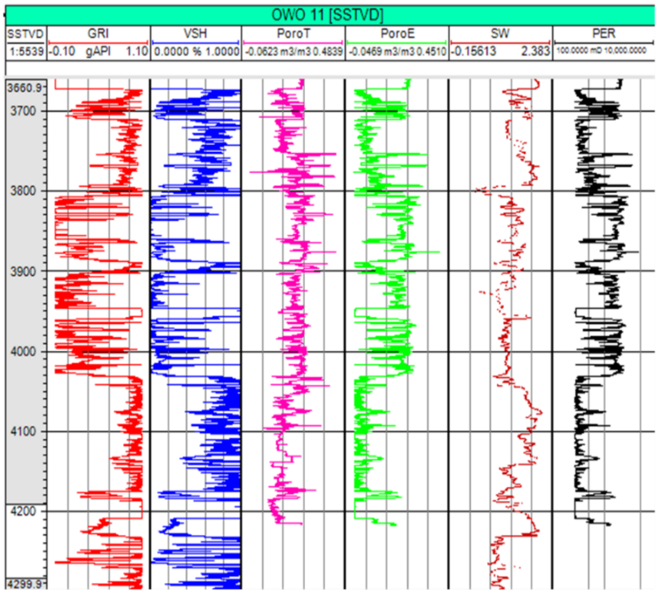


Figure 5: Petrophysical Logs of OWO 11

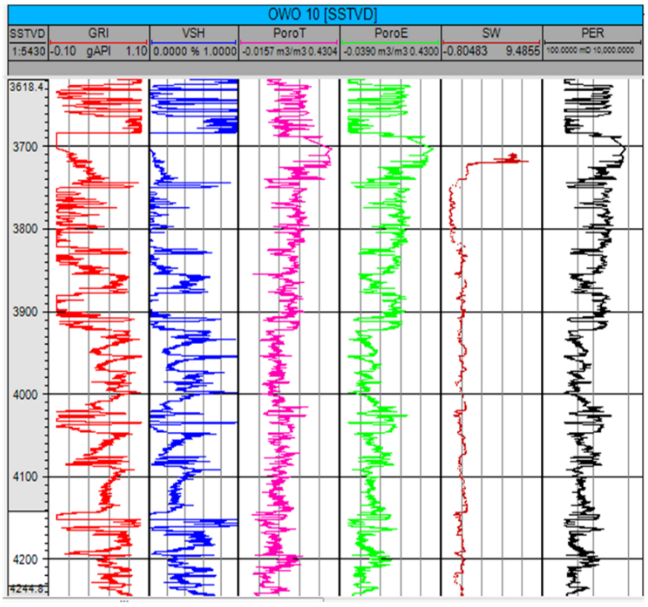


Figure 6: Petrophysical Logs of OWO 10

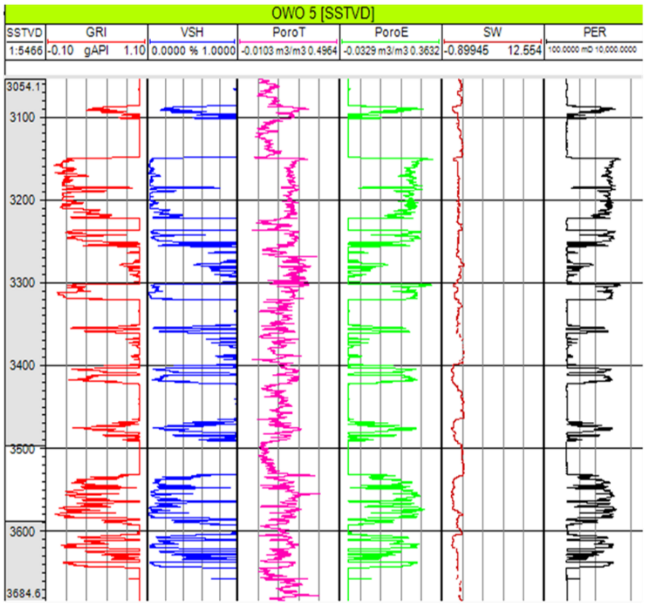


Figure 7: Petrophysical Logs of OWO 5

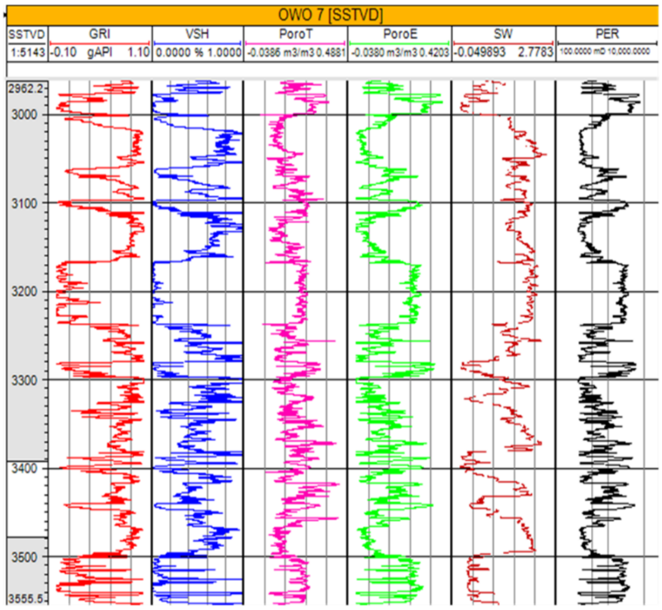


Figure 8: Petrophysical Logs of OWO 7

4.1.4 Geomechanical Display

Figure 9 – 11 shows the geomechanical display in log form of the reservoirs in all the wells. The calculated geomechanical properties are as follows:

1. Young's modulus
2. Poisson's ratio
3. Bulk modulus
4. Shear modulus
5. ${}^{v_p}/_{v_s}$ ratio

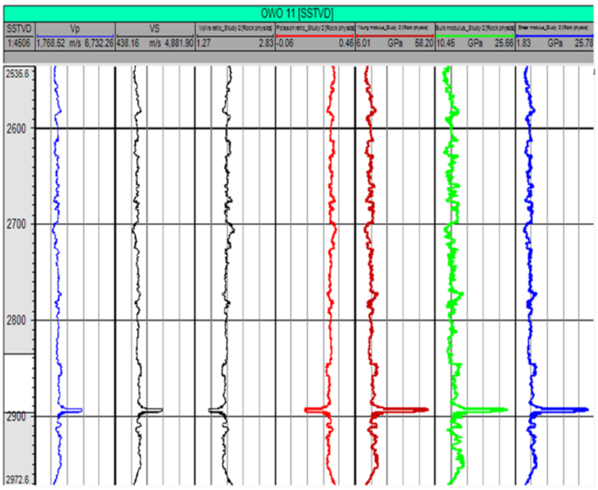


Figure 9: Geomechanical Logs of OWO 11

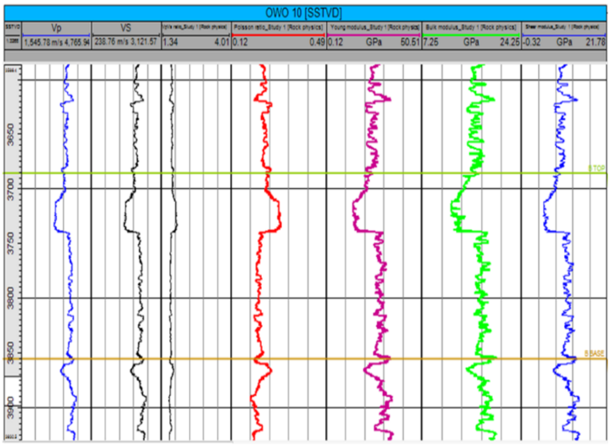


Figure 10: Geomechanical Logs of OWO 10

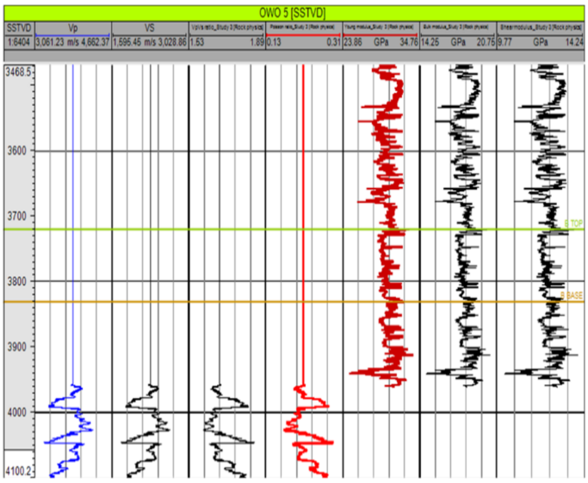


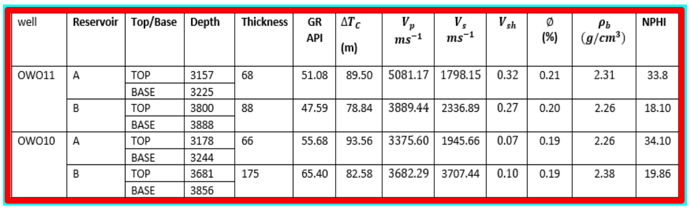
Figure 11: Geomechanical Logs of OWO 5

4.1.5 Parameter Evaluation

Table 2 – 4 shows the petrophysical parameters, geomechanical parameters and sand predicting parameters of the wells of interest (wells considered which are OWO 11 and OWO 10).

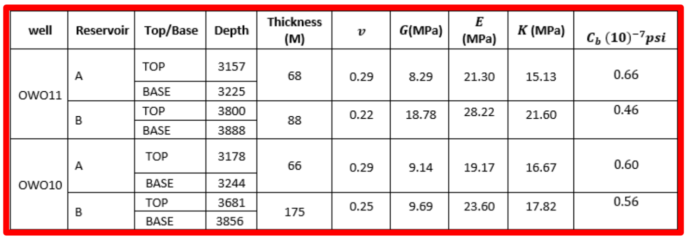
Table 4.2: Petrophysical Parameter of the Wells

Table 2: Petrophysical Parameter of the Wells



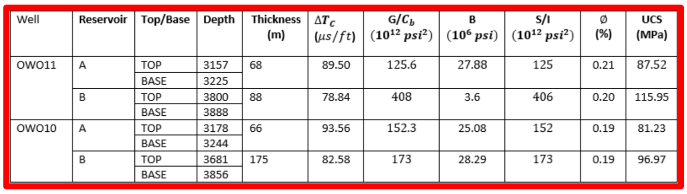
well	Reservoir	Top/Base	Depth	Thickness	GR API	ΔT_C (m)	V_p ms^{-1}	V_s ms^{-1}	V_{sh}	Ø (%)	ρ_b (g/cm^3)	NPHI
OWO11	A	TOP	3157	68	51.08	89.50	5081.17	1798.15	0.32	0.21	2.31	33.8
		BASE	3225									
	B	TOP	3800	88	47.59	78.84	3889.44	2336.89	0.27	0.20	2.26	18.10
		BASE	3888									
OWO10	A	TOP	3178	66	55.68	93.56	3375.60	1945.66	0.07	0.19	2.26	34.10
		BASE	3244									
	B	TOP	3681	175	65.40	82.58	3682.29	3707.44	0.10	0.19	2.38	19.86
		BASE	3856									

Table 3: Geomechanical Parameter of the Wells



well	Reservoir	Top/Base	Depth	Thickness (M)	v	G(MPa)	E (MPa)	K (MPa)	$C_b\ (10)^{-7}psi$
OWO11	A	TOP	3157	68	0.29	8.29	21.30	15.13	0.66
		BASE	3225						
	B	TOP	3800	88	0.22	18.78	28.22	21.60	0.46
		BASE	3888						
OWO10	A	TOP	3178	66	0.29	9.14	19.17	16.67	0.60
		BASE	3244						
	B	TOP	3681	175	0.25	9.69	23.60	17.82	0.56
		BASE	3856						

Table 4: Sand predicting parameter of the wells



Well	Reservoir	Top/Base	Depth	Thickness (m)	ΔT_C $(\mu s/ft)$	G/C_b $(10^{12}\ psi^2)$	B $(10^6\ psi)$	S/I $(10^{12}\ psi^2)$	Ø (%)	UCS (MPa)
OWO11	A	TOP	3157	68	89.50	125.6	27.88	125	0.21	87.52
		BASE	3225							
	B	TOP	3800	88	78.84	408	3.6	406	0.20	115.95
		BASE	3888							
OWO10	A	TOP	3178	66	93.56	152.3	25.08	152	0.19	81.23
		BASE	3244							
	B	TOP	3681	175	82.58	173	28.29	173	0.19	96.97
		BASE	3856							

4.2 Discussion

4.2.1 Discussion of Results

In predicting whether a well will produce fluids without producing sand has been the goal of many well completion engineers and research projects There are a number of analytical techniques and guidelines to assist in determining if sand control is necessary. In the present study, two most sophisticated approach to predicting sand production, is the estimating petrophysical properties from well-logs and the use of geomechanical numerical models developed to analyze sand prediction/fluid flow through the reservoir in relation to the formation strength. These approaches are considered a valid solution which can provide results with a reasonable level of accuracy in predicting sanding in reservoir. The prediction required is on a reservoir-by-reservoir basis. The data used in this study is collected from four wells located at a hydrocarbon field in central Niger Delta of Nigeria, and of the four wells, two were used for sand prediction because one of the wells has no sonic log, while the sonic log in OWO 5, ranged outside the reservoir of study.

Five methods were used in predicting sand production. These methods are as follows:

1. Porosity method
2. Acoustic wave travel time
3. Sand production index (B)
4. Schlumberger sand production index (SI)
5. Shear modulus to bulk compressibility ratio

4.2.2 Prediction of Sanding using Porosity Method

The porosity value of OWO11 in reservoirs A and B are 0.21% and 0.20% respectively, while the porosity values of OWO10 in reservoirs A and B are 19% as shown in Table 4.

The porosity of a formation is used as a guideline as to whether sand control is needed. If the formation porosity is greater than 30%, the probability of the need for sand control is high because of the lack of cementation. A formation porosity of less than 20% indicates that the formation is consolidated and there may be no sand production in the formation/reservoir. The porosity values in the two wells are below the threshold value of 30% for sand production from a reservoir. Based on the calculated porosity values from the two reservoirs, sanding is not likely to occur in the field.

4.2.3 Prediction of Sanding using Acoustic Wave Travel Time Method ΔT_C

The acoustic wave travel time values in the two reservoirs in well OWO11 and OWO10 ranges from $78.84 - 93.56\ \mu s/ft$ as shown in table 4.4. Based on the $\mathbf{\Delta T_C}$ method, if sonic compressive time is greater than $104\ \mu s/ft$, the formation will produce sand. The result obtained from this study is below the value of $104\ \mu s/ft$ for sand production to occur. The reservoir is not likely to produce sand.

4.2.4 Prediction of Sanding using Sand Production Index (B)

In this research, predicting sanding using sand production index (B), shows that the values of sand production index obtained in the reservoirs falls between $3.6\ \times 10^6\ psi - 28.96\ \times 10^6\ psi$ as shown in Table 4.4. Sand control technique is required in a reservoir when the sand production index (B) in the reservoir is less than$2.9\ \times 10^6\ psi$. Research carried out by Bianlong *et al.,* 2013 obtained a sand production index (B) of $0.73\ \times 10^6\ psi$ in their reservoir of study. They concluded that sanding was likely to occur. The study shows that, sanding is not likely to occur in the study area based on the results obtained.

4.2.5 Prediction of Sanding using Schlumberger Sand Production Index (S/I)

From this research, predicting sanding using Schlumberger sand production index (S/I), shows that the values of Schlumberger sand production index obtained in the reservoirs falls between $125 \times 10^{12}\ psi^2 - 406\ \times 10^{12}\ psi^2$ as shown in Table 4. Sand control technique is required in a reservoir when the schlumberger sand production index in the reservoir is less than $1.24\ \times 10^{12}\ psi^2$. Based on the result obtained in this research using Schlumberger sand production index (S/I), it is observed that sanding is not likely to occur in the reservoirs. In their research, Bianlong *et al.,* 2013, used the Schlumberger sand production index to predict if their reservoir is likely to produce sand. The values they obtained were less than $1.24\ \times 10^{12}\ psi^2$ which indicated that the reservoir was likely to produce sand.

4.2.6 Prediction of Sanding using Shear Modulus to Bulk Compressibility Ratio (G/C_b)

Results of G/C_b as shown in Table 4.4. reveal that the analytical values of G/C_b obtained are much greater values than the threshold value $125\ \times 10^{12}\ psi^2\ - 406\ \times 10^{12}\ psi^2$.

According to Tixier *et al.,* 1975, the threshold values for sanding using G/C_b is $0.8\ \times 10^{12}\ psi^2$. The values obtained from the field of studies are far above the threshold value. Thus, indicating that the reservoirs are not likely to produce sands during drilling. Researchers such as Ehsan and Ebrahim, 2015, used G/C_b to estimate sanding in their studies, the values they calculated were higher than the threshold values for sanding, indicating that their reservoirs did not produce sand.

5. CONCLUSIONS

Well logs data of two wells were analysed for petrophysical and geomechanical properties of the study area. These properties were used to derive various parameters that were used to predict the likelihood of the occurrence sanding in a reservoir. Five sand production methods (Porosity, Acoustic wave travel time, Sand production index (B), Schlumberger sand production index (SI), Shear modulus to bulk compressibility ratio) were used in predicting sanding in the reservoirs of interest. From the results of this research, the following conclusions are reached:

1. It is observed that none of the reservoirs is likely to produce sand during drilling.
2. The reservoirs were well consolidated for sanding to occur as shown from the porosity values of the reservoirs.
3. Different methods (Porosity, Acoustic wave travel time, Sand production index (B), Schlumberger sand production index (SI), Shear modulus to bulk compressibility ratio) of sand production prediction were used in this research work to obtain accurate result and the results shows that the reservoirs were highly compacted and consolidated and would not produce sanding during production.

6. RECOMMENDATION

It is recommended that to forestall sanding during the lifespan of any well during production, well logs should be used to predict the likely occurrence of sanding during well exploration so that control or management strategies would be developed and applied during well design.

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