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Rock Physics and Geo-Mechanical Analysis to Enhance Sanding Prediction in Oil Wells in "Chi Field" Offshore Niger Delta

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

An integrated approach of rock physics and Geomechanical analyses was adopted in this study to enhance the prediction of sanding in oil wells within 'CHI' field offshore Niger Delta.
The data used for this study include suite of wireline logs from three wells, base map and checkshot. concept of geomechanics was used in evaluating and understanding the rock mechanical properties of the reservoirs. Two reservoirs namely (RES1 and RES2) were mapped and interpreted. Elastic and geomechanical parameters were evaluated within the field, the parameters include; Poisson ratio, Young modulus, Bulk modulus, Shear modulus, and Unconfined compressive strength (UCS). The elastic properties of rocks are affected by geological factors which include: Lithology, Depth and Anisotropy. In addition, rock physics analysis was carried out using the friable, constant and contact cement model to quantitatively characterize the lithology and also investigate the degree of cementation, compaction trend and environment of deposition with emphasis on the reservoir. The geomechanical parameters reveal that the reservoirs within the study area is predominantly unconsolidated sandstone and friable shale which serves as reservoir seal. The result shows that the reservoir sand units have low Poisson ratio, Young modulus, Bulk modulus, Shear modulus and high UCS (0.31Gpa, 11.5GPa, 0.06GPa, 4.3GPa, 337.5psi respectively), with high compressibility value of 0.08GPa at reservoirs intervals. This suggest that the reservoir rocks are brittle with high potential to tensile failure.

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Keywords: Geomechanical; poisson ratio; young modulus; bulk modulus and UCS.

1. INTRODUCTION

The petroleum industry is facing a future where new technologies, creativity and integration of different disciplines, are the core of focus for higher exploration success rates and improved oil recovery. The recent increases in global demand for hydrocarbons and declining production from mature provinces are driving a new phase of international exploration for petroleum resources in deep offshore basin [1]. Sanding is a common problem in production and injector wells located in weak or poorly consolidated sandstone reservoirs [2]. Recent clastic sediments of the Pliocene and younger Tertiary ages are particularly troublesome and sand production problem maybe expected whenever wells are completed in unconsolidated formations [3]. Sand failures also occurs in older formation when in-situ rock strength is reduced by poor completion and production practice. Sanding prediction is necessary because some sand control techniques such as downhole solidification, emulsification, and gravel packing are very costly hence, it is better to predict the possibility of a formation to produce sand rather than applying sand control techniques without knowledge [4] The crucial step to effective rock mechanics solutions is hidden in obtaining rock mechanical parameters data like elastic moduli and estimating the strength of rock formation. Therefore, an economic production in such reservoirs will require a good understanding of the reservoir geomechanics. Adequate knowledge of the geomechanical properties of hydrocarbon reservoirs play an important role in designing recovery well, enhance recovery, and in safe drilling [5,6].

Identified areas where severe sanding problems are experienced among others include Nigeria, Trinidad, Indonesia, Egypt, Venezuela, Malaysia, Canada tar sands and Gulf of Mexico. The reservoirs in these formations lie between 1066.8 m and 3048 m [3].

1.1 Geology of the study Niger Delta Area

The Niger Delta has been proved over recent years to be a prolific oil and gas province that is situated in the Gulf of Guinea in the West Coast of Central Africa Fig. 1. These province covers about 300,000sqkm and includes the geologic extent of the Tertiary Niger Delta Petroleum System. The Niger Delta started to evolve in early Tertiary times when Classic River input increased [7,8]. Generally, the delta prograded over the subsidizing continental-oceanic lithospheric transition zone, and during the Oligocene spread on to oceanic crust of the Gulf of Guinea. The weathering flanks of outcropping continental basement sourced the sediments through the Benue-Niger drainage basin [9]. The Stratigraphic sequence of the Niger Delta comprises three broad lithostratigraphic units namely a continental shallow massive sand sequence the Benin Formation a coastal marine sequence of alternating sands and shales the Agbada Formation and a basal marine shale unit-the Akata Formation [10,11,12]. The sediments were deposited in pro delta environments; the sand percentage here is generally less than 30%. The Agbada Formation consists of alternating sand and shales representing sediments of the transitional environment comprising the lower delta plain (mangrove swamps, floodplain, and marsh) and the coastal barrier and fluviomarine realms. The sand percentage within the Agbada Formation varies from 30 to 70%, which results from the large number of depositional off lap cycles. A complete cycle generally consists of thin fossil ferrous transgressive marine sand, followed by an off lap sequence which commences with marine shale and continues with laminated fluviomarine sediments followed by barrier sand/or fluviatile sediments terminated by another transgression [13 (Inyang et al., 2017) [14]. The Benin Formation is characterized by high sand percentage (70 – 100%) and forms the top player of the Niger Delta depositional sequence. The massive sands were deposited in continental environment comprising the fluvial realms (braided and meandering systems) of the upper delta plain.

2. MATERIALS AND METHODOLOGY

Three suite of well logs data acquired in a field around Niger Delta sedimentary basin was utilized for this research this data was collected from a reputable oil company in Nigeria. "CHI" field is a field located in the Niger Delta. The original name for the field was not disclosed due to some constraint and it was designated as 'CHI' field to protect the confidentiality of the data. It is located within Latitudes 04°33'02.368N and 04°49'02.368N and Longitudes 03°47'42.249E to 04°36'22.239E. Hydrocarbon and non-hydrocarbon bearing sands were identified from gamma ray, resistivity, neutron and density responses. Well log correlation was done using the principle of similarities in log signatures across the wells. Rock physics concept was utilized to understand the nature of the sediments with respect to the geology. Using rock physics relationships, several cross-plots were employed for the qualitative characterization of the reservoir sands. Mechanical properties of the field were determined using wireline logs. Several Geomechanical parameters were deduced for the study area of the field in order to enhance the prediction of Sanding in oil wells within the field. Sanding prediction was done using Schlumberger sanding prediction index method (S/I). The method was used to generate the prediction of sanding parameters of the studied reservoir in the study area. The results from this study will provide a better understanding in sanding prediction within the field. The result affirms the high potential sanding of the studied reservoirs.

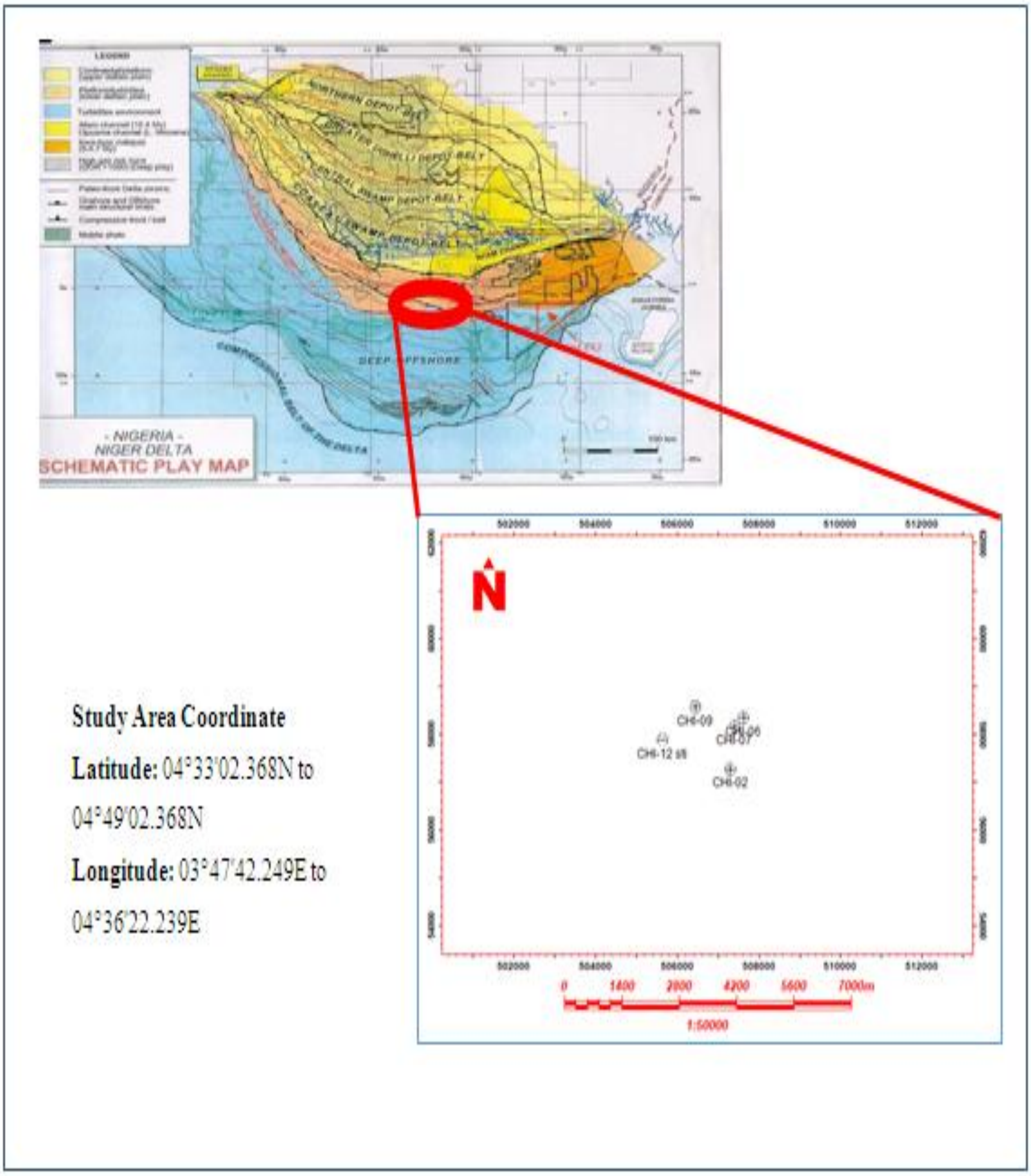

Fig. 1. Location and the base map of the study area

The way a material is loaded greatly affects its mechanical properties and largely determines how, or if, a component will fail; and whether it will show warning signs before failure actually occurs. Stress is defined as the force per unit area of a material.

$$\sigma = F/A \quad (1)$$

σ= Stress, F = Force, A = Area

Strain is said to be response of a system to an applied stress. When a material is loaded with a force, it produces a stress, which then causes a material to deform.

It is expressed as:

$\epsilon = (\Delta L)/L$ where; ϵ=strain, ∆l=change in length, l=original length (2)

Young's modulus is the ratio of the longitudinal stress to the longitudinal strain when a solid body is loaded by longitudinal stress within the elastic limit.

$$E = (Stress(\sigma))/(Strain(\epsilon)) \quad (3)$$

Poisson's ratio is the ratio of lateral strain to axial strain. It is expressed as:

$$\mu = \text{lateral stress/longitudinal strain} \quad (4)$$

Shear modulus is the ratio of shear stress to shear strain. It is expressed as:

$$G = \text{shear stress/shear strain} \quad (5)$$

On the other hand, Bulk modulus is the ratio of the applied stress to the volumetric strain when a solid body is subjected to uniform stress throughout its surface. It is expressed as:

$$K = E/(3(1-2\mu)) \quad (6)$$

The geomechanical properties can then be modeled based on well logging tools such as density and acoustic velocities, Gamma Ray and Neutron.

Wireline measurements will be converted to mechanical properties using the established relationship above.

The above relationship that exist between these parameters will be utilized in this research for the geomechanics analysis of the studied field.

2.1 Elastic and Geomechanical Parameters

The reservoir elastic and properties were deduced. The estimated elastic parameters were cross-plotted to discriminate between the nature of sediments in term of compaction, cementation and other diagenetic events in relation to geology in the target reservoirs.

3. RESULTS AND DISCUSSION

3.1 Well Log Interpretation

Two hydrocarbon-bearing reservoirs (RES1 and RES2) were identified and correlated across the two wells using gamma ray and resistivity logs Fig. 3. The reservoirs correlated were based on the high resistivity readings and continuity across the sand beds (indicating the presence of hydrocarbon), continuity of the sand units across the wells, and relative formation density and neutron logs separation. Well-log correlation was performed to delineate the geometry and continuity of sand bodies within the field. The general stratigraphy is alternation of sand and shale layers typical of Agbada Formation. The sand units are generally dirty comprising thin shale interbedding.

3.2 Rock Physics Analysis

Sediment compaction were investigated for the degree of cementation it exhibited and the effect on the porosity. To investigate this, rock physics cement models were utilized. These models account for the data of the porosity and velocity, color coded by gamma ray and depth. The models of contact cement, constant cement and friable sand are color red, light green and purple respectively.

Fig. 4 shows the cross plot of porosity and velocity for CHI-02 well sediments color coded with gamma ray. The three rock physics cement models utilized for this research were overlaid. The two major lithology where validated with low gamma ray said to be sand and high gamma ray shale. It could also be observed that most of the data points from the wells scattered between the cement and constant cement model. This suggest that the reservoir sands are not cemented compare to the friable shale unit. Fig. 5 shows the cross-plot of porosity and velocity for CHI-02 well sediment color coded with depth with the three rock physics cement models utilized for this research. It could be observed that handful of data set from the deeper depth in the region of 4500 meters cluster around the constant cement sand model which is an indication that the intervals experienced cementation. But the porosity values are considerably high indicating the initial cementation stage [15].

Generally, the higher porosity values cluster across the constant sand line, while lower porosity values cluster across the friable cement line. These reservoir formations can therefore, be interpreted as fairly cemented sand to unconsolidated sands compare to the friable shales. The crossplot for the reservoir intervals show that the reservoir sediments are unconsolidated (Fig. 6 and Fig. 7).

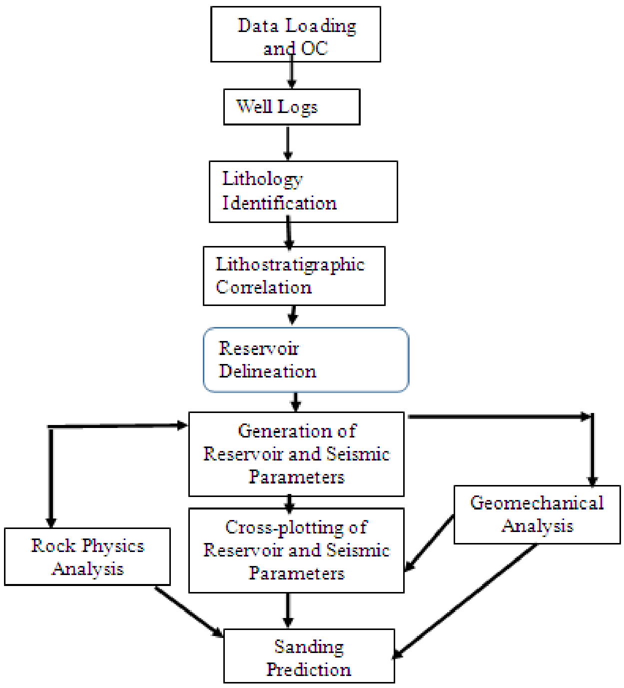

Fig. 2. Methodology flow chart

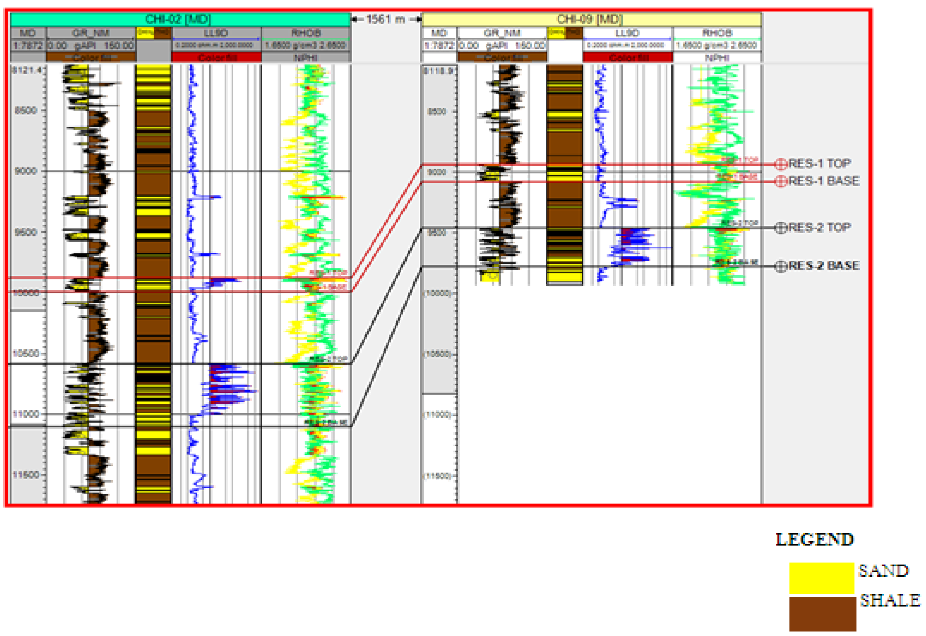

Fig. 3. Lithostratigraphic correlation of CHI well 02 and 09

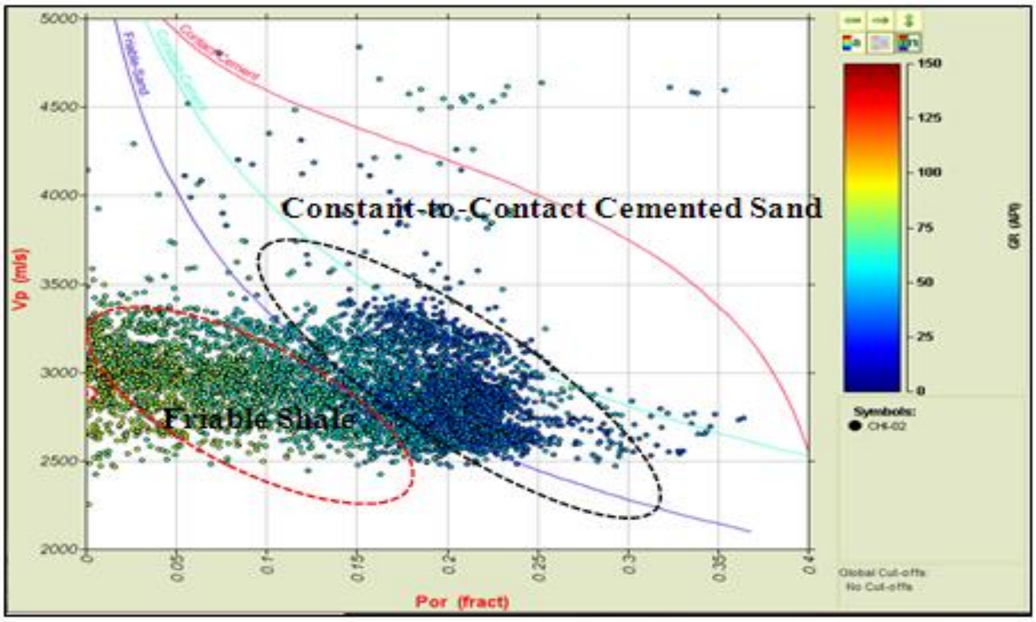

Fig. 4. Cross plots of Velocity against Porosity Color-coded with gamma ray for CHI-02 well

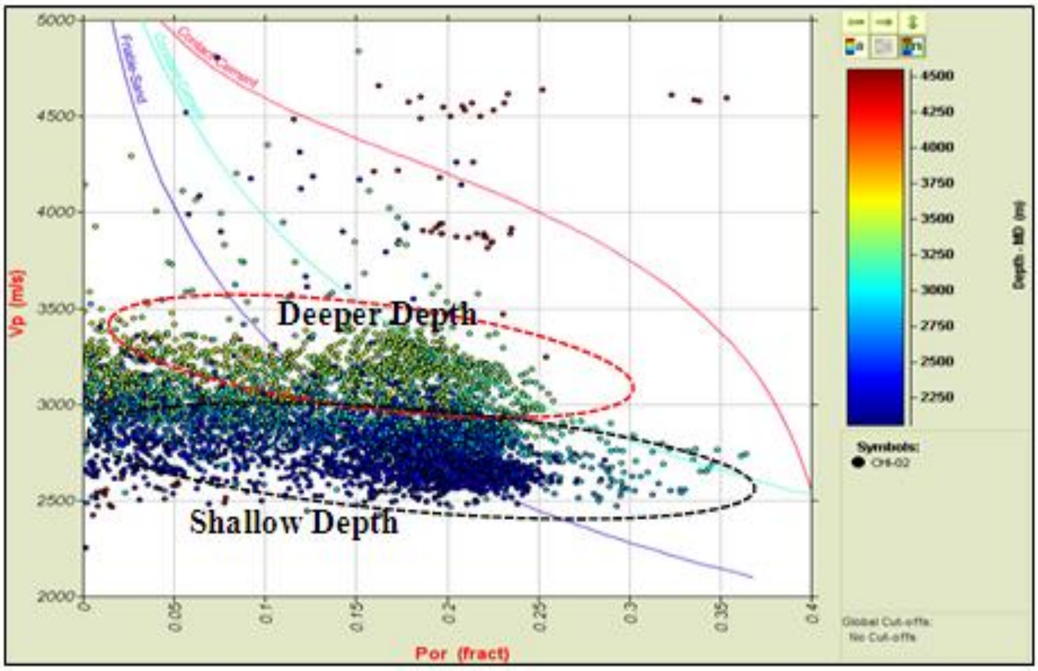

Fig. 5. Cross plots of velocity against porosity color-coded with depth for CHI-02 well

3.3 Elastic Parameters

Elastic parameters estimated in a particular geologic environment is directly related to the nature of the sediments. These parameters were generated to give understanding about the nature of the sediments within the studied field. The parameters generated include; Poisson ratio, Young modulus, Vp/Vs ratio, Mu rho, Lambda rho, Acoustic impedance, Shear impedance, Bulk modulus and Shear modulus.

Fig. 8 and Fig. 9 shows the elastic parameters generated for CHI-02 well. The parameters are Acoustic impedance, Vp/Vs, Poisson ratio, Young modulus, Bulk modulus, and Shear modulus. Reservoir intervals RES 1 and RES 2 and their corresponding cap rock intervals which are shale that serves as the reservoir seal were all estimated and interpreted. The significant variations in properties between the cap rocks and the reservoir sand units in individual well unit can be observed.

The cap rocks which are shale could be seen to have high Poison ratio, low Young modulus and high elastic moduli. Hence, this makes the shale more ductile, stiffer, and less compressible. This will therefore make the shale more prone to compressive shear failure, but better fracture stimulation barriers. However, the reservoir rocks, have relatively low Poisson ratio, high Young modulus and elastic moduli. Hence, strength of the rock is more brittle with higher potential for tensile failure.

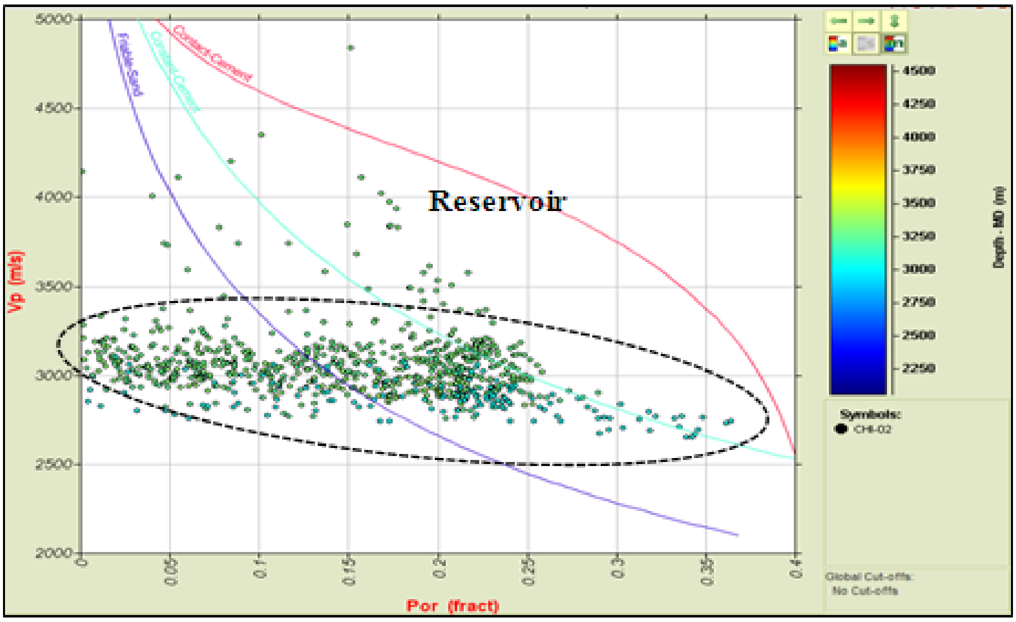

Fig. 6. Cross-plots of velocity against porosity color-coded at reservoir interval with Depth for CHI-02 well

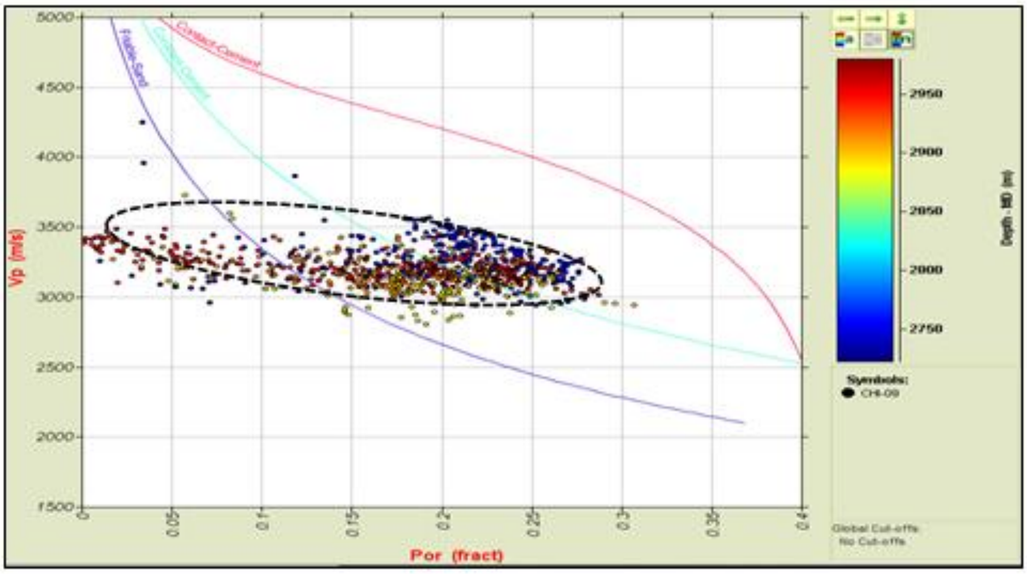

Fig. 7. Cross-plots of velocity against porosity color-coded at reservoir interval with depth for CHI-09 well

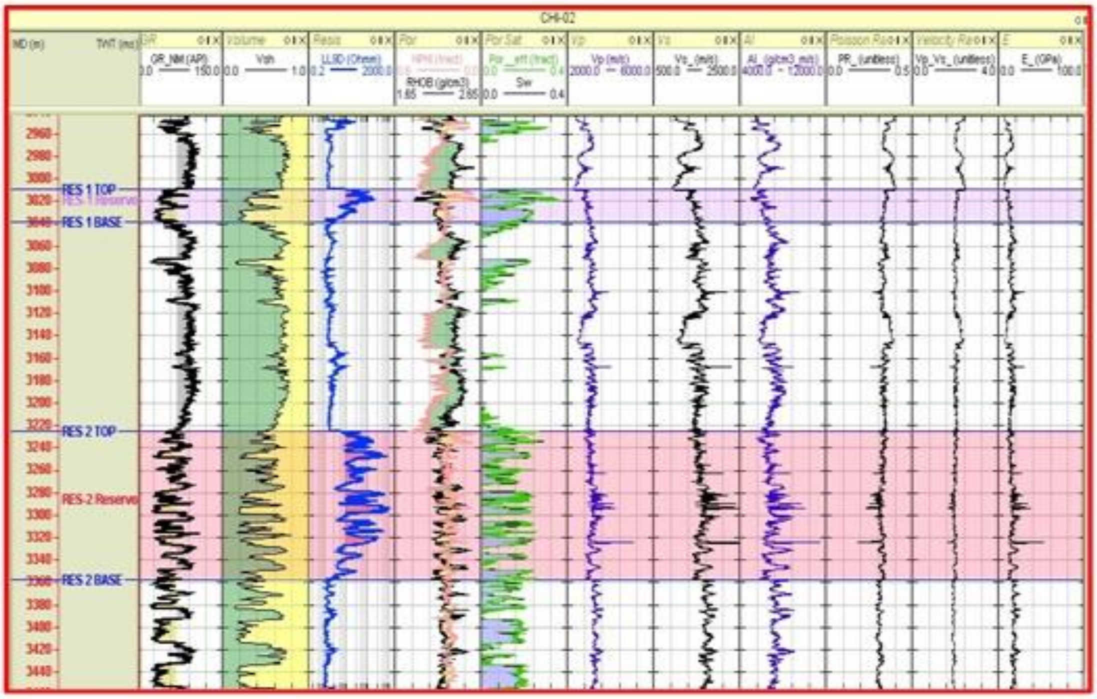

Fig. 8. Log plots of elastic and reservoir parameters generated for CHI-02 well

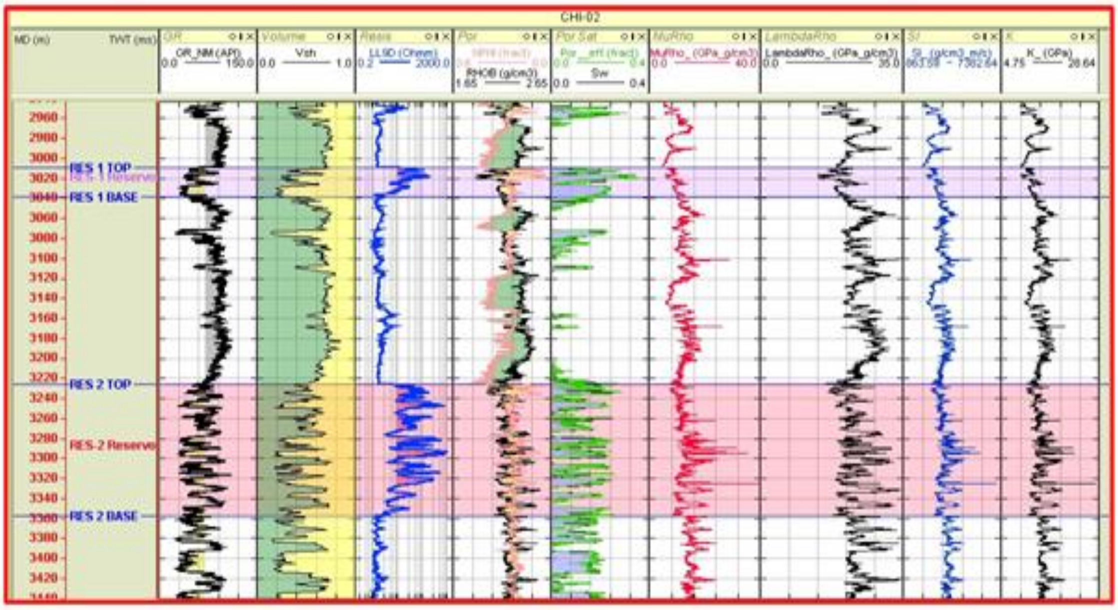

Fig. 9. Log plots of elastic and reservoir parameters generated for CHI-02 well

3.4 Sanding Prediction

Sanding prediction was done using Schlumberger sanding prediction index method (S/I). When the Schlumberger sand production index of a formation is less than 1.24×1012psi2 the formation is likely to produce sand and sand control may be necessary [16]. This method solely depends on the calculated geomechanical parameters (Table 1). The method was used to generate the prediction of sanding parameters of the studied reservoir in the studied area.

From the table the value ranges between $0.99\times10^{12}psi^{2}$ and $1.00\times10^{12}psi^{2}$ with an average of $0.99\times10^{12}psi^{2}$. The result shows that reservoir

Table 1. Summary of sand prediction method of the studied reservoir using the schlumberger prediction index

WELLS	Bulk Modulus (K) Gpa	Compressibility(Cb) Gpa	S/I
CHI-02			
RES 1	11.91355	0.083938	0.99
RES 2	14.16398	0.070602	1.0
CHI-09			
RES 1	4.968	0.066809	0.99
RES 2	14.362	0.069628	1.0
CHI-12			
RES 1	14.897	0.067128	0.99
RES 2	15.049	0.06645	1.0

RES1 and RES2 formations fall below the threshold cutoffs of sanding. This suggests that reservoirs RES1 and RES2 will have high potential of sand influx. Similarly, this result validate that the delineated reservoirs are highly unconsolidated.

4. CONCLUSION

An integrated approach of rock physics and geomechanical analyses was adopted in this study to enhance the prediction of sanding in oil wells within ‘CHI’ field offshore Niger Delta. The data used for this studied include a suite of wireline log from three wells, base map, and checkshot. Gamma ray log was used to identify the lithology in the study area, resistivity log was employed for fluid discrimination (oil, water) and neutron-density logs indicated porosity as well as fluid types. The concept of geomechanics was used in evaluating and understanding the rock mechanical properties of the reservoirs. Rock physics diagnostic aided in evaluating the rock properties of the reservoir sands. Elastic and geomechanical parameters were evaluated to determine the mechanical properties of the formation rocks within the oil wells in the field, the parameters include; Poisson ratio, Young modulus, Bulk modulus, Shear modulus, and Vp/Vs ratio. The elastic properties of rocks are affected by geological factors such as: Depth of burial, Lithology and Anisotropy etc. In addition, rock physics analysis was carried out using the Dvorkin and Nur [17] model to quantitatively characterize the lithology and also investigate the degree of cementation, compaction trend and environmental deposition of the sediment with more emphasis on the reservoir sands of ‘CHI’ field. The cross plots validated the lithology’s from the gamma ray log. The model quantitatively revealed that sediments that falls between the constant cement and friable sand was interpreted as sands that are poorly cemented or unconsolidated sands. This sand lithology is influenced by depth of burial, depositional trends and other diagenetic events. The quantitative interpretation of geomechanical parameters reveal that the reservoirs within the ‘CHI’ field is predominantly unconsolidated sandstone and friable shale which serves as reservoir seal. The result shows that the reservoir sand units have low Poisson ratio, Young modulus, Bulk modulus, Shear modulus and Unconfined compressive strength, higher compressibility and porosity at the reservoirs intervals. This suggest that the reservoir rocks are brittle with high potential to tensile failure.

Furthermore, cap rock showed high value of Poisson ratio due to its ductility which is controlled primarily by clay content, high Young modulus, Bulk modulus, Shear modulus and unconfined compressive strength, lower compressibility and porosity. This suggest the cap rock is stiffer due to high moduli. Adopting Schlumberger sand production index for sanding prediction analysis, the result affirms the high potential sanding of the studied reservoirs.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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