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Full Length Research Paper

Optimization of drilling parameters in the development plan of an unexplored area of gulf of Guinea

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The purpose of this study was to optimize drilling parameters in development plan of an unexplored Area of Gulf of Guinea in Nigeria. Well data and well manuals were used. A model and an Excel sheet were developed to correlate true vertical depth, cost and days/period, rate of penetration, rotary speed, depth, weight on bit, and bit diameter per day/meter drilled as it progresses. Findings show that we can drill deeper wells at less cost and time. We were able to predict the Rate of Penetration using real field data gathered in Unexplored Area of Gulf of Guinea to obtain operating parameters that leads to maximize rate of penetration. With these results, hopefully the next group of wells that would be drilled in future will be drilled almost three times faster than this case study wells and at half of their cost.

Keywords: Optimization**,** drilling parameters, development, plan, unexplored area.

INTRODUCTION

The Gulf of Guinea is one of the most prolific hydrocarbon provinces of the world. The Niger Delta is a Paleocene to Recent, wave-dominated delta situated in the Gulf of Guinea and extending into the northern Unexplored Area. Following the Mesozoic rifting of the Atlantic, sedimentation began with Albian drift deposits. Sediments filled the Benue Trough and by Late Eocene time began to prograde across the existing continental slope into the deep sea. Continued seaward progradation since the Eocene has extended the continental margin to its present position. Modern seismic data and improved models of sand distribution indicate that in places prospective acreage can extend up to 300 km from the present-day coastline of Nigeria. Extensive regional 2 Dimensional (2D) and 3 Dimensional (3D) multi-client seismic data shot by a number of seismic Contractors provided high quality regional dataset that have enabled unprecedented insight into the tectono-stratigraphic evolution of the Niger Delta and especially the deep-water Province. The total sedimentary prism, an area of some 140,000 km^2, has a maximum stratigraphic thickness of about 12 km.

The Unexplored Area (UA) of Gulf of Guinea is an area of overlapping maritime Boundary claims as shown in Figure 1. It covers an area of 30,000 km^2 in the oil rich Gulf of Guinea and located at varying water depth of 1863 – 2140 m. A case study of four consecutive exploratory wells drilled in Gulf of Guinea is taken into consideration: Iris-1XR, UA 4, noncommercial gas; Oxalis-1X, UA 3, noncommercial gas; Aster-1X, UA 4, dry well; and Freesia-1X, UA 4, noncommercial gas, where UA simply means Unexplored Area of Gulf of Guinea. The relationship between the drilling parameters of the exploratory wells drilled in the area was compared to optimize the Development Plans. The relationship between the current four wells in progress in the zone, drilling and reservoir parameters were taken into consideration.

Paul, Geir and Thamarat (1993) stated that optimized drilling techniques have significantly reduced drilling costs, and detailed treatment is given to the interactions of the most important drilling variables. Results indicate that better data, more experience, and confidence will result in greater savings in the future (Paul et .al, 1993).

Drilling optimization is necessary to minimize cost/expenditure, save time and to ensure safety. The parameters involve in the Bingham's rate of penetration

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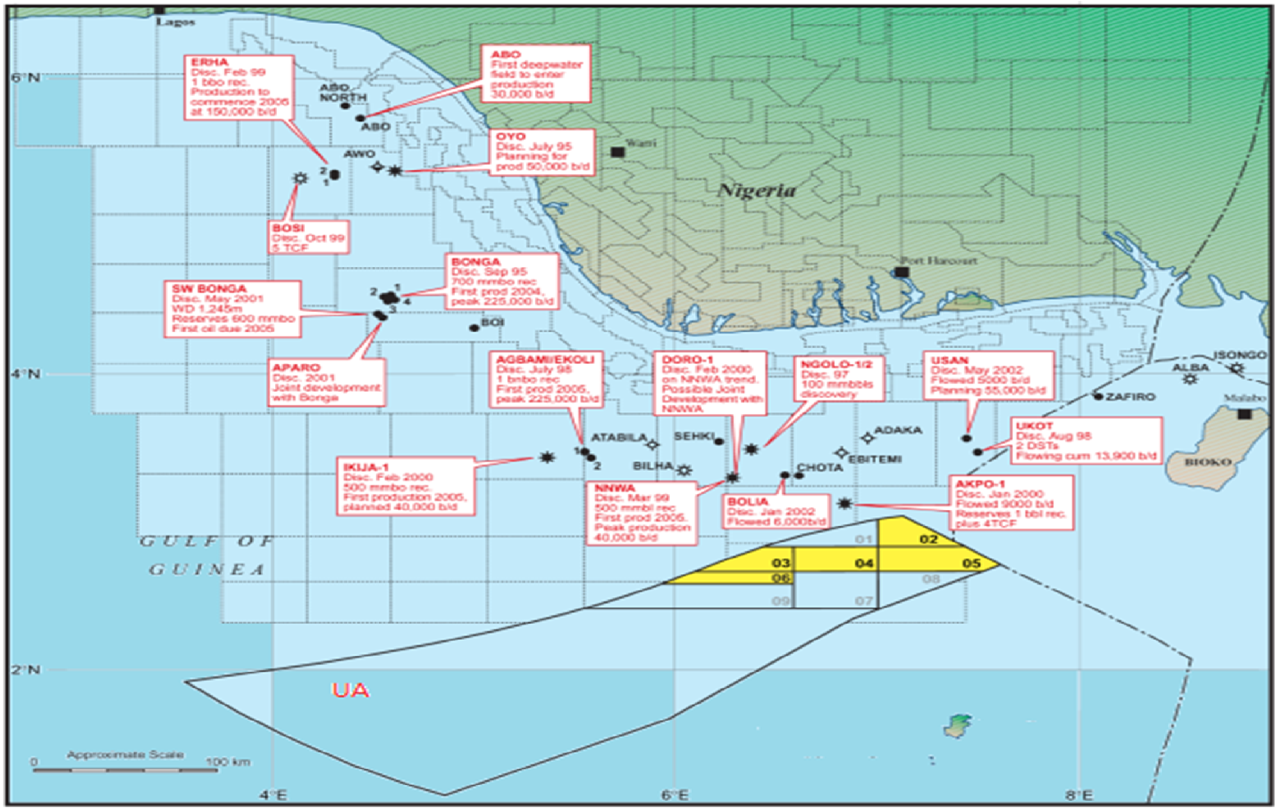

Figure 1. Regional Geology of the Gulf of Guinea examined.

Table 1. Drilling parameters of examined wells.

	Days spent		Cost(million dollars)		
WELLS	**Planned**	**Actual**	**Planned**	**Actual**	**TVD (ft)**
Iris-1XR, UA 4	31	32	31	41	12300
Oxalis-1X, UA 3	32	32	41	43	11491
Aster-1X, UA 4	35	29	47	39	13684
Freesia-1X, UA 4	37	32	52	45	12625

Source: (Personal Survey of Well data, 2011)

equation; penetration rate, formation drillability constant, weight-on-bit, bit diameter, bit weight exponent and rotary speed were considered.

To optimize drilling operations, it is necessary to establish criteria for evaluating drilling performance, identify the variables that affect this performance and determine how to control these variables to our advantage. Figure 1 shows the regional geology of the examined area.

METHODOLOGY

The methodology used in optimizing the drilling parameters of the four wells as shown in Table 1, 2, 3 and 4 (i.e. Iris-1XR, UA 4, Oxalis-1X, UA 3, Aster-1X, UA 4 and Freesia-1X, UA 4) drilled in Unexplored Area were examined to develop a simple and reliable tool to predict the performance of the wells' drilling parameters. This is to evaluate the economic feasibility and to enhance development plan of the area.

Well data, well manuals, internet and Society of Petroleum Engineers publications were used to obtain all the necessary information.

Calculations and optimization

Several attempts have been made to combine various drilling variables into a single optimization model,

Table 2. Section 17 ½ Drilling Parameters.

Wells	Weight on Bit, W(lbs)	Rotary Speed in Revolution per minute (RPM)	Drilling Bit Diameter, d_B(in)	True Vertical Depth, TVD(ft)	Rate of Penetration, ROP(ft/hr)	Optimized Rate of Penetration, ROP_{opt}(ft/hr)
Iris-1XR, UA 4	10000	35	17.5	1561	92	97
Oxalis-1X, UA 3	10000	30	17.5	981	90	95
Aster-1X, UA 4	10000	40	17.5	1509	98	103
Freesia-1X, UA 4	10000	38	17.5	1076	91	96

Source: (Personal Survey of Well data, 2011)

Table 3. Section 12 ¼" Drilling Parameters.

Wells	W(lbs)	RPM	d_B(in)	Depth(ft)	ROP(ft/hr)	ROP_{opt}(ft/hr)
Iris-1XR, UA 4	30000	75	12.25	2132	157	168
Oxalis-1X, UA 3	30000	70	12.25	4113	153	164
Aster-1X, UA 4	30000	80	12.25	1509	164	174
Freesia-1X, UA 4	30000	76	12.25	2893	158	169

Source: (Well data and Personal Survey, 2011)

Table 4. Section 8 ½" Drilling Parameters.

Wells	W(lbs)	RPM	d_B(in)	Depth(ft)	ROP(ft/hr)	ROP_{opt}(ft/hr)
Iris-1XR, UA 4	30000	115	8.5	2014	60	78
Oxalis-1X, UA 3	30000	110	8.5	823	59	75
Aster-1X, UA 4	30000	120	8.5	3611	98	84
Freesia-1X, UA 4	30000	116	8.5	2080	61	80

Source: (Personal Survey of Well data, 2011)

Bingham's equation, from which the developed concept of the dc exponent is one commonly used for this purpose:

$$\frac{dD}{dT} = a\left[\frac{W}{dB}\right]^d \times N^e \quad (1)$$

$$\frac{dD}{dT} = aw\sqrt{N}$$

Where: $\frac{dD}{dT}$ = penetration rate, ft/hr
a = matrix strength constant
d = formation drillability
e = rotary speed exponent
W = weight-on-bit, 1000 lb_f
d_B = bit diameter, inches
N = rotary speed, revolutions/minute (RPM)

This empirical relationship is commonly used in field calculations, and has been adapted as a tool for predicting pore pressures. It assumes a threshold bit weight of zero, a value of one for the rotary speed constant and perfect bottom hole cleaning. It accounts for formation and other effects by assigning constants (a and b) based on local drilling conditions. Other correlations have been developed to describe how mud properties, formation characteristics and other variables affect penetration rate. The term drillability constant describes the effect of formation strength and bit type on penetration rate, as well as the effects of drilling variables that have not been mathematically modeled. It is a dimensionless constant, and is numerically equal to the penetration rate that would be attained under the defined "normalized conditions.

However, Jordan and Shirley (1966, 1972) re-organized this equation to be explicit in "d". This equation was then simplified by assuming that the rock which was being drilled did not change (a = 1) and that the rotary speed exponent (e) was equal to one. The rotary speed exponent has been found experimentally to be very close to one, this removed the variables which were dependent on lithology and rotary speed (Keith and Tow, 1978). The following equations were developed and used to generalized the above equation and makes it useful in most areas.

Table 5. Drilling parameters.

Hole size(in)	A	d	E	W (lb)	N (rpm)	Av. ROP (ft/hr)	Av.ROP_{opt}(ft/hr)
17 ½	0.008278	0.56	2.71	1 – 10000	35	93	98
12 ¼	0.000846	0.56	2.71	2 – 30000	75	158	170
8 ½	0.000159	0.21	2.71	5 – 30000	115	70	80

Source: (Personal Survey of Well data, 2011)

$$\mathbf{d} = \frac{\log\left(\frac{\mathbf{R}}{\mathbf{60N}}\right)}{\log\left(\frac{\mathbf{12W}}{\mathbf{10^6B}}\right)} \quad \textbf{(2)}$$

It can be seen that the d-exponent equation takes no account of mud weight. Since mud weight determines the pressure on the bottom of the hole the greater the mud weight the greater the chip hold-down effect and therefore the lower the ROP. A modified d-exponent (dc) which accounts for variations in mud weight has therefore been derived and is as follows:

$$\mathbf{dc = d(MW1 \div MW2)} \quad \textbf{(3)}$$

Equation 1 was used to produce Table 7 which is Sample of inputs and output of modeled Rate of penetration function

A summary of drilling parameters of examined four wells which include cost, days spent and true vertical depth (TDV) are shown in Table 1.

Drilling Parameters of the four wells (i.e. Iris-1XR, UA 4; Oxalis-1X, UA 3; Aster-1X, UA 4 and Freesia-1X, UA 4) in three sections are shown in Table 2, 3 and 4.

Rate of penetration in Table 4 should be properly monitored to avoid blow out.

Analysis of Sections

At Section 17 ½”, the rate of penetration for the four wells (i.e. Iris-1XR, UA 4; Oxalis-1X, UA 3; Aster-1X, UA 4 and Freesia-1X, UA 4) were 92, 90, 98 and 91 optimized to be 97, 95, 103 and 96 respectively.

At Section 12 ¼” the rate of penetration for the four wells (i.e. Iris-1XR, UA 4; Oxalis-1X, UA 3; Aster-1X, UA 4 and Freesia-1X, UA 4) were 157, 153, 164 and 158 optimized to be 168, 164, 174 and 169 respectively.

At Section 8 ½” the rate of penetration for the four wells (i.e. Iris-1XR, UA 4; Oxalis-1X, UA 3; Aster-1X, UA 4 and Freesia-1X, UA 4) were 60, 59, 98 and 61 optimized to be 78, 75, 84 and 80 respectively.

All ROP’s were optimized except Aster-1X, UA 4 at Section 8 ½”, the formation at that region was feared to be fragile (soft formation) and damage was anticipated to either the formation, drilling assembly or surface equipment.

RESULTS

In obtaining the optimum performance of the drilling parameters of the Unexplored Area, an Excel sheet was developed and used to enable the calculation and correlation of True Vertical Depth, Rate of penetration, Rotary speed, Weight on bit, and bit diameter per section drilled as drilling progresses. Table 5 gives formation drillability, rock’s matrix strength constant, rotary speed exponent, weight-on-bit (ranges in a given section), rotary speed, average rate of penetration and optimized average rate of penetration (ranges in a given section) as obtained from the model which shows that in some parts, exerting high Weight on bit and Rotary Speed, the Rate of penetration value decreases due to hole cleaning problem and bit floundering. In this work, the parameters that affect any drilling operation were grouped into two most important factors: Hydraulic factors and Mechanical factors. However, more emphasis was given to the mechanical factors (i.e. weight on bit, bit size and rotary speed) but lithology and mud weight were also touched which are integral parts of hydraulic parameters. Finally, optimize drilling operations aimed at establishing criteria for evaluating drilling optimization performance, identifying the variables that affect this performance, determining how to control these variables to the advantage of the wells in Unexplored Area of Gulf of Guinea and related fields were obtained.

DISCUSSION OF RESULTS

A number of drilling parameters were analyzed to identify the performance of a drilling operation. No single parameter was able to adequately describe how well an operation has been accomplished. Table 5 shows that the average penetration rate of each section has been optimized or improved to a certain number. Table 6 shows the range by which each of the parameters can be operated within the limit of safety (i.e. without causing damage to either the formation, drilling assembly or surface equipment) so that the model should not be a source of problem to the drilling operation. Table 7 is a sample of the model (Bingham equation) that was developed from Excel sheet to facilitate and help to compare the relationships that exist between the various

Table 6. Range of parameters used in the model.

S/No.	Parameter	Dimension
1	Hole Size (inch)	17.5 - 8.5
2	Depth (ft)	0 - 3500
3	W (1000lb)	1 – 30
4	N (rpm)	30 – 150
5	MW (pcf)	60 – 145
6	ROP (ft/hr)	30 – 200

Source: (Personal Survey of Well data, 2011)

Table 7. Sample of inputs and output of modeled Rate of Penetration function.

	Bit size	Dept	W	N	MW	ROP
Input	17.5	2500	20	90	133	160
Target	17.5	2500	?	?	133	?

Source: (Personal Survey, 2011)

Table 8. Results of optimization applying Bingham model for Mud Weight for each 200 ft.

Depth	Weight on bit (W)	Rotary Speed (N)	Mud Weight (MW)	Rate of penetration (ROP)
0	10	40	62	132
200	10	40	62	132
400	10	40	62	132
600	10	40	62	132
800	20	60	65	144
1000	20	60	65	144
1200	20	60	65	144
1400	20	60	65	144
1600	20	100	80	155
1800	20	100	80	155
2000	30	100	120	171
2200	30	100	120	171
2400	30	100	125	171
2600	30	120	125	171
2800	30	120	140	188
3000	30	120	140	125
3200	30	120	65	120
3400	30	120	65	120

Source: (Personal Survey, 2011)

drilling parameters involved in optimization performance. Table 8 is an implementation of table 7 (the model) taking at an interval of 200 ft over a wide range to enable one study the relationship that exist between the variables so as to know with certainty which of these parameters directly or indirectly affects drilling performance as well as penetration rate so that time taken to drill a given section can be reduced to the minimum level which will significantly save cost and consequently improve the field development plan.

Some problems may develop after the drilling program has been started; Formation tops may vary from those of the program, bit performance may be much lower than expected, pump pressure may be lower than planned or well 'kicks' may require premature weighting-up of the mud. In order to prevent problems which are likely to

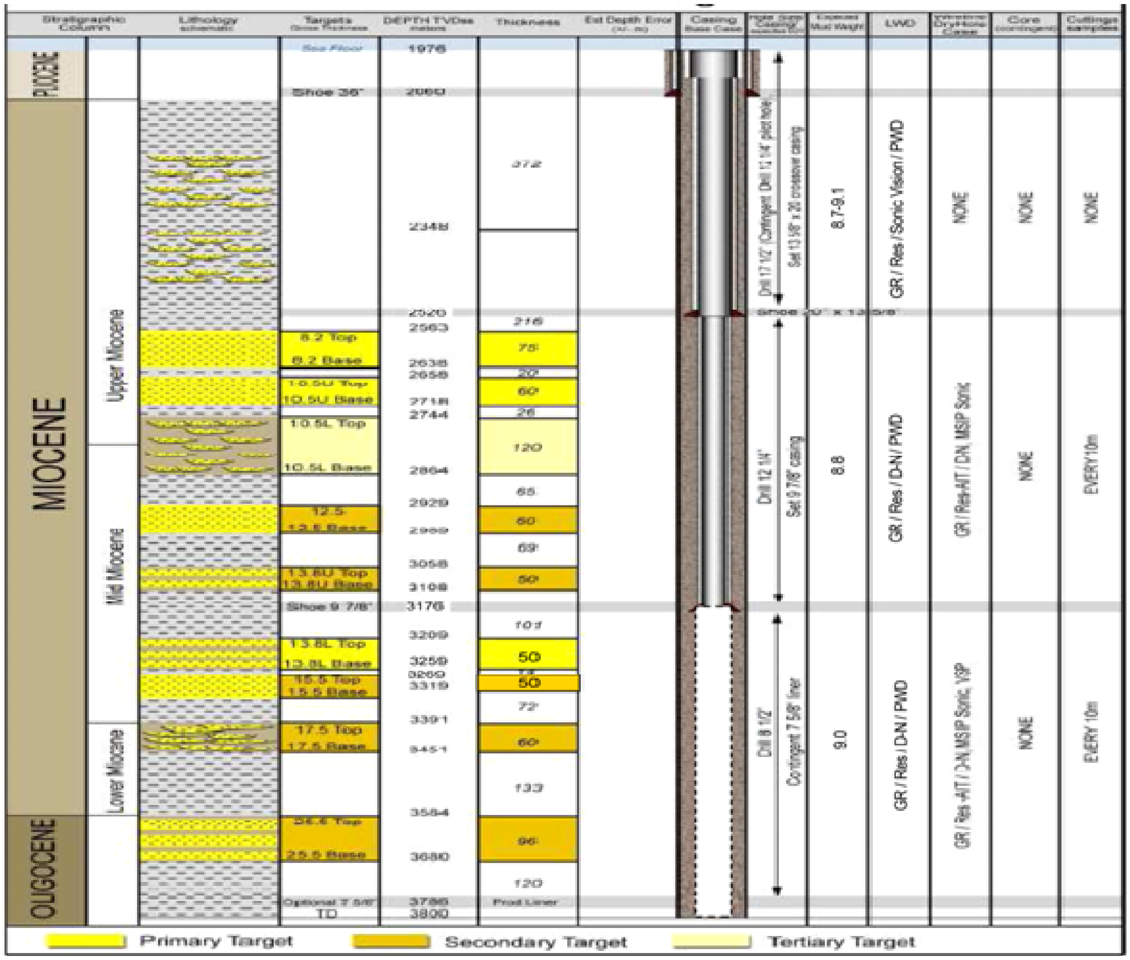

Figure 2. Iris-IXR.

come up from seriously disrupting implementation factors, the drilling optimization program should be planned to have as much flexibility as possible. The drilling recommendations can be changed to fit the rig equipment and then rerun through the computer. Also, equipment can be rented or modified to satisfy the optimum recommendations. Improvements in rig days, bit rotating hours, feet per bit, feet per hour, and hours per bit have resulted in savings ranging from 6 to 132 percent, compared with drilling experience on selected control wells. Examples of what can be accomplished through proper application of optimization procedures are shown on Tables 5 and 8.

Moreover, the developed model can be effectively applied to most fields (oil and gas drilling), using a computer program but Excel sheet is preferable because of its features and simplicity. Data can directly be fed into the model since it is made in such a way that optimum rate of penetration (ROP) can be predicted or calculated automatically based on the input information (data). Goal seek (a feature in an Excel sheet) provides room for determining the desired penetration rate because it has the ability to predict the weight on bit and the rotary speed required to give particular or specific penetration rate that might be needed in a given hole section.

In general, optimization work has been directed toward the deeper, more expensive holes, with little or no regard to the shallow, less costly wells. This is primarily because of economics, as it is normally believed that there is little to be gained by optimizing a well drilled to 4,000-5,000 ft in 100 to 150 rotating hours. Contrary to this belief, savings can be realized as shown in Table 8.

Figures 2, 3, 4 and 5 explained the well architecture, geological age and the lithology of the three sections examined as indicated in Table 2, 3 and 4.

CONCLUSION AND RECOMMENDATIONS

Increasing weight on bit or rotary speed does not always increase the rate of penetration. In this study a new model based on bit size (cm), depth (m), weight on bit (454 kg), rotary speed (rpm), mud weight (pcf) and rate of penetration (m/hr) was designed to predict the rate of

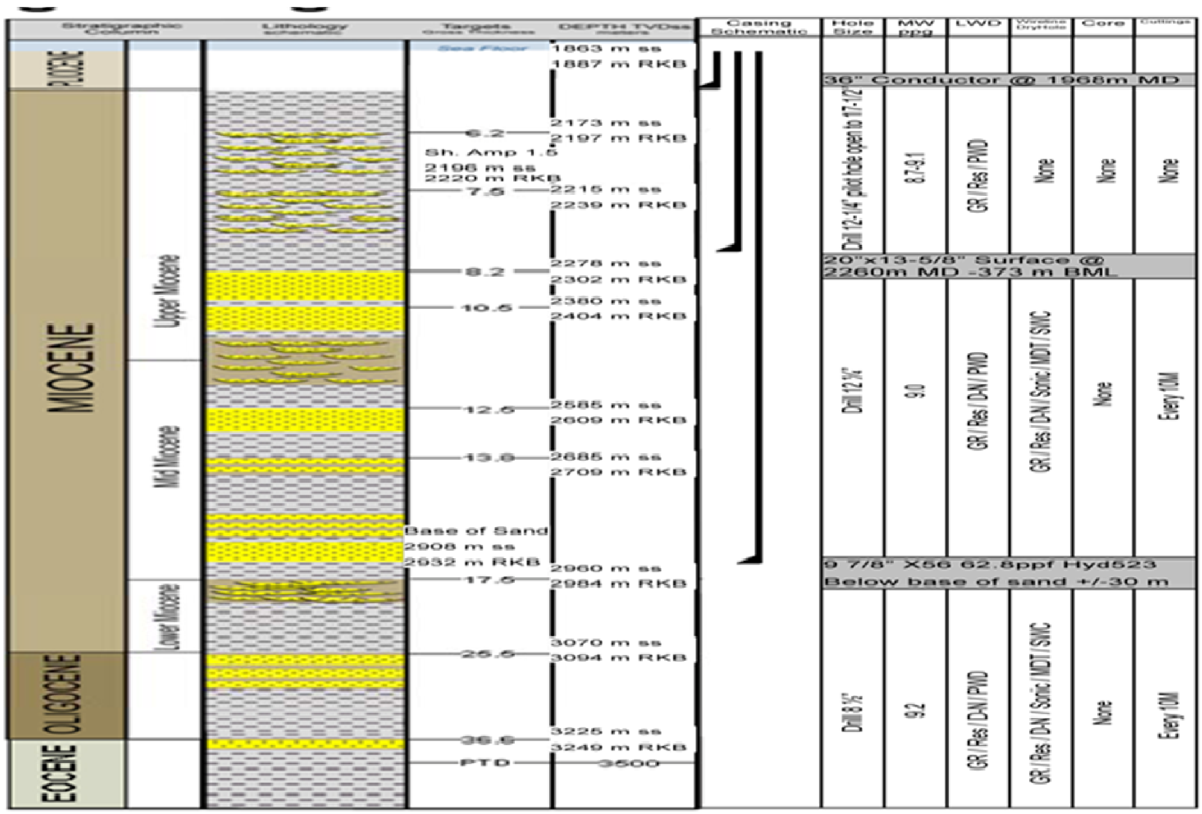

Figure 3. Oxalis-1X.

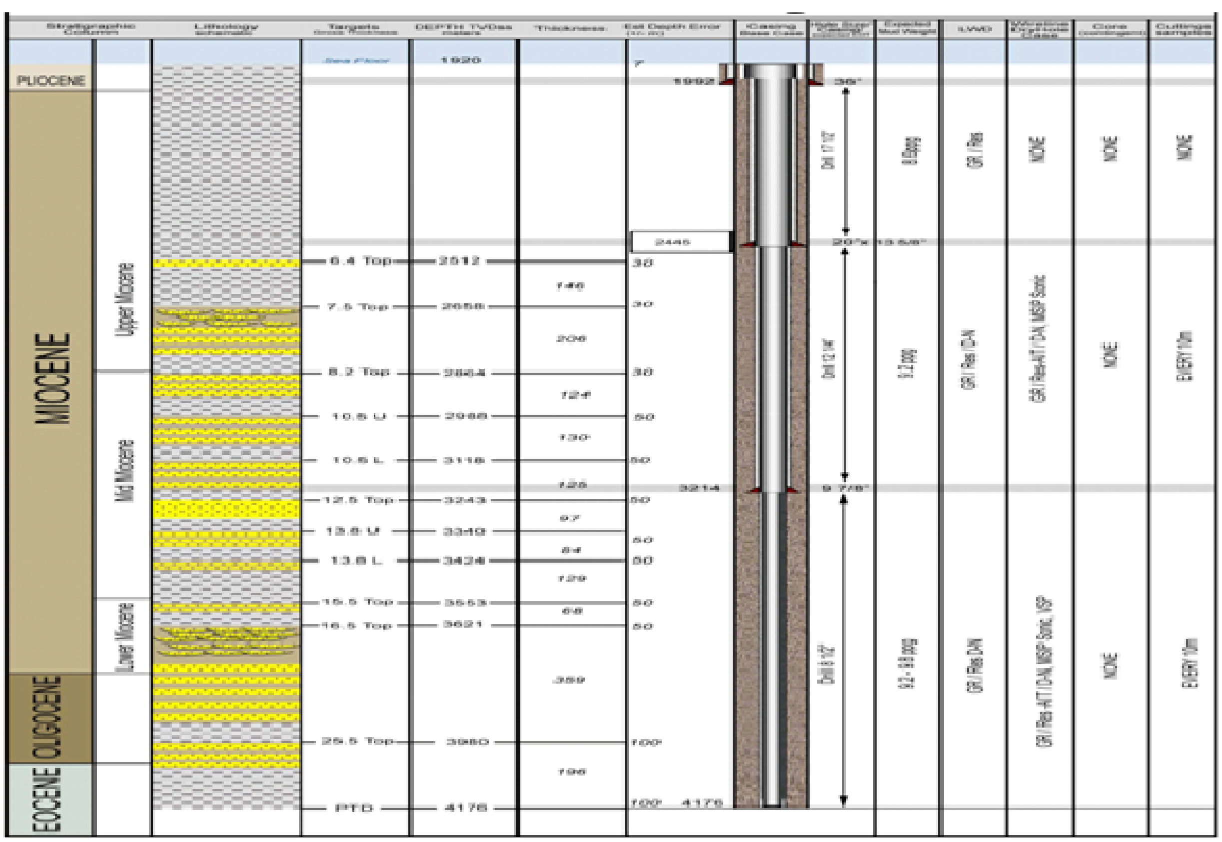

Figure 4. Aster-1X.

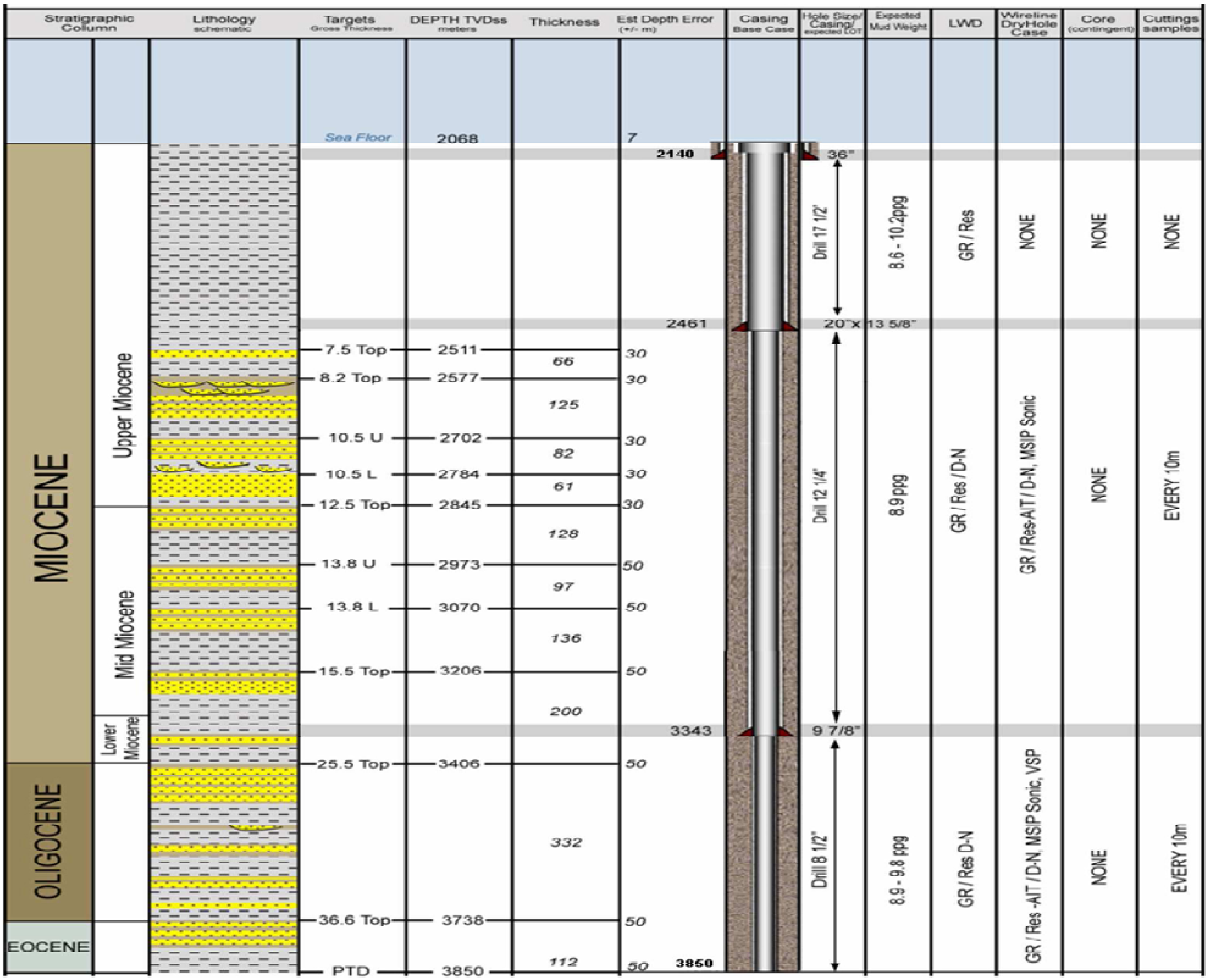

Figure 5. Freesia-IX.

penetration using real field data gathered in Unexplored Area of Gulf of Guinea .The new model as shown in Table 7 was successful in predicting rate of penetration to obtain operating parameters that lead to maximize rate of penetration. The corresponding model was implemented in a procedure using excel sheet which is one of the most reliable methods of optimization and at different depths the parameters leading to maximum were obtained. This model and its result/procedure can be used or applied to indicate the optimum economic result obtained from each combination of drilling parameters and points out the direction for technical innovation which is the most valuable in predicting drilling performance in all zones of the Unexplored Area or any similar area in Gulf of Guinea field in the future.

The model proposed will be a stepping stone or an action to solve the drilling problems of the Unexplored Area of Gulf of Guinea. This model should be explored by the various drilling companies operating in the Gulf pf Guinea. It should be appropriately founded for further research work.

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