



Predicting Sanding Potential Using Empirical Method in “Ebendo” Field, Niger Delta, Nigeria

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ABSTRACT: Sand formations represent a large fraction of oil and/or gas reservoirs in the world, hence it becomes imperative to determine the competency of the reservoirs to produce sand-free hydrocarbon. This informed the empirical technique adopted in this study to evaluate elastic parameters such as shear modulus (G), bulk compressibility (Cb), shear modulus to bulk compressibility (G/Cb) ratio and Unconfined Compressive Strength (UCS) to determine sand influx in the “Ebendo” Field, Niger Delta, Nigeria. To achieve this goal, seven (7) hydrocarbon-bearing sand units with thicknesses ranging from 12.51 to 48.63 m were identified at depth range of 1884.79 - 3350.15 m across the four (4) wells. These elastic parameters were estimated at the interval of interest. The range of values obtained for G/Cb ratio in EBD (01 and 02) is 1.49×10^{12} - 5.40×10^{12} psi² while the range of values for G/Cb ratio in EBD (04 and 06) is 0.06×10^{12} - 0.41×10^{12} psi². This result suggests that EBD (01 and 02) have no potential to sanding while EBD (04 and 06) have a high probability of sanding when compared to the threshold value of 0.8×10^{12} psi². The production history of the “Ebendo” Field also correlates with the findings of this study. The low values of UCS in EBD (04 and 06) also agrees with the observation. Thus, this study has shown the efficacy of using empirical method as a quick approach to predicting sand production in the “Ebendo” Field and this technique could be used in other fields with similar geological setting.

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The need to evaluate formation strength from elastic constants becomes necessary to determine whether a formation is capable of producing at high flow rates without sand. If the formation cannot sustain high flow rates without sand, then it would be 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 (Eyinla and Oladunjoye, 2014). The production of sand along with the formation fluid (gas, oil and water) could be attributed to many factors such as the nature of the formation (unconsolidated or poorly consolidated) (Amiebenomo and Adewale, 2015), the strength of the formation, the stability of

flow and drop in pressure within the well (Khamehchi *et al.*, 2014). It is therefore vital to consider the potential of a well to sanding before producing from the well. The problems associated with sand production could be controlled with improve prediction techniques and sand control measures at reduced cost (Vahidoddin *et al.*, 2012; Khamehchi and Reisi, 2015). The major approaches to sand production prediction are (i) the use of empirical methods (Khamehchi and Reisi, 2015), (ii) theoretical modeling (Mohamad-Hussein and Ni, 2018) and (iii) laboratory experiments (Shabdirova *et al.*, 2019). The empirical approach is based on the use of field data to establish relationships between well data acquired during production and properties of the subsurface

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lithologies encountered in the boreholes (Eyinla and Oladunjoye, 2014; Khamehchi and Reisi, 2015). This is the technique adopted in this study due to the available data. Modified approaches that combined two or more of these three approaches have also been used some literature to predict sanding potential in wells (Sulaimon and Teng, 2020). Eyinla and Oladunjoye (2014) predicted the sand-free production safety limits from shear wave velocity and elastic moduli calculated from well logs. The study combined elastic modulus of strength to establish a range of minimum values at which sand production will not arise (given a certain flow rate). Khamehchi and Reisi (2015) used shear modulus to bulk compressibility ratio to successfully predict sand production in certain in Oilfield in Iran. The findings established that values of shear modulus to bulk compressibility ratio less than 0.8×10^{12} psi² is indicative of potential to sanding. This technique was supported with several case studies from regions around the world known for sand production. They however specified that when production exceeds critical drawdown pressure (which can be predicted using Unconfined Compressive Strength (UCS) method), sanding can occur in a well that has been certified sand free. The estimation of UCS is important for characterizing rock strength at depth (Chang, 2004). Many empirical relationships for UCS have been proposed for application in various rock types by Chang (2004). The study emphasized the significance of local calibration before any relationship is used. Sulaimon and Teng (2020) evaluated the use of shear modulus to bulk compressibility ratio to predict potential sanding and suggested that the approach could be combined with a geomechanical model for better prediction.

However, there is paucity of information on sanding potential in the Niger Delta region despite the massive sand mining activities in the region, therefore, the objective of this paper is to predict the sanding potential using empirical method in “Ebendo” Field, Niger Delta, Nigeria.

MATERIALS AND METHODS

Description of the study area: The “Ebendo” field is located onshore central Niger Delta with approximate distance of 100 km north-west of Port Harcourt, it covers about 65 km² (Fig. 1) and was operated by Energia. “Ebendo” field was farmed out of the former OML 56 in 2003 as a marginal field. The field has been producing since 2009 and at some point, reached over 6,000 BOPD in production for the first three development wells EBD (01, 02, and 03) (Africa oil and gas report, 2017, Energia limited, 2022). In 2014, a total of four development wells EBD (04, 05, 06 and 07) were drilled back-to-back (Energia limited, 2022). Hydrocarbon exploration and exploitation does not only require the knowledge of hydrocarbon in-place; however, mechanical competency of the reservoir rock must also be known (Eyinla and Oladunjoye, 2014). This informed the evaluation of sanding potential in the “Ebendo” field using well data. Elastic parameters such as shear modulus, acoustic impedance (AI), bulk compressibility, ratio of shear modulus (G) to bulk compressibility (C_b) were estimated, UCS was calculated and plots of some petrophysical parameters at the interval of interest were used to predict sanding in “Ebendo” Field. This will help reduce the risk and cost associated with hydrocarbon production, likewise, determine the appropriate sand control measure that would be required to ensure effective and enhance hydrocarbon production in “Ebendo” field.



Fig 1: Map showing the location of “Ebendo” in Niger Delta, Nigeria

The Niger delta is situated on the Gulf of Guinea on the west coast of central Africa. It is one of the world's major hydrocarbon provinces, with proven ultimate recoverable reserves of approximately 26 billion bbl of oil and an undervalued, but probably vast gas resource (Doust and Omatsola, 1990). The major stratigraphic units recognized in the Niger Delta oil and gas province are Akata, Agbada and Benin Formations, from the oldest to the youngest. The three formations represent prograding depositional facies that are distinguished based on sand-shale ratios (Short and Stäuble, 1967). The Agbada formation is an alternating sequence of sandstone and shale of delta-front, distributary channel, and deltaic plain origin. It is the major petroleum-bearing unit (Doust and Omatsola, 1990) (Fig. 1). The sandstones are medium to fine-grained, fairly clean and locally calcareous, glauconitic, and shelly. Niger delta reservoir sands are of considerable porosity and tend to be weakly or completely unconsolidated, the terrain is highly susceptible to sand production. The unconsolidated sands are loose and are susceptible to being produced into the wellbore and to the surface, unlike the consolidated (compacted) sands that are carried by fluid drag force. In addition, the rate at which the formation's fluid is produced is another factor that can lead to sand production in a well (Amiebenomo and Adewale, 2015).

Data: The data used in this study was obtained from the Nigerian Petroleum Development Company Limited (NPDC) through the permission of the Department of Petroleum Resources (DPR). Well data from four wells within "Ebendo" field were used in this study. The wells are EBD (01, 02, 04 and 06) respectively.

Data Analysis Of Well Logs: The sand units were identified using lithology logs (Gamma ray and self-potential logs) while the fluids were discriminated using the resistivity, porosity, and density logs. Hydrocarbon prospecting sands identified were also correlated across the four (4) wells. Gamma ray, resistivity and porosity logs were used for the correlation (Fig. 2). The well grain size distribution plot was carried out by plotting water saturation (fraction) against porosity (fraction) according to Adeoti *et al.*, (2015) and using the grain size differentiator lines as proposed by Asquith and Gibson (1982).

Determination of Elastic Parameters: For this study, shear sonic log data was not available, so a compressional sonic log was used as an alternative approach to evaluate elastic constants. Based on the empirical relationship between shaliness and

Poisson's ratio of the sand as described by Anderson et al., (1973).

$$\mu = 0.125q + 0.27 \quad 1$$

Where μ is Poisson's ratio and q is the shaliness index defined as:

$$q = \frac{\phi_s - \phi_D}{\phi_s} \quad 2$$

Where: ϕ_s = sonic derived porosity, ϕ_D = density derived porosity

Poisson's ratio calculated from Equation (1) was put in to estimate shear modulus, G and bulk modulus, K in Equations (3 and 4):

$$\text{Shear Modulus, } G = A \frac{\rho_b}{\Delta t_c^2} \times 1.34 \times 10^{10} \text{ psi} \quad 3$$

$$\text{Bulk Modulus, } K = \frac{1}{c_b} = B \frac{\rho_b}{\Delta t_c^2} \times 1.34 \times 10^{10} \text{ psi} \quad 4$$

$$\text{Acoustic Impedance, } AI = \frac{10^6}{\Delta t_c} \times \text{density} \quad 5$$

Where: $A = \frac{(1 - 2\mu)}{2(1 - \mu)}$ and $B = \frac{(1 + \mu)}{3(1 - \mu)}$

C_b = bulk compressibility, ρ_b = bulk density (gm/cc) and Δt_c = compressional transit time (μ s/ft).

The conversion factor included in the Equations (3 and 4): 1.34×10^{10} is a factor to convert bulk and shear moduli in psi units.

Determination of Unconfined Compressive Strength (UCS): According to Schlumberger Oilfield Glossary, the maximum axial compressive strength that can be withstood by a right-cylindrical sample under unconfined condition is UCS. The compressive stress is applied along one axis, the longitudinal axis of the sample used. An empirical relationship was developed between the Young's modulus and the UCS for Upper Agbada and the Benin formations by Salawu et al., (2016). The relationship is represented by Equation (6).

$$\text{UCS} = 0.3966E + 1.1956 \quad 6$$

Where: UCS = Unconfined compressive strength (UCS), MPa and E = Young's Modulus, GPa

Empirical Method from Field Observation: In this study, the elastic parameters such as shear modulus

(G), acoustic impedance, bulk modulus (K), bulk compressibility (C_b), and the ratio of shear modulus to bulk compressibility (G/C_b) of the prospect zones were estimated and some were cross plotted to predict the sand production potential at these zones. The empirical relation of the ratio of shear modulus to bulk compressibility was used to predict sand influx. This empirical relation states that once the threshold value $G/C_b = 0.8 \times 10^{12} \text{ psi}^2$ is exceeded, there is a high probability of sanding but when less than there is a low risk of sanding (Khamehchi and Reisi, 2015).

RESULTS AND DISCUSSION

Seven (7) hydrocarbon sand units were identified and correlated across most of the wells in the study area (Fig. 2). EBD (01) has five (5) hydrocarbon sand units with thickness range between 21.3 - 48 m at a depth range of 1884.42 - 3148.72 m. EBD (02) has seven (7) hydrocarbon sand units of thickness range between 12.5 - 45.6 m at a depth range of 1930.4 - 3315.72 m. EBD (06) has seven (7) sand units with thickness between 14.98 - 45.09 m at a depth range of 1904.99 - 3349.12 m. While EBD (04) has three (3) hydrocarbon

sands of thickness range between 12.65 - 26.03 m at a depth range of 3174.47 - 3315.72 m.

Estimated Elastic Parameters

Well 1: EBD 01 show relatively high values of shear modulus and acoustic impedance (Table 1). The bulk compressibility ranges from $3.69 \times 10^{-07} \text{ psi}^{-1}$ to $5.85 \times 10^{-07} \text{ psi}^{-1}$, while the ratio of shear modulus to bulk compressibility (G/C_b) ranges from $1.66 \times 10^{12} \text{ psi}^2$ to $5.40 \times 10^{12} \text{ psi}^2$. The G/C_b values are higher than the threshold value of $0.8 \times 10^{12} \text{ psi}^2$. The UCS values calculated from EBD 01 are relatively high (Fig. 3a).

Well 2: EBD 02 sands also show relatively high values of shear modulus and acoustic impedance (Table 1). The bulk compressibility ranges from $3.74 \times 10^{-07} \text{ psi}^{-1}$ to $5.91 \times 10^{-07} \text{ psi}^{-1}$ while the ratio of shear modulus to bulk compressibility (G/C_b) ranges from $1.49 \times 10^{12} \text{ psi}^2$ to $3.89 \times 10^{12} \text{ psi}^2$ (Table 1). The G/C_b values are higher than the threshold value of $0.8 \times 10^{12} \text{ psi}^2$. The UCS values calculated from EBD 02 are relatively high (Fig. 3b).

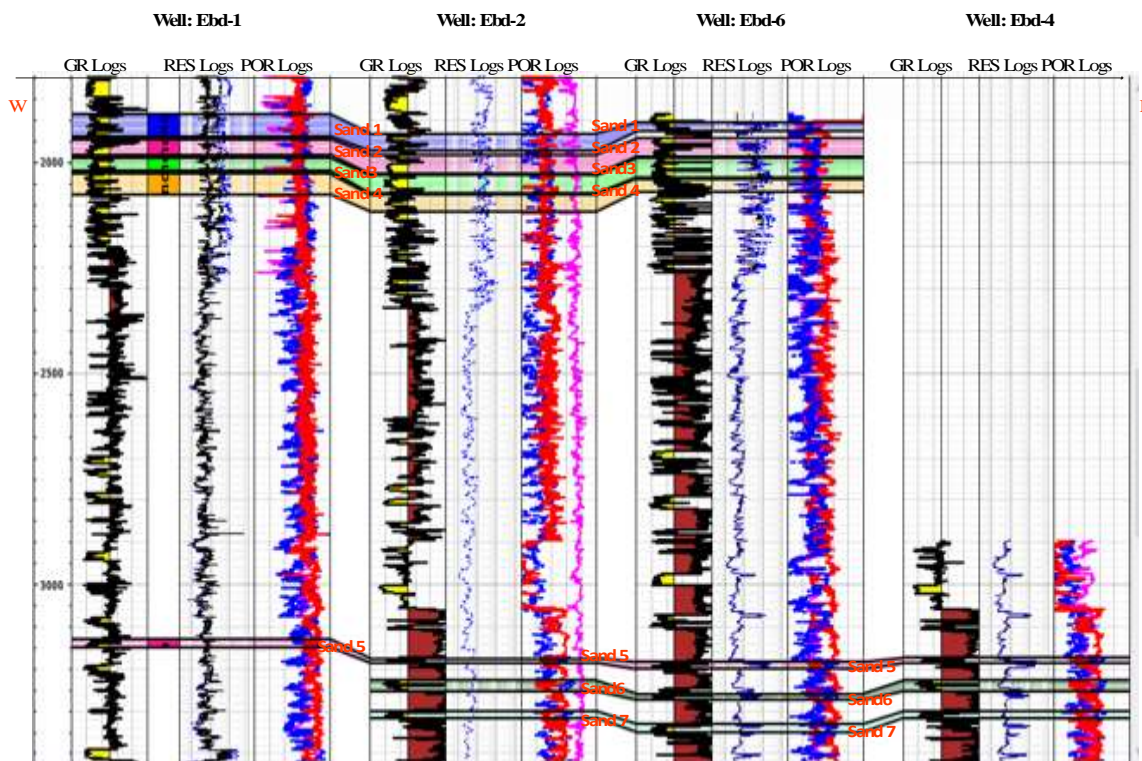


Fig 2: Correlation panel of seven hydrocarbon-bearing sands across wells in the study area

Well 4: EBD 04 sands show relatively low values of shear modulus and acoustic impedance (Table 1). The bulk Compressibility ranges from $9.71 \times 10^{-07} \text{ psi}^{-1}$ to $1.33 \times 10^{-06} \text{ psi}^{-1}$ while the ratio of shear modulus to bulk compressibility ratio (G/C_b) ranges from $0.219 \times$

10^{12} psi^2 to $4.05 \times 10^{12} \text{ psi}^2$ (Table 1). The G/C_b values are lower than the threshold value of $0.8 \times 10^{12} \text{ psi}^2$. The UCS values calculated from EBD 04 are relatively low (Fig. 4a).

Table 1. Estimated elastic parameters for EBD 01, EBD 02, EBD 04, EBD 06 sands

Sand	μ^1	$G[\text{psi}]^2$ *E05	$K[\text{psi}]^3$ *E05	AI^4 [(m/s)*(g/cc)]	$C_b[\text{psi}^{-1}]^5$ *E07	$G/C_b[\text{psi}^{-2}]^6$ *E12	UCS ⁷ [MPa]
EBD 01							
1	0.260	9.74	17.07	6706.61	5.86	1.66	8.38
2	0.263	10.50	18.62	7056.37	5.37	1.96	8.95
3	0.249	11.52	19.14	7238.04	5.22	2.20	9.60
4	0.245	11.52	18.75	7172.04	5.33	2.16	9.57
5	0.204	19.96	27.08	9283.80	3.69	5.41	15.11
EBD 02							
1	0.272	9.09	16.91	6620.18	5.91	1.54	7.96
2	0.263	10.44	18.51	7030.31	5.40	1.93	8.91
3	0.268	9.76	17.76	6835.92	5.63	1.73	8.44
4	0.291	8.51	17.55	6696.28	5.69	1.49	7.63
5	0.277	14.00	26.71	8628.32	3.74	3.74	11.67
6	0.156	18.64	20.88	8271.67	4.79	3.89	13.49
7	0.210	16.70	23.20	8405.04	4.31	3.87	12.90
EBD 04							
5	0.335	3.60	9.71	4962.18	0.10	0.35	3.82
6	0.328	2.92	7.51	4153.16	0.13	0.22	3.32
7	0.333	3.02	8.07	4326.35	0.12	0.24	3.40
EBD 06							
1	0.350	1.41	4.24	3028.24	0.24	0.06	2.81
2	0.342	1.60	4.53	3129.02	0.22	0.07	3.02
3	0.351	1.78	5.37	3463.86	0.19	0.09	3.28
4	0.355	1.78	5.54	3530.89	0.18	0.10	3.35
5	0.320	4.06	9.89	4860.77	0.10	0.40	1.31
6	0.326	3.55	9.02	4977.38	0.11	0.32	3.77
7	0.316	4.07	9.74	4819.63	0.10	0.39	3.81

¹Poisson's Ratio; ²Shear Modulus; ³Bulk Modulus; ⁴Acoustic Impedance; ⁵Bulk Compressibility; ⁶Shear Modulus / Bulk Compressibility ratio; ⁷Unconfined compressive strength, MPa

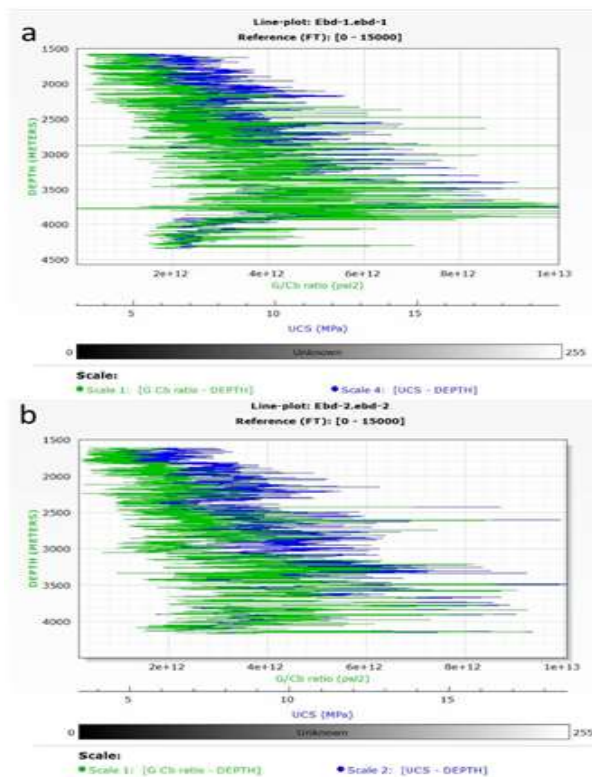


Fig 3: G/Cb and UCS values with depth. a) EBD 01 and b) EBD 02 sands are higher than the threshold value of 0.8×10^{12} psi² which indicates that there is no potential to sanding

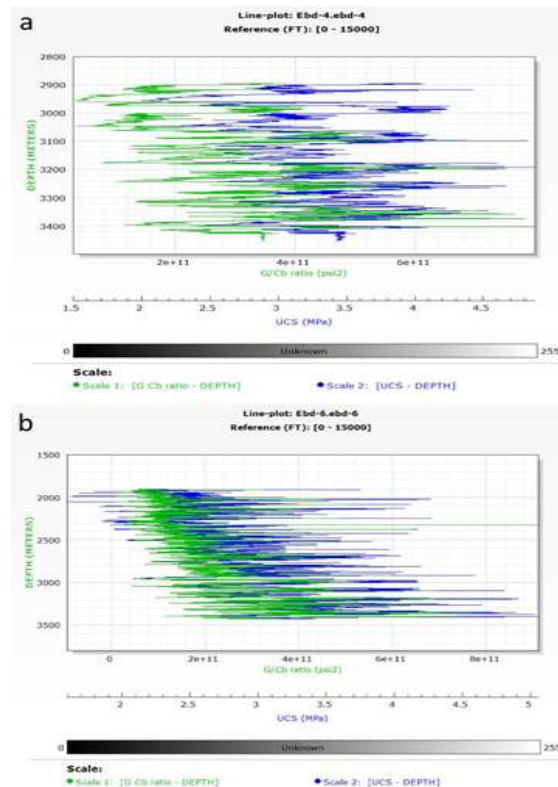


Fig 4: G/Cb and UCS values with depth. a) EBD 04 and b) EBD 06 sands are lower than the threshold value of 0.8×10^{12} psi² which indicates that there is a potential to sanding

Well 6: EBD 06 sands also show relatively low values of shear modulus and acoustic impedance (Table 1). The bulk Compressibility ranges from $9.66 \times 10^{-07} \text{ psi}^{-1}$ to $1.01 \times 10^{-06} \text{ psi}^{-1}$. The Shear modulus to Bulk Compressibility ratio (G/C_b) ranges from $0.599 \times 10^{12} \text{ psi}^2$ to $0.414 \times 10^{12} \text{ psi}^2$ (Table 1). The G/C_b values are lower than the threshold value of $0.8 \times 10^{12} \text{ psi}^2$. The UCS values calculated from EBD 06 are relatively low (Fig. 4b). The relatively high UCS values calculated from EBD (01) and EBD (02) (Figs. 3a and b respectively) are classified as moderately hard rock according to the National Engineering Handbook UCS classifications (2012). While the relatively low UCS values calculated from EBD (04) and EBD (06) (Figs. 4a and b) are classified as soft rock according (NEH, 2012). The higher G/C_b values for the sands in EBD (01) and EBD (02) (Figs. 3a and b) suggests that they have no sanding potential (Khamehchi and Reisi, 2015) and this agrees with the relatively high acoustic impedance values at these zones (Table 1). However, the lower G/C_b values for the sands EBD (04) and EBD (06) (Figs. 4a and b) indicates that they have the potential for sanding (Khamehchi and Reisi, 2015) and this agrees with the relatively low acoustic impedance values at these zones (Table 1).

Grain size distribution plots: For EBD (01, 02 and 06), the sands with lower gamma ray values (purple to blue) fall under coarse grain distribution while others fall under the very fine and fine to medium grained sand (Fig. 5a, b and 6b). For EBD 04, the sands with lower gamma ray values (purple to blue) fall under coarse grain sand (Fig. 6a). The distribution of the sands on the grain size distribution plots imply that the grains are moderately well sorted with corresponding good to excellent porosities according to Etu-Efeotor (1997). This is supported by favorable petrophysical parameters such as, low water saturation, high hydrocarbon saturation and high permeability associated with the zones. The plots also reveal that sands in EBD (01 and 02) are relatively more compacted (coarse, fine to medium grain and very fine-grained sand) than sands in EBD 04 and 06 (coarse and fine to medium grained sand).

The study identified seven (7) hydrocarbon-bearing sand with thicknesses ranging from 12.51 to 48.63 m across the four (4) wells and the range of values for G/C_b ratio suggests that EBD (01 and 02) have no potential to sanding while EBD (04 and 06) have a high probability of sanding. This raises obvious questions as regards, i) Why wells within the same field have contrasting sanding potentials? and ii) What are the consequences for sanding in the “Ebendo” field? In this section, these questions will be addressed as the main themes of discussion.

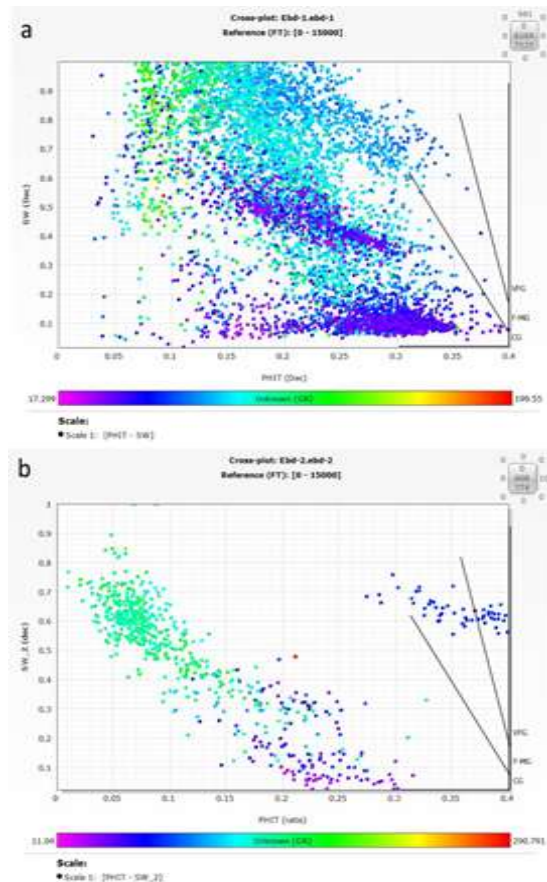


Fig 5: A tripartite plot of water saturation, porosity and gamma ray values for a) EBD 01 and b) EBD 02 (CG= coarse grained sand, F-MG= fine to medium grained sand VFG=very fine grained sand)

Contrasting sanding potentials within the same field: In this study the Acoustic impedance, (AI) which is the product of compressional wave velocity and density can be used to explain the contrasting sanding potential. Calculated AI for EBD (01 and 02) with no potential to sanding, are higher than the AI for EBD 04 and 06 which have high probability of sanding (Table 1). This is consistent with observations made in other studies (Sulaimon and Teng, 2020). Sands with higher AI values tend to be more consolidated compared to sands with lower AI values (Narongsirikul et al., 2019). Sulaimon and Teng (2020) successfully applied shear modulus to bulk compressibility ratio as a quick assessment to predict potential to sanding in clean sands. Another plausible explanation for the unconsolidated nature of the sands in EBD (04 and 06) and the consolidated nature of sands in EBD (01 and 02) may be the proximity of the wells. The Niger delta basin is located on a passive continental margin near the western coast of Nigeria where compaction is relatively slow as compared to active margins (Tuttle et al., 1999). This may also result in the unconsolidated nature of the sands in EBD (04 and 06).

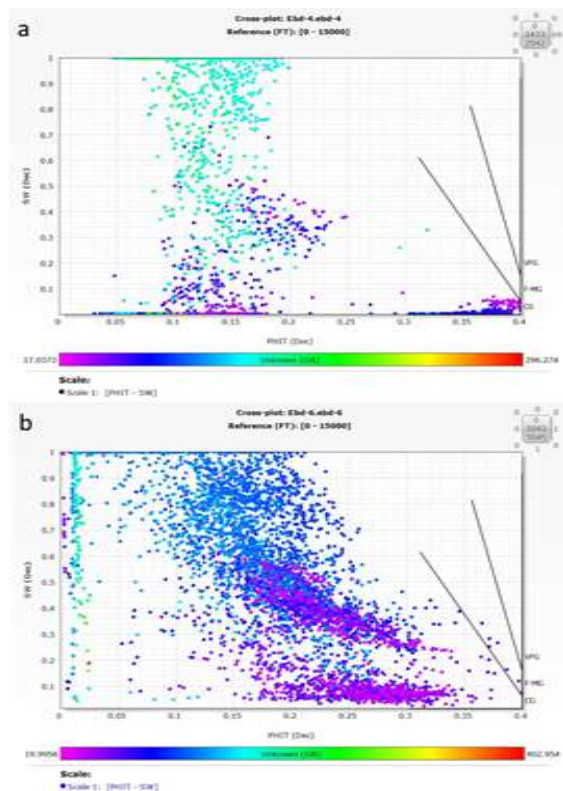


Fig 6: A tripartite plot of water saturation, porosity and gamma ray values for a) EBD 04 and b) EBD 06 (CG= coarse grained sand, F-MG= fine to medium grained sand VFG=very fine grained sand)

Consequences of sanding in the “Ebendo” Field: The production history of the “Ebendo” field suggest an average decline in production from over 6,000BOPD since 2009 for the first three development wells (EBD 01, 02, and 03) (Africa oil and gas report, 2017, Energiya limited, 2022) to about 1,276 BOPD (Africa oil and gas report, 2017) in 2016, that was after four more development wells (EBD 04, 05, 06 and 07) were drilled in 2014. A plausible explanation for the decline in production could be the probability of sanding observed in EBD (04 and 06) which are among the new set of development wells drilled in 2014. In addition, it is important to note that the rate at which a formation’s fluid is being produced can lead to sanding in a well (Amiebenomo and Adewale, 2015). As a result, when production exceeds critical drawdown pressure (which can be predicted using UCS method), sanding can occur in a well that has been certified sand free as in the case of EBD (01 and 02) according to this study (Khamehchi and Reisi, 2015).

Conclusion: A quick approach to predicting sanding potential using empirical method have been carried out in this study. Using well data, elastic parameters such as shear modulus (G), acoustic impedance (AI), and bulk compressibility (C_b) were estimated, UCS was

calculated and plots of some petrophysical parameters at the interval of interest were used to predict sanding. The findings of this study have been validated by the production history of the wells. This approach can easily be applied even when drilling operations are still taking place and certain decisions must be made immediately. This study has shown the efficacy of using elastic parameters to predict sand production in the “Ebendo” field, which could be adopted in other fields with similar geological settings.

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