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Analysis on Well Drilling Example of Deepwater Block in the Gulf of Mexico

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Abstract

With the innovation and development of offshore oil drilling technology, drilling wells in deep waters areas have become an important activity for the development of new hydrocarbon reservoirs in this type of environment. CNOOC (China National Offshore Oil Corporation) won the rights to exploit two unexplored deepwater blocks in the Gulf of Mexico, in a bid realized by the Mexican Government (CNH), in 2016. The challenge to combine the newest technology with the oil industry experienced knowledge to lead the exploration and development of these deep-water blocks in Mexico is around the corner. Therefore, the basic techniques for deep waters wells drilling and the main potential risks are expounded in this paper. A set of deep waters wells drilling processes and methodologies are previously designed, and a specific case is demonstrated next, which provides a referential model for deep waters wells drilling in the Gulf of Mexico.

Keywords

The Gulf of Mexico, Deepwater Drilling, Directional Drilling, Bottom Hole Assembly (BHA)

1. Preface

With the constant innovative development of offshore oil drilling technology and continuous use of 10,000 feet large drilling equipment of CNOOC, the offshore oil deepwater drilling capacity has been greatly improved. The Gulf of Mexico has rich oil and gas reserves, and its deepwater blocks belong to the USA and Mexico (**Figure 1**) respectively according to different geographic positions. At the end of 2016, CNOOC won the bid of Block 1 and Block 4 in the deepwater area of Burgos Basin of Perdido Folded Belt Zone with regard to the deepwater block in the Gulf of Mexico. Block 1 covers an area of 1678 Km^2, the water depth is 1000 m - 3100 m, and the offshore distance is 160 Km. Block 4 covers an area of 1877 Km^2, the water depth is 600 m - 2000 m, and the offshore distance is 140 Km. CNOOC won 100% rights of these two blocks. Previously, Pemex had certain discoveries in the southern Trion and eastern Supremo blocks of Block 1 N. PEMEX carried out the operation of two exploratory wells from 2012 to 2014, which was close to #1 Block N of CNOOC. It is estimated that the oil reserves of Supremo Block are 125 million barrels [1]. Therefore, it is rather important to make preparations in advance: design and optimize the drilling technologies according to the characteristics of the Gulf of Mexico.

Figure 1. Deepwater area of the Gulf of Mexico.

2. Introduction to Geological Structure of the Gulf of Mexico

The hydrocarbon reservoir formations of the deepwater blocks from the Gulf of Mexico belong to the Cenozoic and Mesozoic Eras. Cenozoic is a terrigenous clastic rock deposition. In the Mesozoic Era is possible to find 2 source rocks that generated the hydrocarbons that feed the reservoirs rocks from the Cenozoic: the Upper Jurassic Tithonian and the Upper Cretaceous Turonian [2]. Another important point to have in consideration is the presence of salt in the area, which is well developed due to the intense activity in the zone, forming different types of structures: salt canopy, salt stock, salt sheet, salt wall, salt weld, salt tongue, etc. Normally these salt structures are located above the reservoir formations, and, if this salt layer is too old, it can become a gypsum bed layer. The structural and stratigraphic geology of the Perdido Fold Belt Area is very complicated, increasing the difficulties of the drilling activities in the zone.

3. Drilling Difficulties of the Deepwater Blocks

Compared to the shallow water area, the main drilling difficulties in the deepwater zone in the Gulf of Mexico are as follows:

3.1. Obvious Geological Disaster of Shallow Stratum and Great Drilling Difficulty of Surface Layer

For the deepwater blocks in the Gulf of Mexico, the seafloor relief is rugged, the water bottom fluid and the seabed are unstable. Within 1500 m under the mud surface, the probability of the existence of shallow gas and gas hydrates is high.

These unstable factors pose a threat to the surface layer drilling to a large extent [3].

Shallow gas: the undisturbed structure of the layer under the mud surface may be destroyed and the effective formation pressure could be reduced. In the surface layer operation, if the shallow gas is encountered during the drilling, the wellhead would collapse or blow out and other high potential risks may be caused.

Hydrate: in the surface layer operation, due to the change of gradient of pressure between the seafloor sediment and upper stratum, the formation cavitation pressure and bursting pressure space ratio is small, the well leakage, collapse, well kick or even jamming risks greatly rise.

3.2. Narrow Density Window, High-Risk Coefficient during the Drilling Cycle

With the continuous increase of water depth, the formation fracture pressure gradient decreases. Therefore, the window between the formation pore pressure gradient and formation fracture pressure gradient is very narrow [4]. According to the actual drilling example of a deepwater block in the Gulf of Mexico, obvious changes may take place in several hundred meters with regard to the formation pressure coefficient. It raises a tougher requirement for the mud system. Once the treatment is improper, the well leakage or even blowout may easily occur. At present, the common technology in the Gulf of Mexico is the lowering of the multi-layer casing. However, while the risk is avoided, the number of bottom hole assemblies required for drilling is increased; resulting in a great increase in drilling costs.

3.3. Salt Gypsum Bed Drilling

In the area of the deepwater block of the Gulf of Mexico, there are tremendous salt layers (**Figure 2**). According to the exploration of deepwater blocks in the Gulf of Mexico which belongs to the USA, some salt layers could be up to 6100 m thick [1]. The deepwater blocks of the Gulf of Mexico in the Mexico region have not been developed on a large scale. When PEMEX carries out the exploration, it has discovered the salt layer. Many reservoirs are under the salt layer. During the drilling, the drilling of the salt layer is inevitable, which poses a great challenge to the drilling operations.

Since the salt body density is fixed (the formation apparent density gradually increases as the pressure coefficient increases), the salt body density is lower than the formation apparent density. As the salt body moves upwards, the fracturing rubble zone at the salt bottom or on the salt body side is caused. The cavitation pressure, fracture gradient and fissure of the formation cannot be quantitatively forecast, so, high well risks control is necessary.

When the salt body is encountered, due to the wriggle of the salt body [1], the salt body reversely intrudes into the borehole. Under the high temperature and high-pressure conditions, the reverse intrusion into the borehole is often faster, leading to the jamming risk.

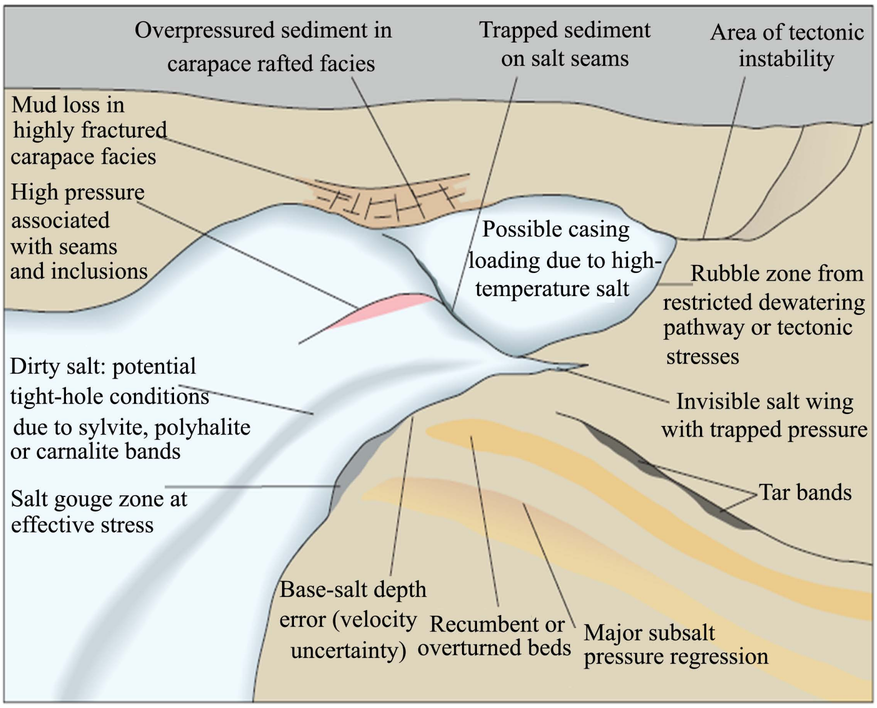

Figure 2. Geological structure of salt gypsum bed.

3.4. Tough Mud and Well Cementing Fluid Requirements

The change of temperature gradient of deepwater operations is great. Generally, the seafloor temperature is 3˚C - 5˚C, and it could be lower than 0˚C in some areas. Before the arrival at the formation, the drilling mud or well-cementing fluid will undergo a process of obvious temperature decrease. Consequently, adverse effects may be left on the drilling fluid, such as a great increment of the viscosity and jelling. Besides, in a low-temperature environment, gas hydrate may easily occur, and icing or even pipeline blocking may easily happen too [5]. Since the change of formation pressure coefficient is obvious, tougher requirements are raised for the mud. Under different formation pressure coefficients, the pressure inside and outside the borehole should be balanced, to guarantee the stability of the well wall. The low bursting pressure gradient and possible abnormal high-pressure formation need tougher requirements for the well cementing.

4. Analysis of Concrete Case

Based on the abovementioned operation difficulties, with one of two wells, namely, XXX 1 and XXX 1DL, besides #1 Block N from CNOOC as an example, reference is provided for the development of CNOOC's deepwater blocks in the future.

4.1. Introduction to Basic Data of XXX 1 Well

The operator of the XXX 1 well is PEMEX, drilled using the Deepwater Drilling Platform BICENTENARIO. XXX 1 well is in the north of the Gulf of Mexico

(**Figure 3**) and it is 178 km away from Tamaulipas. It is adjacent to the border with the USA in the north, connected with Kamay and Pegaso in the east, and the Perdido Fold Belt in the west. It is parallel to Northern Latitude 24˚30' in the south and it is close to Silvertip, Tobago, Trident and Great White oilfields of the USA. The water depth of the area is 2535 m, the design total depth of the well is 6224 m, the final drilled well depth is 6119 m, and the drilling time was 143 days. The seafloor temperature is 5˚C, and the maximum bottom hole temperature is 146˚C.

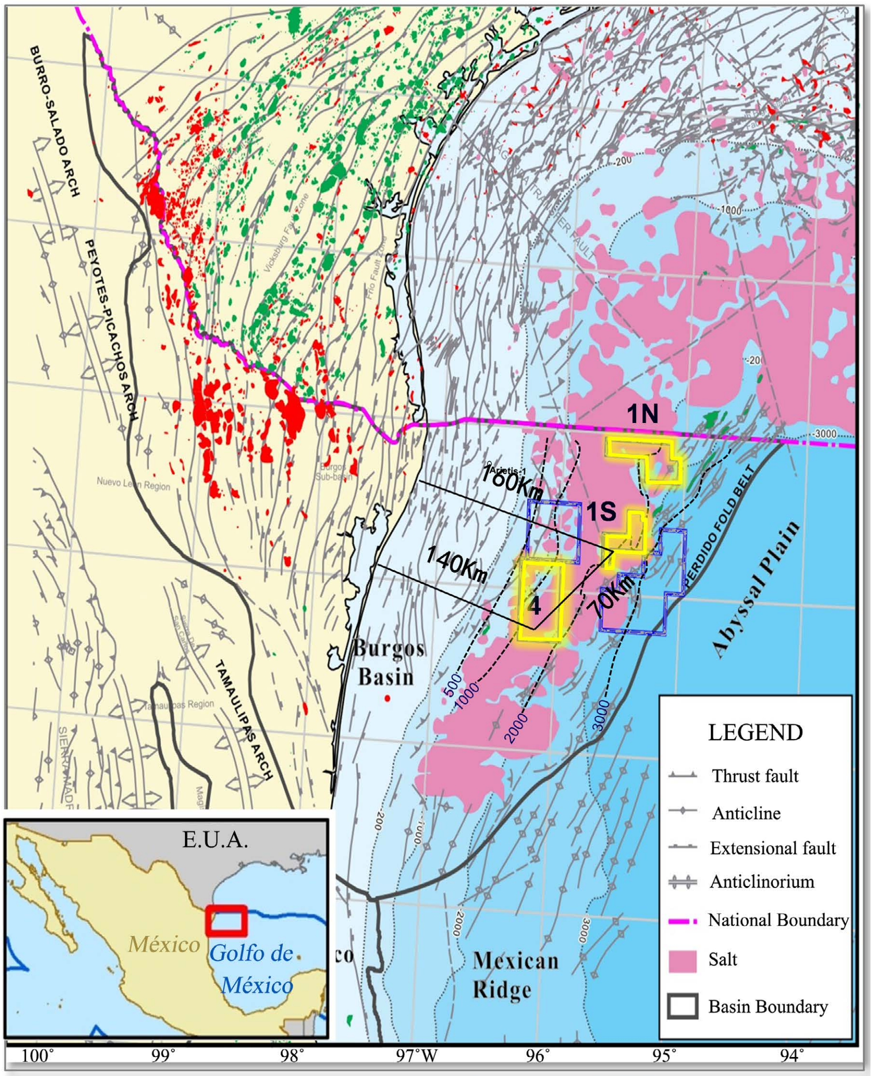

Figure 3. Relative geographical location of XXX 1 well and #1 block and #4 block of CNOOC.

Refer to **Table 1** for the analysis of formation lithology of XXX 1 Well.

In order to effectively avoid the geological risks and effectively balance the formation pressure coefficient, the well depth structure and casing procedure (**Table 2**) of the well have been optimized, and the structure of 7 different casings has been designed. Within 1500 m under the mud surface, 4 different casings are used. In particular, at 3050 m - 3450 m, the pressure change is considerable, requiring a mud density between a range of 1.05 - 1.70 g/cm^3, being too obvious the pressure increase, and it is especially important to increase the number of casings of the well structure. At the same time, the multi-layer casing can favorably avoid the risk of intrusion of the salt gypsum bed into the borehole (for the deepwater blocks of the Gulf of Mexico, the salt gypsum bed is normally present in the oilfields near to the border between the USA and Mexico in most cases). The advantages of large-time drilling drill bits are as follows: when the complexities are encountered and the drilling of the borehole of such stage is finished in advance, 1 - 2 conventional casings could be added to the well structure, and the geological risk is effectively isolated.

Table 1. Drilled geology and stratum of XXX 1 well.

Age	Stratum	Vertical Depth (calculate from sea level)	Lithology
Cenozoic	Sea Bottom	2535 m	Offshore clay
	Pleistocene-Plio	2655 m	Fine particle and poorly cemented sandstone, poor classified bioclastic rock and soft-semi-hard shale, some sandy and calcareous stones
	Upper Miocene	2955 m	Semi-hard plastic shale, slight calcareous and squamose structure, fine particle sandstone lamination and shale matrix calcareous bonding
	Upper Eocene	3170 m	Fine-grain shale and calcareous sandstone stromatolite
	Lower Eocene	3800 m	Soft-semi-hard shale, sandy and calcareous stones, fine sandstone and sandstone of calcareous matrix stromatolite in some places.
	Lower Eocene/Wilcox	4130 m	Sandstone and shale and fine grain gravel stromatolite is formed by anorthosite, metamorphic, sedimentary and auxiliary minerals (target layer)
	Upper Paleocene	4675 m	Medium shale layer to well cemented fine-grain sandstone layer
	Paleocene/Whopper	5670 m	Moderately classified fine sandstone (target layer)
	Total depth	6195 m	

Table 2. Well depth structure of XXX 1 Well.

Casing Diameter (Inch)	Drill Bit Diameter (Inch)	Interval Depth (m)	Length (m)	Fluid Category	Density (g/cm^3)
36"	26" × 33"	2564 - 2664	100	Seawater mud	1.05
28"	26" × 33"	2664 - 3050	386	Seawater mud	1.05

Continued

22"	26"	3050 - 3450	400	Seawater mud	1.05 - 1.70
18"	12¼" × 22"	3450 - 3900	450	Oil base mud	1.17 - 1.20
13⅝"	12¼" × 16½"	3900 - 4700	800	Oil base mud	1.20 - 1.29
11⅞"	12¼" × 14¾"	4700 - 5300	600	Oil base mud	1.29 - 1.42
9⅞"	10⅝" ×12¼"	5300 - 6224	924	Oil base mud	1.42 - 1.45

4.2. Drilling Operations Implementation and Problems

4.2.1. 36-In Pipe Adopts the Conventional Ejection Lowering Technology of Deepwater Operations [6]

In the pipe string, the conventional bottom hole assembly is lowered, and the drill bit is 4 - 6 cm outside the pipe. The mud ejected from the drill bit directly returns from the pipe to the wellhead and then it is discharged, the annular frictional coefficient is reduced, and it enters the formation under the pipe dead weight and bit pressure effect. After the operation is completed, it is not required to cement the well, so the loss and wellhead sinking due to the well cementing are prevented, and the drilling day work expenses are saved economically.

Casing procedure: 28 in & 22 in.

Bottom hole assembly: drilling bit 26 in + RSS 11 in + Motor 9½ in + stabilizers 25¾ in + PWD 9½ in + stabilizers 9½ in, drill collar 9½ I.

4.2.2. 28 in & 22 in Casing and 26 in Borehole Bottom Hole Assembly

Casing procedure: 28 in & 22 in.

Bottom hole assembly: drilling bit 26 in + RSS 11 in with stabilizers 25¾ in + stabilizers 9½ × 26 in + hole opener Reamer 22 × 33 in + MWD/APWD/LWD 9 in + drill collar 9½ in + drill collar 8 in.

The reaming while drilling technology has been used in these two well sections, so as to increase the casing structure and avoid the downhole risk due to the change of pressure gradient.

4.2.3. 18 in Casing and 12¼ in Bottom Hole Assembly

Casing procedure: 18 in.

1st bottom hole assembly: drilling bit 12¼ in + RSS + APWD + MWD + LWD, stabilizers 12 in, concentric hole opener 15 in, hydraulic hole opener 22 in, drill collars 8 in, Jars 8 in.

LWD includes acoustic wave, resistivity, gamma, density, and the like. The reaming while drilling technology is used as well.

2nd bottom hole assembly: drilling bit 18⅛ in, stabilizers 9½ × 18⅛ in, Rhino Reamer hole opener 22 in, drill collars 9½ in, stabilizers 9½ × 17½ in, Jars 8 in.

The pigging drilling rig is used in the 2nd bottom hole assembly.

4.2.4. 13⅝ in Casing and 12¼ in & 17½ in Bottom Hole Assembly

1st bottom hole assembly: drilling bit 12¼ in + RSS with stabilizers 12⅛ in + APWD/MWD/Sonic/SADN/GR/Resistivity LWD 8 in, stabilizers 12 in, hole opener 15 in, drill collars 9½ in, stabilizers 9½ × 16 in, bottom filter 9 in, drill collars 8 in, Jars 8 in. In this section, at 4080 m, 4137 m and 4230 m, the coring operation is carried out.

2nd bottom hole assembly: drilling bit 17½ in + RSS + APWD/MWD/LWD.

For this well section, in order to match the drilling coring operation, 12¼ in bottom hole assembly is used for the first drilling. After the drilling is finished, the large size 17½ in bottom hole assembly is used, so as to play the role of pigging and reaming. Meanwhile, LWD equipment is used again, to determine the target position, and then the wireline logging operation is carried out.

4.2.5. 11⅞ in & 9⅞ in Casing and Bottom Hole Assembly

RSS + LWD bottom hole assembly is continuously used in these two well sections.

However, at 5554 m in the drilling of the well, since pulling out of the hole was too fast, the swabbing effect happened, having a lot of silt rock drill cuttings in the vibrating screen. In the meantime, pulling out of the hole at the bottom is difficult. It is inferred that the downhole collapse occurs. The lifting hanging load is increased, the torque is increased, and the large displacement circulation is performed to remove the jamming. During the circulation, many silt rock drill cuttings are still seen. In order to guarantee the subsequent drilling, the drilling rig is pulled to the wellhead, and the casing is lowered. A casing level in the well structure is added for 8½ in well section, and the drilling is finished at 6119 m.

4.3. Application of Directional Well and Logging While Drilling Equipment

4.3.1. RSS

Except for the surface layer, the rotary steering (directional well equipment) has been used in other well sections of XXX 1 Well. Such equipment favorably controls the borehole track. The drilled borehole is more regular than the borehole drilled by the motor. At the same time, the near-bit gamma may be favorable to know the to-be-drilled formation, and the formation could be pre-interpreted.

4.3.2. LWD

LWD tools of the well include pressure measurement while drilling (annular), resistivity, gamma, neutron, density, acoustic wave and other high-end LWD devices. Primarily, the device of pressure measurement while drilling (annular) measures the annular pressure. Due to the deepwater operation, the change of formation pressure is great. As the water depth increases, the problem of change of pressure becomes prominent. The annular pressure measurement system while drilling may be favorable to detect the pressure change in the annulus, the drilling fluid could be adjusted in advance, and major downhole risks, such as well kick, blowout and jamming, are prevented.

Through the LWD equipment, the formation evaluation is improved, so as to pre-interpret the formation lithology, know the formation porosity and permeability, and pre-identify the reservoir.

4.4. Salt Gypsum Bed

Even if no salt gypsum bed is encountered in this well, this area is close to the border between the USA and Mexico. Through the optimization of bottom hole assembly, RSS, reaming while drilling technology, drill bit selection and the like, the salt gypsum bed event is prevented in this well.

4.5. Drilling Fluid and Well Cementing

The water depth of the Well is 2535 m, and the seafloor temperature is 3˚C. In order to reduce the effects on the drilling due to the temperature decrease, and prevent the obvious change of rheological property of drilling fluid, the manifold is enveloped by the insulating layer, so as to reduce the jelling of drilling fluid, constrain the gas hydrate generation and avoid the manifold blocking [7]. In terms of casing well cementing, considering the seafloor low-temperature effect and the effect of low formation fracture pressure gradient, low-density cement is used, the setting time of cement is reduced, the internal and external pressure is balanced, and the effective well cementing is achieved.

5. Conclusion

The deepwater drilling technology in the Gulf of Mexico is increasingly matured. However, as CNOOC just set foot in this sea area, there is a huge challenge. How to cope with the shallow geological disaster, narrow density window and salt gypsum bed which may easily occur during the well drilling process and how to meet the fluid requirement of the drilling mud and cementing fluid, how to optimize the well depth structure, bottom hole assembly and design the suitable drilling mud, well-cementing system and other key steps are the targets to achieve a successful operation. Through the analysis of the actual drilling experience of TRIÓN 1 well, main risk points and control measures in the operation of deepwater block in the Gulf of Mexico are analyzed. By the design scheme, the potential risks are effectively avoided. The reasonable experience in the drilling of deepwater blocks in the Gulf of Mexico is summarized, and a road to success with referential significance is provided for the development of #1 Block and #4 Block of CNOOC subsequently.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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