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Trinidad and Tobago's First Deepwater Drilling Campaign

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Abstract: *Trinidad and Tobago is endowed with abundant oil and gas reserves both onshore and offshore. Most of the reserves offshore have been found in the shallow water shelf area. Over the last decade exploring the deep waters beyond the shelf (>1,000 meters) has been looked at with much anticipation. However, the eight (8) wells drilled thus far have not found hydrocarbons in commercial quantities. It is important to note however, that many geo-scientists believe the exploration work in the deepwater proved the existence of a working hydrocarbon system. The drilling phase of the exploration activities in the deepwater blocks (i.e. Blocks 25a, 25b, 26 and 27) produced many challenges. This paper looks at the major problems, risks and uncertainties encountered during the drilling of these wells and highlights key lessons that would be useful for further drilling in the deep and ultra deep waters off Trinidad and Tobago. The main objectives of well drilling would be examined. Results showed that some of the wells were unable to reach their technical objectives. As a result, the actual number of days and cost for some wells were less than that originally planned.*

Keywords: *Deepwater, Drilling, Trinidad and Tobago*

Nomenclature

bbls	Barrels
BOP	Blow out Preventer
DHI	Direct Hydrocarbon Indicator
EMW	Effective Mud Weight
Ft	Feet
HC	Hydrocarbon
LOT	Leak off Test
LNG	Liquefied Natural Gas
LWD	Logging While Drilling
MDT	Modular Drill Stem Test
MWD	Measurement While Drilling
ppg	Pounds per gallon
psi	Pounds per square inch
PSC	Production Sharing Contract
RIH	Run in Hole
ROV	Remote Operated Vehicle
3D	Three-dimensional
TD	Total Depth

1. Introduction

In Trinidad and Tobago (T&T), the petroleum industry is one of the oldest in the hemisphere and historically, energy has been important to our economy. The first successful onshore well was drilled in 1866, and the first export of oil from Brighton took place in 1910. Not until 1968 though was commercial oil discovered off the east coast. This was followed by the discovery of gas off the north coast in 1971. In the 1990's, significant gas had been discovered in the east coast marine area. This coupled with the establishment of several natural gas-based petrochemical plants and LNG plants prompted the search for more hydrocarbons in the deeper waters. This paper looks at the major problems, risks and uncertainties encountered during the drilling of wells, and discuss the lessons learnt for drilling in the deep and ultra deep waters off Trinidad and Tobago.

2. Reserves and Production Sharing Contracts

The oil and gas fields in T&T are depicted on the map in Figure 1. The solid areas indicate the oil fields while the shaded areas show the gas fields. The remaining proved and unproved reserves stand at about 570 million barrels of oil (National Energy Policy Consultations, 2010) and about 27 trillion cubic feet of gas (MEEA, 2010). Most of the hydrocarbon bearing acreage on the east coast of Trinidad is under Exploration and Production licensed agreements. Operations in the west coast area and on land are presently conducted by the state-owned company. Production sharing contracts (PSCs) were re-introduced in 1998, as T&T move into the deep-water exploration campaign.

The government of Trinidad and Tobago uses PSCs as vehicles to achieve a comprehensive exploration programme (Jupiter, 1998). This programme must be completed within a specified time frame that will optimise benefits derived by the state from any discovery being made. Natural gas is making an increasing contribution to the national economy with continuous further expansion anticipated.

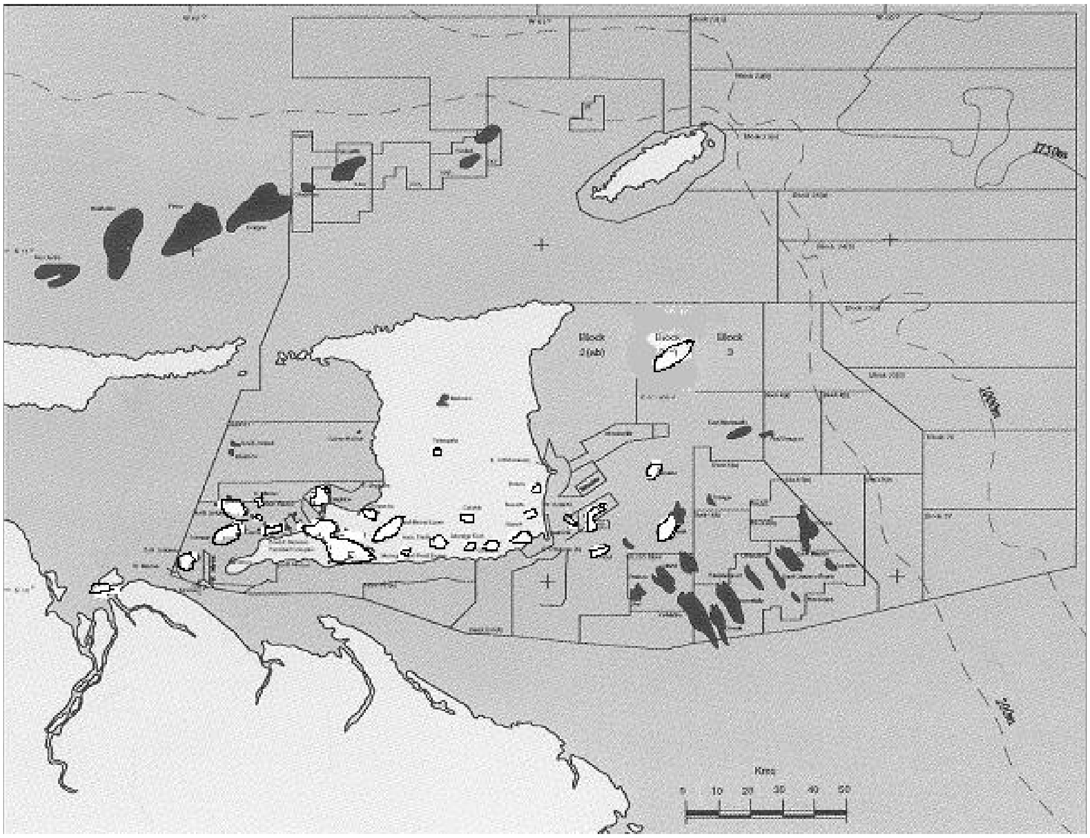

Figure 2. Oil and Gas Fields in Trinidad and Tobago

As a result, it is imperative that natural gas exploration, development and commercialisation be effectively managed. Under the E&P licenses and the original PSC in 1974, no clear provisions were made for natural gas. The PSC contracts of 1996-1998 contain clauses that specifically address the development of natural gas, if such was found in the deepwater exploration campaign.

3. Deepwater Blocks

The blocks awarded in February 1998 were 25a, 25b, 26 and 27 (see Figure 2). These blocks are in the deepwater acreage, and the contracts involved:

- A five-year exploration phase of work programmes,
- Exploration wells to minimum commitment depths,
- Acquisition and processing of seismic data, and
- Attaining signature bonuses.

There are several objectives of the drilling campaign. These are summarised below:

1) To determine the presence of reservoir quality sands in the deep-water blocks.
2) To determine the hydrocarbon content of the primary and secondary objectives in the area.
3) To evaluate the pore pressure environment in the acreage and compare with predicted pressures.
4) To test the hydrocarbon potential of trapping configurations within the province of Trinidad deep water.
5) To gather valuable proprietary information in view of forthcoming and ultra deep water bid rounds (such as mud logging, Logging while drilling (LWD), wireline, pressure gradients, and fluid samples.)
6) To determine the presence of economic accumulations of hydrocarbons.
7) To prove that hydrocarbon charge has taken place in the deep water Columbus basin.
8) To drill the wells safely and within time and budget targets, and
9) To provide calibration of seismic data set and geological model for deep water.

4. Pre-drill Challenges

The deepwater sea floor is typical of mud volcanoes and seeps. Mud volcanoes are frequently conical and high relief in nature and can range from 165 ft to 7,500 ft in diameter and height from 130 ft to 400 ft (Leonard, 2000). Seeps are common on the seafloor and are fluid migration pathways that increase the risk of shallow water flows in the deepwater operations. There is also the possibility of gas hydrates in the shallow sediments (McCannell, 2001).

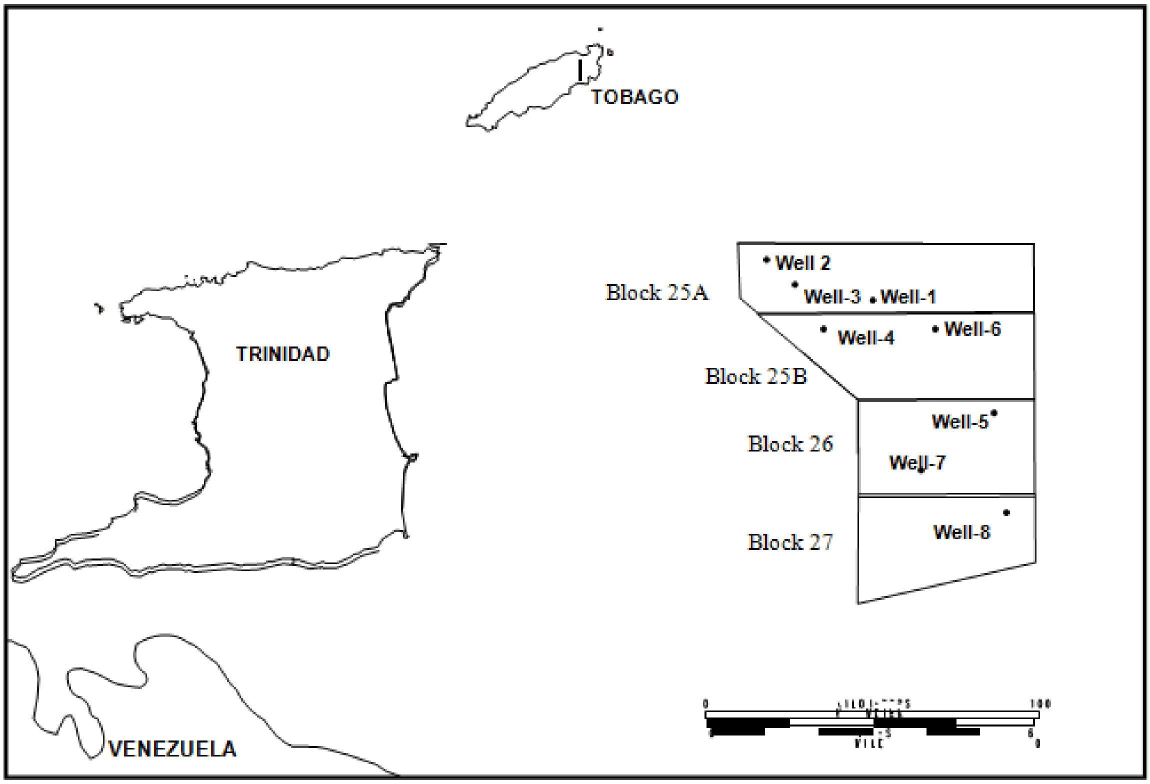

Figure 2. Location Map - Blocks 25a, 25b, 26 and 27, Trinidad and Tobago

Deepwater geohazard surveys indicate the following shallow hazard assessment.

1) There are high risks associated with shallow water flows.
2) Localised shallow hydrocarbon reservoirs may be present in the upper 2,800 ft of sediments.
3) Very high currents were expected along channel margins. The high currents arise from eddies which break off from the main North Brazil Current (NBC). These currents can increase riser ball joint angles and riser tensions to above normal operational limits.
4) The possibility of over pressure in the subsurface due to fluid expulsion features. Active mud flows can put unacceptable lateral load on structural casing. Given their size and relief, side slopes may be unstable and should be considered when designing mooring pattern or picking a surface location. Hard ground, present near mud volcanoes and active sea floor vents, may impact anchor placement, deployment and tensioning.
5) There are high variable surfacial and near surface sediments with variable shear strength values that could impact structural casing design and emplacement methods as well as anchor holding capacity.
6) There are easily identifiable surface faults, and
7) Submarine channels with steep and unstable margins may be present and serve as conduits for turbidity flows.

Good well planning would be key to the success of reaching the objectives. Some wells were planned attempting to address as many of the geohazard problems as possible. Mitigations for the deep-water regional geohazards and uncertainties are considered. A pilot hole could be drilled to assist with uncertainty in the shallow region. The pilot hole could help 1) identify shallow water flow in the vicinity of the well location, 2) establish hole conditions (pore pressure/hole stability) until the 20” casing depth and beyond if possible, 3) attain a 20” casing setting depth with an objective to optimise casing programme, and 4) optimise jetting programme (with 36” structural pile length and jetting parameters).

Besides, the selection of fit for purpose deepwater drilling rigs which are especially capable of handling high currents and good positioning capabilities is important. There are currents derived from the North Brazil Current that flows northwest along the coast of South America and turns north to offshore Trinidad. Offshore operations can therefore be affected by the types and scales of current, from short-lived high-frequency variations that last just minutes to longer time-scale and more predictable features (such as tidal currents).

5. Deepwater Drilling and Problems Encountered

Table 1 shows a summary of the eight wells drilled in the deepwater acreage. The summary highlights the actual number of days on each well, actual drilled depth and actual cost of well compared to what was planned. It can be seen that none of the wells reached its planned total depth. There are several reasons for aborting drilling operations for these wells (see Table 2). The rig types used were semi submersible dynamic position for three wells and drill ships for five wells. These rigs were supposed to have high current handling capabilities. The table also gives the period during the year the wells were drilled. Seven of the wells were drilled between the October-March period while the other well between the April-June period.

Even though adequate planning went into the drilling of these wells, some major problems associated with deepwater operations were encountered. These include situations arising out of currents, shallow hazards and well problems (see Table 3).

Table 1. A Summary of Wells Drilled in Deepwater Acreage

Well Name	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8
Block	25 a	25 a	25 a	25 b	26	25 b	26	27
Water Depth (ft)	3500	3500	4400	3400	3000	3800	4400	4000
Spud Date	1/10/99	13/1/03	29/1/03	6/12/00	10/2/01	4/3/02	26/4/02	20/12/01
AFE days	38.3	21	17.9	76	80	57.8	43	98
Actual days	29.2	19	15	68	94	31.2	27.6	125
Planned TD (ft)	11500	10500	11000	15000	15200	13700	14500	19500
Actual TD (ft)	10900	9200	8100	12000	14100	11600	12027	16300
AFE Cost (MMUSD)	21	8.48	9.33	34	42	34	31.3	59
Actual Cost (MMUSD)	18.1	7.44	7.93	24.8	35	16.4	34.8	76
Rig Type	Semi-sub	Semi-sub	Semi-sub	Drill Ship	Drill Ship	Drill Ship	Drill Ship	Drill Ship

Table 2. Reasons for Aborting Well Drilling Operations

Well # / Block	LTI	EI	Primary Objective	Secondary Objective	Planned TD Achieved	Remarks
1 (25a)	X	X	YES	YES	X	Increased Pore Pressure. Lack of prospective lower horizons. Well abandoned.
2 (25a)	X	X	YES	YES	X	Deteriorating hole conditions. Abandoned dry hole with gas and condensate shows.
3 (25a)	X	X	YES	NO	X	Abandoned due to mechanical problems.
4 (25b)	X	X	YES	YES	X	Pore pressure and fracture gradients were lower than expected. Abandoned due to hole instability.
5 (26)	X	X	YES	YES	X	Atlantic eddy currents impacted on operations. Pore pressure and fracture gradients lower than expected. Well abandoned due to well control event.
6 (25b)	X	YES	YES	YES	X	Atlantic eddy currents impacted operations. Pore pressure and fracture gradients were lower than predicted. Lack of prospective lower horizons. Well abandoned dry hole.
7 (26)	X	X	YES	YES	X	Pore pressure and fracture gradients were lower than predicted. Slightly over budget. Lack of prospective lower horizons. Well abandoned dry hole.
8 (27)	X	X	YES	YES	X	Atlantic currents impacted operations. Pore pressure and fracture gradients lower than predicted. Exceeded budget and time allocations due to hole problems and sidetracking of well three times. Well control problems. Well abandoned dry hole.

Keys: LTI - Lost Time Incidents; EI - Environmental Incidents; X - No

Table 3. Well Problems Associated with Deepwater Operations

Well# / (Block)	Currents	Shallow Hazards	Well problems /Pore Pressure	Pilot Hole	Non Productive time %
1 (25a)	Yes	Yes	Yes	Yes	10
2 (25a)	No	No	Yes	No	
3 (25a)	Yes	Yes	No	No	
4 (25b)	No	No	Yes	No	16
5 (26)	Yes	Yes	Yes	Yes	18.2
6 (25b)	Yes	No	No	No	22.4
7 (26)	No	No	No	No	5.7
8 (27)	Yes	Yes	Yes	Yes	37

5.1 Problems with Currents

Atlantic Eddy currents had significant impact on Well 5 operations; there were four (4) attempts at running the riser with a resulting downtime of 15.2 days. It took about one week to run the Blow out Preventer (BOP) and riser on Well 8. The drill ship actually went south in order to avoid the strong currents. The highest recorded current during operations on Well 1 was 3.3 knots, which occurred while running wireline logs. However, the rig was able to maintain its position on location.

5.2 Shallow Hazards and Well Problems

Well 1

Well 1 encountered shallow gas which was regarded as minor and slightly overpressure with just a stream of bubbles observed at the wellhead. The flow was observed while drilling the pilot hole. The well was controlled with eleven pounds per gallon (11 ppg) mud and flow checked before continuing operations. While running the BOP on riser during Well 5 operations, a flow was observed at the sea floor. This gradually increased and plumed up to forty-eight feet (48 ft) in height (see Figure 3). A pilot hole was then drilled to five thousand two hundred feet (5,200 ft) and traces of bubbles were seen. The shallow water flow subsided with time. During the Well 3 operations, the 12 ¼" hole was drilled trouble free to a depth of 8,078 ft, when the cameras on the Remote Operated Vehicle (ROV) underwater showed a plume of gases around the BOP stack caused by a buildup of hydrates.

Figure 3. Shallow Water Flow Block 26 Deepwater Trinidad

Well 2

Due to limited drilling margin, the 9 5/8" casing was set early at 7,511 ft. While drilling the 8 ½" hole section, indications of increasing formation pressure again suggested there was inadequate drilling margin to proceed. The well was then reached the total depth (TD) at 8,787 ft.

Well 3

The BOP stack appeared to be leaning at 3-4 degrees at the end of drilling the 12 ¼" hole section (8,074 ft). After performing a flow check and preparing to pull out of the hole, it was observed that there was excessive drag on the assembly and the rate of pull was extremely slow. In attempting to establish circulation that assists in pulling the drill string out of the hole, circulation and rotation were found to be near impossible. The string was held up above the drill collars. The decision was then made to TD of the well at this point.

Well 4

A pore pressure ramp up was expected below the 9 5/8" casing depth and therefore the plan was to drill the 8 1/2" hole as deep as possible and use a 7 5/8" liner to enable drilling a 6 ½" hole to the commitment depth. After setting 7 5/8" liner, the mud weight was increased to 13.5 ppg where a 15.2 ppg leak off test (LOT) was obtained. While cleaning out the 8 ½" rat hole beneath the liner, the hole began packing off and after several days it was impossible to keep the hole open long enough to drill deeper than 12,017 ft. As a result, there was no choice but to reach the TD of the well at this point.

Well 5

Well 5 experienced an increase in pore pressures as indicated by rising connection gas. The well was stopped to circulate and the mud weight was increased to 15.3 ppg. With the increased mud weight, the well began losing returns at a rate of 120 bbls/hr. Calculations indicated that the Effective Mud Weight (EMW) at the 7 5/8" liner shoe was just under the LOT results, providing no kick tolerance. The well reached its TD of 14,085 ft.

Well 6

Three riser tensioner lines broke and all were replaced which led to a one week down time.

Well 7

Well 7 had no shallow hazards issues or major drilling problems. The well reached its TD of 12,027 ft. due to a lack of prospective horizons below this depth.

Well 8

The 8 ½" drilling assembly was RIH and cement was tagged at 15,042 ft. The cement was drilled out, together with float collar and 9 5/8" shoe at 15,179 ft. While drilling through new formation, the pump pressure increased from 3,000 psi to 4,000 psi. There were also losses of 25 barrels in the active system following which the hole packed off. The flow rate was reduced and then slowly increased to full circulation. Ten feet of new formation was then drilled to 15,552 ft and a LOT of 15.3 ppg was obtained. The hole was drilled ahead to 16,751 ft. A drop in pump pressure was observed with erratic torque and the well began to flow (i.e., a 7 bbls salt water kick). The well was killed with 18 ppg heavy pill on bottom, after 14.2, 14.4 and 14.8 ppg mud weights were unsuccessful. The well had to be TD'ed at this point as mud weights and LOT were 0.5 ppg apart and the well could not be controlled.

Figure 4 shows a typical deepwater casing programme schematic. Casing liners are used as casing contingencies in cases where it may be impossible to reach the proposed casing setting depth. These casing contingencies allow the operator to drill as deep as possible with the aim of reaching the total depth. The two casing liners were used in the drilling operations. These were the 16" and 11 ¾" liner casings. In some cases, a 7 5/8" liner can also be used to enable drilling a 6 ½" hole as in the case of drilling Well 4.

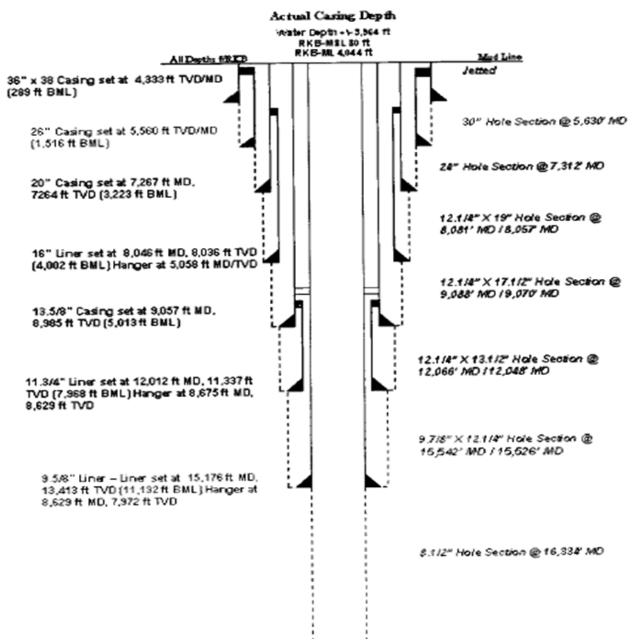

Figure 4. Typical Casing Schematic for Deepwater Operations in Trinidad and Tobago

Some wells (1, 5 and 8) utilised drilling pilot holes (see Table 3). In fact, Well 5 encountered shallow gas flow problems and then it was decided to drill a pilot hole. Well 3 did not utilise drilling a pilot hole but encountered shallow water flows. Non Production Time (NPT) as a percentage of total well time is also highlighted. Information for some wells was not obtained. Some wells showed significant NPT ranging from 16 % to 22%. These include problems associated with BOPs, casing, top drive, weather, shallow water flows and other rig equipment.

Though the problems encountered provided great challenges, the primary objectives of all the wells were penetrated and the data collected can provide a better understanding of the deepwater blocks (see Table 2). Since most of the wells did not reach their total depth, the success of drilling was evaluated looking at days and cost to drill 1,000 ft. Figure 5 shows the proposed and actual days to drill 1,000 ft, and that 50% of the wells were within the proposed days to drill. Figure 6 gives a snapshot of the proposed and actual cost to drill 1,000 ft. It can be seen that 5 of the 8 wells were drilled within budget, and all eight wells were drilled without a lost time incident.

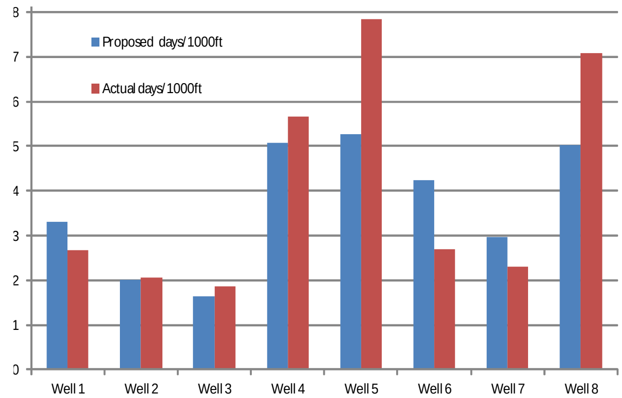

Figure 5. Proposed versus Actual Days to Drill 1,000 ft

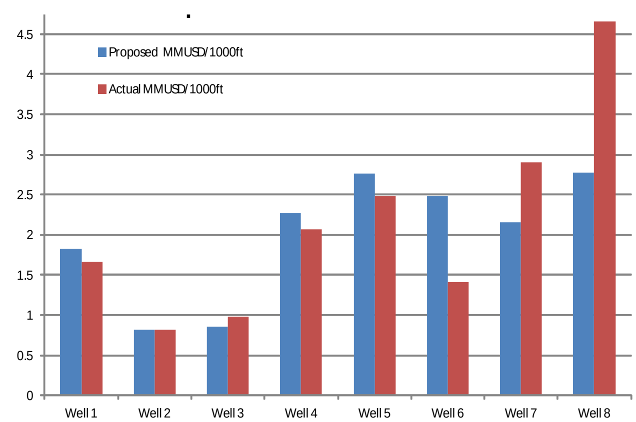

Figure 6. Proposed versus Actual Cost to Drill 1,000 ft

6. Exploration Lessons

This drilling phase gave a better understanding of the blocks in terms of traps, seals, reservoir, source adequacy and geophysical model. Table 4 shows some of the exploration learning for each block and Table 5 gives hydrocarbon indication, reservoir description and data collection for each well.

Thermogenic gas was seen in Blocks 25a and 26. This is likely an indication that there is a migration pathway in the prospect area. Low gas saturation wet sands were seen in Block 25b and this corresponds to seismic reflectors. It is likely therefore that low gas saturated wet sands and hydrocarbon bearing sands showed similar seismic responses. Blocks 25a, 26 and 27 all give positive indication of traps. There still remain questions on the hydrocarbon system viability. Pore pressure prediction was reasonably accurate compared to pre-drill prediction from seismic. The Block 27 well did not achieve the objectives stated in the well's proposal, i.e. drill 300 ft below the reflector event at the base of the TP 25 interval. The logs, cores, check shot surveys and fluid samples data can be used to calibrate the seismic data set and geological model for the blocks.

6.1 Comparison of Actual and Prognosed Depth of Formation Tops

Table 6 provides a comparison of the actual depths of the formation tops with prognosed depth from seismic interpretation. It shows a very close match between the prognosed formation tops and actual formation tops. Block 27 had 5-8% error in formation tops identification and this uncertainty in prediction was because of the poor imaging.

Table 4. A Summary of Exploration Lessons

Block	Trap/Seal	Reservoir	Source Adequacy	Geophysical Model
25 a	The presence of traps, including trapped hydrocarbons in the block	The presence of significant reservoir quality sands in deep-water block 25a confirmed. Some of the objectives had poor reservoir development. Thermogenic hydrocarbons were seen, however the volumes were small	The key questions still remain on hydrocarbon system viability	The rock properties in penetrated intervals were determined. Pore pressure predictions reasonably accurate.
25 b	The riskiness of stratigraphic traps was confirmed; likely reason for failure in the block	The presence of significant reservoir quality sands in deep-water block 25b confirmed. There were more sand in secondary objective than anticipated	The key questions still remain on hydrocarbon system viability	The rock properties in penetrated intervals were determined. Pore pressure predictions were reasonably accurate
26	The large structural closure was present with adequate seal confirmed by hydrocarbon presence	The Pliocene primary objectives lack significant sand. However, sand presence was confirmed in Pleistocene secondary objectives	The presence of thermogenic gas indicates that there is a viable migration pathway in prospect area (most likely deep-cutting faults). Despite adequate migration pathway, no oil was observed	The rock properties in the penetrated intervals were determined. Pore pressure predictions were reasonably accurate. The wells confirmed controlled-amplitude, control phase character of 3D seismic dataset
27	The presence of several different pressure compartments indicate the presence of intraformational seals within the mid to Lower Pliocene	Primary objective were composed of claystones interbedded with thin sandstones while the secondary target interval consisted of claystones with interbedded massive sands	Given that a thermogenic component appears to be absent, the understanding of migration rates and actual mechanism needs to be further reviewed	The rock properties in penetrated intervals were determined

Table 5. Reservoir Description and Hydrocarbon Indication for Each Well

Well # / Block	Hydrocarbon indication	Reservoir Description	Data Collection
1 (25a)	Biogenic and Thermogenic gas	The objective section encountered poorly developed gas bearing sands. Better developed sand were encountered but were all wet.	Gamma, Ray, Resistivity, Density Neutron, Sonic, PWD, Mud Logging
2 (25a)	Biogenic and Thermogenic gas	The target section was dominated by siltstone, sandstone and claystones.	Gamma, Ray, Resistivity, Density Neutron, PWD, Mud Logging
3 (25a)	Wet Sands	The well encountered well developed with good reservoir properties	Gamma, Ray, Resistivity, Density Neutron, PWD, Sidewall cores, Check Shot Survey, MDT, Mud Logging
4 (25b)	Wet Sands. Thin section with biogenic gas	The primary target consisted of a series of well developed from 5 ft to 93 ft thick with good reservoir properties.	Gamma, Ray, Resistivity, Density Neutron, PWD, Sidewall cores
5 (26)	30' section of biogenic gas. Thermogenic gas also seen.	The sands were poorly developed in the primary objective while thin channel sand were encountered in secondary target	Gamma, Ray, Resistivity, Density Neutron, PWD, Sidewall cores, Check Shot Survey, MDT, Mud Logging
6 (25b)	Water wet sands. Small gas peaks of biogenic gas.	The primary objective section comprised mainly of claystone with a series of thin sands and two thick well developed sand bodies.	Gamma, Ray, Resistivity, Density Neutron, PWD, Mud Logging
7 (26)	Wet sands	The sands were well developed often up to 50 ft in thickness	Gamma, Ray, Resistivity, Density, Neutron, PWD, Mud Logging
8 (27)	Several thin packages of biogenic gas	Significant sand development was encountered in the secondary target, with several thin sands in the primary target interval	Gamma, Ray, Resistivity, Density, Neutron, PWD, MDT, Mud Logging

Table 6. Comparison of Actual versus Prognosed Depth for Formation Tops

Block 25 a (Well 1)				
Tops	Prognosed Depth, ft	Actual Depth, ft	Difference, ft	Difference, %
5	3996	3963	33	0.83
10	4416	4374	42	0.95
15	5446	5387	59	1.09
20	6011	5919	92	1.53
30	6706	6552	154	2.30
35	6985	6811	174	2.50
40	7608	7303	305	4.00
45	7930	7666	264	3.30
50	8360	8068	292	3.50
55	8757	8409	308	3.50
55 sand top	8818	8550	328	3.72

Block 25 a (Well 2)				
Tops	Prognosed Depth, ft	Actual Depth, ft	Difference, ft	Difference, %
12(Primary)	7576	7462	114	1.5
11.8	8531	8298	233	2.70
11.7	8938	8921	17	0.18
11	9738	Did not penetrate		

Block 25 a (Well 3)				
Tops	Prognosed Depth, ft	Actual Depth, ft	Difference, ft	Difference, %
Level 55	6481.5	6890	44	0.70
Level 70	7907	7874	33	0.42
Level 75	9016	Did not penetrate		
Level 90	10056	Did not penetrate		

Block 25 b (Well 4)				
Tops	Prognosed Depth, ft	Actual Depth, ft	Difference, ft	Difference, %
P82	7363	7585	222	2.90
P105	8937	8955	18	0.20
P110	9515	9510	5	0.05
P115	9741	9790	49	0.50
P121	10027	10010	17	0.17
P150	10781	10790	9	0.08
P165	11628			

Block 26 (Well 5)				
Tops	Prognosed Depth, ft	Actual Depth, ft	Difference, ft	Difference, %
P120	7582	7642	60	0.80
P100	9550	9540	10	0.10
P150	11940	11877	63	0.53
P190	13240	13240	156	1.16

Block 25 b (Well 6)				
Tops	Prognosed Depth, ft	Actual Depth, ft	Difference, ft	Difference, %
P80 (Secondary)	6758	6765	7	0.10
P100(Secondary)	7282	7325	43	0.60
P150(Primary)	10914	10890	24	1.10

Block 26 (Well 7)				
Tops	Prognosed Depth, ft	Actual Depth, ft	Difference, ft	Difference, %
P133(Primary)	9575	9507	68	0.71
P150(Secondary)	10251	10200	51	0.50

Block 27 (Well 8)				
Tops	Prognosed Depth, ft	Actual Depth, ft	Difference, ft	Difference, %
TP 50 (Secondary)	12185	11661	524	4.30
TP 35 (Primary)	13819	12998	764	5.50
TP 25 (Primary)	15354	14116	1238	7.60
TP 25 base (Primary)	16164	Not Penetrated		

6.2 Exploration Implications

Block 25a

1) The lack of proven hydrocarbon in reservoirs increases the concern of the potential of the block.
2) The presence of thermogenic gas (up to C5 in some cases) indicates there is a viable migration pathway in the block.

Block 25b

1) The chance of success of other stratigraphic trap prospects is lower than originally assessed due to inability to distinguish low saturation gas from other hydrocarbon scenarios.
2) The lack of any thermogenic hydrocarbon indicators (shows other than C1) suggests hydrocarbon charge to subsurface reservoirs remains unproven from the tertiary source interval.
3) The block's seismic dataset can be confidently used for lithology prediction.

Block 26

1) The block's seismic dataset can be confidently used for lithology prediction.
2) The lack of sand in some of the primary objectives significantly increases reservoir risk for deeper intervals on the blocks.
3) The presence of small amounts of thermogenic gas indicates there is a migration pathway in the block.
4) Well 5 would be important in calibrating seismic response to potential reservoir sands in deeper intervals since Vertical Seismic Profile (VSP) data and core data were obtained.

Block 27

1) The well's inability to prove up a working petroleum system has increased the charge risk on Block 27 prospects.
2) According to the well's objective statement, to be considered a good exploration test, the well should have tested the entire primary target interval (TP35 to base TP 25), hence validating the model for significant reservoir presence in the lower Pliocene. This well did not achieve the objectives stated, i.e. drill 300 ft below the reflector event at the base of the TP 25 interval to be considered a good exploration test. The well did not completely penetrate the TP25 seismic target hence it cannot be considered an effective test. The well penetrated the top of the TP25 primary target and drilled 30 feet of sands that were partially logged by the gamma ray tool and described by the well site loggers. No wireline or VSP data was collected and the absence of a caliper log hindered detailed petrophysical evaluation whilst establishing a proper tie to the seismic data was not a straightforward process.
3) Reservoir continuity and thickness was a significant prospect risk because the quality of imaging did not allow for proper segment definition.
4) Post drill analysis can involve calibration of the seismic reflectivity to sands; hence some reduction in uncertainty but segment definition remains difficult.
5) The trap, a large four-way closure, is fairly robust and was not assigned a high risk. Modular Drill Stem Test (MDT) pressures confirm the presence of intra formational seals in the mid to lower Pliocene section, indicating the mudstones associated with condensed sections can be effective seals.

6.3 Acreage enhancement studies

There are other acreage enhancement studies that were undertaken on a speculative basis by several independent consultants that provide further insights into the Deep Atlantic area from several different perspectives. For instance, a piston core survey of the area was undertaken by TDI Brooks International in 2003 and details the presence of live thermogenic hydrocarbons over the acreage. Biostratigraphic Associates Trinidad Ltd has also completed a detailed stratigraphic transect from onshore, through to shallow water and deepwater wells, incorporating the North and East Coast Marine areas, Northern and Southern Basins and Central Range (MEEA, 2012).

The following points therefore need to be evaluated in future deepwater drilling:

1) Many wells reached their TD early because of various well problems.
2) The wells probably drilled the structural plays which turned out to be negligible.
3) There may be need to target the stratigraphic packages off structure.
4) There were limited understanding of the shelf zone and stratigraphy. This is a slope and shelf edge area. It could be a misinterpretation of the shelf zone.
5) Wells encountered gas column in Blocks 25(a) and 26 proving prospectivity of area.

7. Discussions

The impact of currents on deepwater drilling operations could be reduced if there was access to reliable current measurements and/or forecasts. A combination of data sources and numerical modeling should be used by deepwater operators in T&T to provide effective current advisory information for their deepwater campaign. The regulatory body in T&T should require operators to have a current monitor on the rig and the results from monitoring can be compiled in a Meteorological and Oceanographic data set for the country.

Due to North Brazil Current reduced intensity during April-June period (Sharma et al., 2009); it seems that the best period to drill deepwater wells in Trinidad is between April and June. Significant currents in the Gulf of Mexico led to the US Minerals Management Service to conduct several current studies. One such study report published in 2008 was the "Deepwater Currents in the eastern Gulf of Mexico" that helped operators drilling deepwater wells in the Gulf of Mexico (Nixon et al., 2009).

Since currents affected the drilling operations, there are several concerns for selection of rigs for deepwater operations in Trinidad. These include high current environment, emergency disconnect capabilities and loop current response time. The rigs used were a semi sub and drill ships. Therefore knowledge of rig motions, station keeping system, riser tensioner system, drift off analysis and ROV deployments are some of the main parameters required for evaluation.

The presence of thermogenic gas found in a couple of wells indicates the existence of a dynamic hydrocarbon system, though still poorly understood. Well 1 encountered several dry gas-bearing sands within massive to finely laminated sandstones. Well 5, though lacking reservoir, did encounter gas in thin sandstone packages. Isotopic analysis of the gas samples suggested a mixture of thermogenic and biogenic components. Well 2 also encountered thermogenic gas. Hydrocarbons were found associated with combination stratigraphic and structural traps, hence validating the trapping mechanisms predicted.

There still remain numerous stratigraphic and structural traps yet to be tested. The eight wells drilled to date have proven a gas-prone younger section, though it is very likely that heavier hydrocarbon components may exist at deeper horizons. This is supported by increasing molecular weight with depth of gas molecules associated with Well 1 (Mullin, 2001). The failure of all wells to reach the intended total depths highlights the challenges of drilling in the basin. However, it is hoped that lessons learned will be carried forward into future drilling in the Deepwater Blocks. If we compare with the Gulf of Mexico experience, since 1975 there have been 285 deepwater discoveries from drilling in excess of 2200 hundred exploration wells and this represents a 1 in 8 chances of success (Nixon et al., 2009).

8. Conclusion and Recommendations

While investigating into the problems, risks and uncertainties encountered during the drilling of wells, several conclusions could be drawn from this study. These are:

1) The actual versus prognosed depths of formation tops were generally very close.
2) 50% of the wells were within the proposed drilling days while 5 of the 8 wells were drilled within budget. None of the wells reached their planned TD.
3) Pore pressures and fracture gradients were generally on the low to medium side of predicted values.
4) There were no major environmental incidents.
5) Low gas saturated wet sands and hydrocarbon bearing sands showed similar seismic responses.
6) Data collected can provide calibration of seismic data set and geological model for deepwater, and
7) Some good reservoir quality sands were encountered in most wells.

Future well designs in the deepwater acreage should place more emphasis on overpressure sands, gassy sediments, high pore pressure and gas hydrates could also be encountered. If new well sites are selected, top-hole conditions should be analysed for each new location. New deepwater operators should place more focus on casing and mud plan designs to mitigate and/or contain overpressure sands, and possible gas from the moderate and high-risk zones on the top-hole prognosis. This includes a contingency plan for possible shallow flows from even units assessed with low risk.

MWD logging should be used for the top-hole portion of the well. Besides, drilling pilot holes should be considered before spudding the exploration well especially in Shallow Water Flows (SWFs) prone areas. In addition to objectives of the pilot hole mentioned earlier, this hole could be very useful in direct measurements of formation pore pressure and fracture gradients and gas hydrate accumulations.

The major drilling problems include well control, lost circulation, stuck pipe and well stability and therefore require substantial pre-drill studies, modeling, and real time adjustments to help mitigate these events in the future. Therefore, data from this first deepwater drilling campaign should be used in these future studies.

It is recommended that the best period to drill deepwater wells in Trinidad is April to June. Besides, evaluation of rig motions, station-keeping system, riser tensioner system, drift off analysis and ROV deployments of deepwater is necessary for deepwater drilling operations in Trinidad. A recalibration of the seismic data set should be done and re-divide the deepwater blocks for future exploration work, considering the presence of thermogenic gas in some blocks.

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