PSA Multi-Disciplinary Approach for Planning a Horizontal Well in an Enhanced Oil Recovery Field, Forest Reserve, Trinidad*

Reshma D. Maharaj[1], Therese A. Steele[2], and Michael Budri[3]

Search and Discovery Article #20329 (2015)**
Posted November 2, 2015

*Adapted from poster presentation given at AAPG Latin America and Caribbean Region, 20th Caribbean Geological Conference 2015, Port-of-Spain, Trinidad & Tobago, West Indies, May 17-22, 2015

[1]Exploration and Geophysics department, The Petroleum Company of Trinidad and Tobago, (Reshma.Maharaj@petrotrin.com)
[2]Prospect Generation department, The Petroleum Company of Trinidad and Tobago
[3]Reservoir Engineering department, The Petroleum Company of Trinidad and Tobago

Abstract

The Upper Morne L'Enfer (UML'E) thermal project is located in the Forest Reserve field and targets production from the A1, A2 and B units of the UMLE unit of the Morne L'Enfer Formation. Primary production from the area began in 1969 and continued up to 2000. In April 2000, a drilling programme commenced and in 2004, a pilot thermal project was implemented with cyclic steam stimulation as the main production mechanism. From 2007 to present, the thermal project was expanded to the southeast, to increase productivity of the heavy oil hydrocarbons. Using geological, geophysical and reservoir data, two horizontal wells were proposed in 2014, to further expand the Enhanced Oil Recovery (EOR) area to south. The planned horizontal wells target the A1 sand, which is clean, shows a consistent blocky log character and has high resistivity and permeability. The paleo-bathymetry for the UMLE is non-marine to marginal marine. The reservoir sand is interpreted as a distributary channel with tidal influence. The identification of the depositional environment was of great importance in order to delineate areas where the sands are best developed and thus plan EOR patterns with greater accuracy. The reservoir model was built using geological model and rock properties, after which a production history match was done. Following the initial well design, the proposed wells were viewed on the 3D North West District (NWD) seismic dataset. Interpretation of the reservoir showed subtle changes in the dip of the sand, which the previous interpretation, using only well logs, was not able to discern. Because of the 3D interpretation, changes in the well design were made so the horizontal well path remains within the reservoir interval. The chance of success has increased with the integration of the seismic data that allowed better 3D visualization of the Geological Model and more accurate placement of the horizontal well to achieve optimum results.

A Multi-disciplinary Approach for Planning a Horizontal Well in an Enhanced Oil Recovery Field, Forest Reserve, Trinidad.

Reshma D. Maharaj, Therese A. Steele & Michael Budri

GEOLOGICAL FRAMEWORK

SCOPE

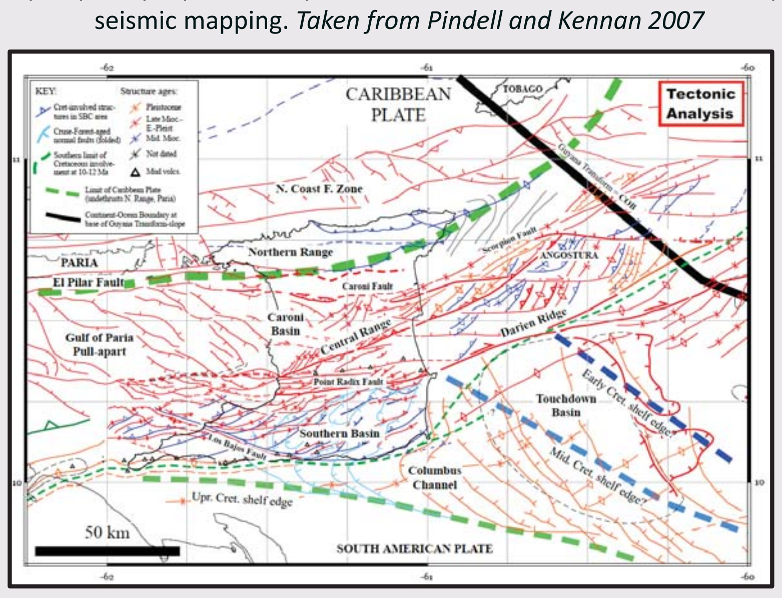
This project integrates geological, geophysical and reservoir engineering data to plan two horizontal wells in the an Enhanced Oil Recovery Area, Forest Reserve Field. The proposed wells will increase production and mitigate past drilling and production issues. The initial well design was based on a Reservoir Model generated from Geological Data and Rock Properties. Changes to the well design were made after 3D Seismic Interpretation showed subtle changes in dip that was critical to the well placement.

INTRODUCTION

REGIONAL FRAMEWORK

- **The oblique collision of the Caribbean and South American Plates and a period of compression gave rise to the main structural features in the mid-Miocene.**
- **From mid-Miocene to present day, transpression predominates in the Southern Basin, Trinidad.**
- **The regional trend of the structural elements is northeast-southwest.**

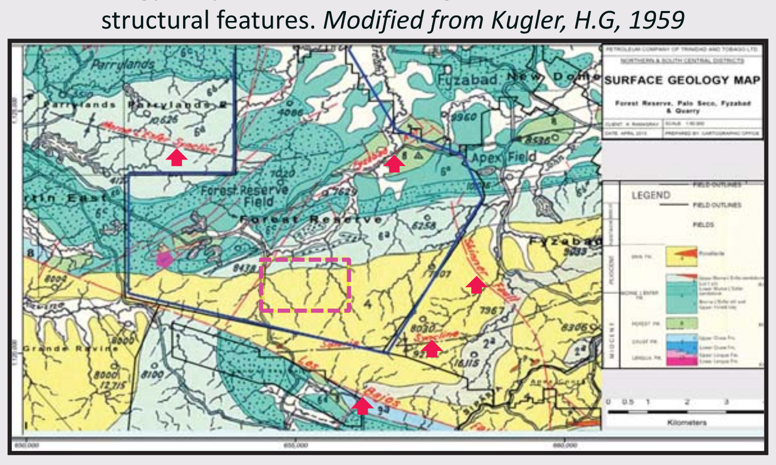
FIGURE 1: Map of principal present day structural elements of Trinidad, based upon extensive seismic mapping. *Taken from Pindell and Kennan 2007*



LOCAL GEOLOGY

- **The Forest Reserve Field is located in the Southern Basin.**
- **The main structural features are the Fyzabad Anticline which trends northeast-southwest and plunges to the southwest, the Skinner Fault, the Los Bajos Fault zone and the Siparia Syncline.**
- **These structures provided a trap for the hydrocarbons that were re-migrated from breached mid-Miocene, hydrocarbon bearing structures.**

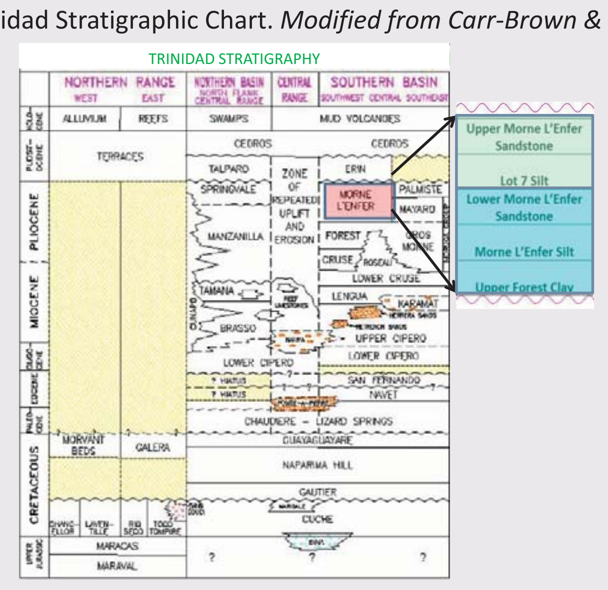
FIGURE 2: Surface Geology map of Trinidad showing the Forest Reserve Field and surrounding structural features. *Modified from Kugler, H.G, 1959*



STRATIGRAPHY

- **The main oil-bearing zones in the field are the Cruse, Forest and Morne l'Enfer (MLE) Formations.**
- **The reservoir of interest is found in the MLE formation and was deposited during the Pliocene.**
- **The MLE consists of unconsolidated sands, interbedded silts, clays and lignites, porcellanites (Saunders & Kennedy, 1968)**
- **Sedimentological descriptions of the outcrops and full-hole core show ripple marks, cross-bedding and channeling.**

FIGURE 3: Trinidad Stratigraphic Chart. *Modified from Carr-Brown & Frampton 1979*



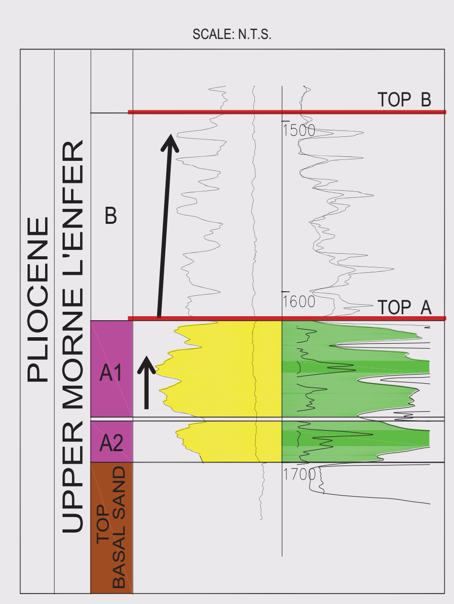
STUDY AREA

- **The study area lies within the Forest Reserve Field and is located on the southern flank of the Fyzabad Anticline.**
- **It is approximately 2.5 km²**
- **There are 150 wells in the UMLE area.**
- **Data used in this project include: cores, paleontological data, residual logs, production data, log motif's and electric well logs.**
- **The A1 sand is the primary objective in this study.**
- **Below the A2 sand, there is a clean blocky sand with high resistivity. This sand is fresh-water bearing, throughout the fault block.**
- **Production is mainly heavy oil from the A1 and A2 units of the Upper Morne l'Enfer (UMLE) Formation.**

TYPE LOG

- **A1 sand is clean and has a blocky character throughout the EOR area.**
- **It has high resistivity (>20 Ω) and permeability (42.9-1774 mD).**
- **The overlying clay (2-10 ft.) which is laterally continuous may provide a seal for the reservoir. This is the correlative marker across the area.**

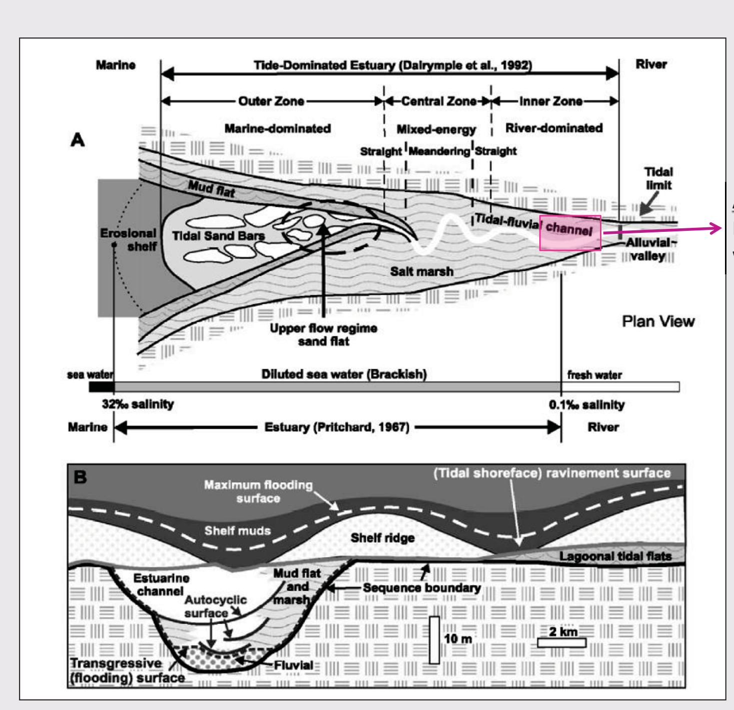
Figure 4: Type log showing the log motif and interpretation of the sediments deposited.



DEPOSITIONAL ENVIRONMENT

- **Identification of the geometry and architecture of channel systems is key to understanding reservoir heterogeneities in heavy oil areas (Wach & Vincent, 2007).**
- **As such the depositional environment was studied to make a geologically sound interpretation of the sand trends using log signature mapping and analogs for transitional zones.**
- **UMLE is usually barren in foraminifera. From the paleontological data the bathymetry was interpreted as non-marine to marginal marine.**

FIGURE 5: Depositional Environment of a Tide-Dominate Estuary. *Modified from Yoshida et. al. 2004; Taken from http://aapgbull.geoscienceworld.org /content/88/10/1433.abstract*



(A) Distribution of morphological components (in plan view) of an idealized tide dominated estuary

(B) Hypothetical, coast-parallel cross section showing the stratigraphy of a transgressive systems tract in a tide-dominated estuarine to shelfal setting

GEOLOGICAL INTERPRETATION

FIGURE 6: Strike Section.
The strike generally follows the regional trend SW-NE.

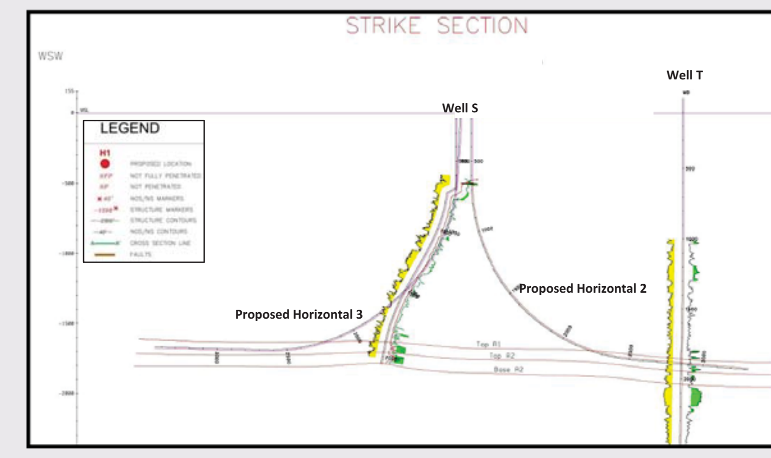


FIGURE 7 : Dip Section.
The beds dip 20° below the 1000 ft. structure contour and 30-40° above it. The dip is generally NW-SE.

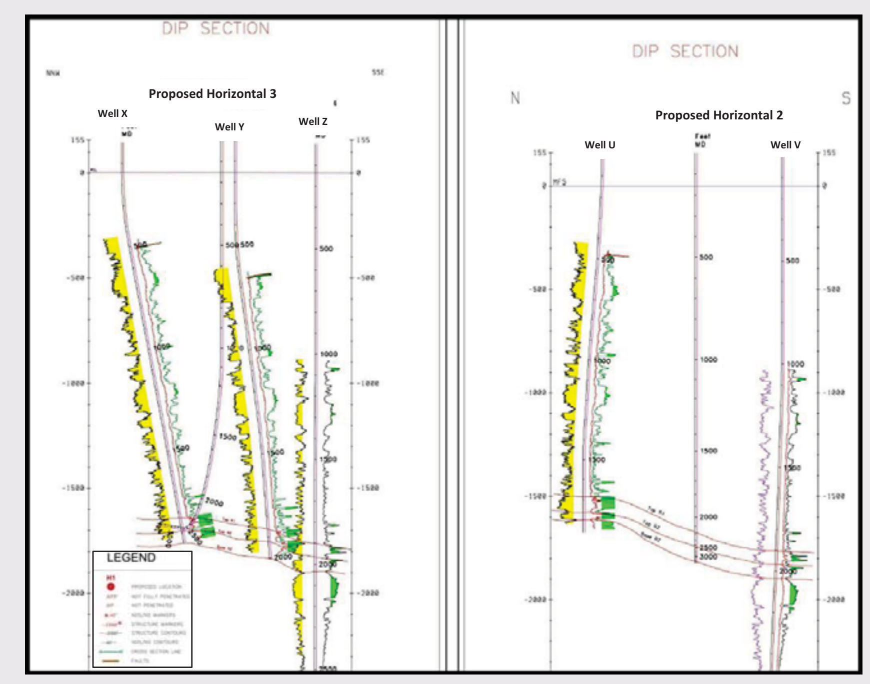


FIGURE 8: Structure Map on A1 unit.
The UMLE area is bounded by two faults. One trending NNE-SSW and the second NW-SE. The two faults intersect in an up-dip position north of the main study area. The OWC is interpreted to be at -1825 ft.

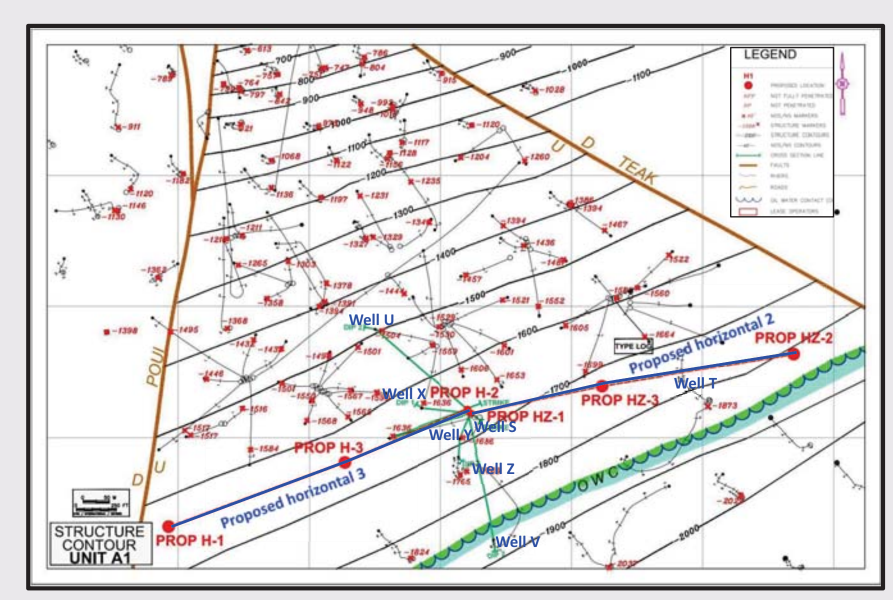


FIGURE 9: Net Sand Map on A1 unit.
The depositional environment and geomorphology of distributary channels was used in generating the sand map. The sands trend in a NE-SW direction and vary in thickness from 20-40 ft.

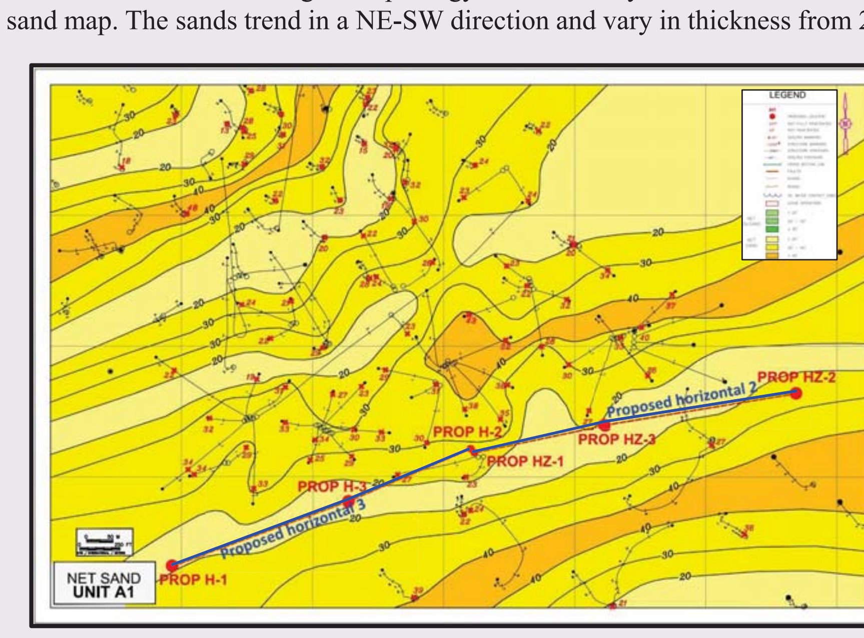
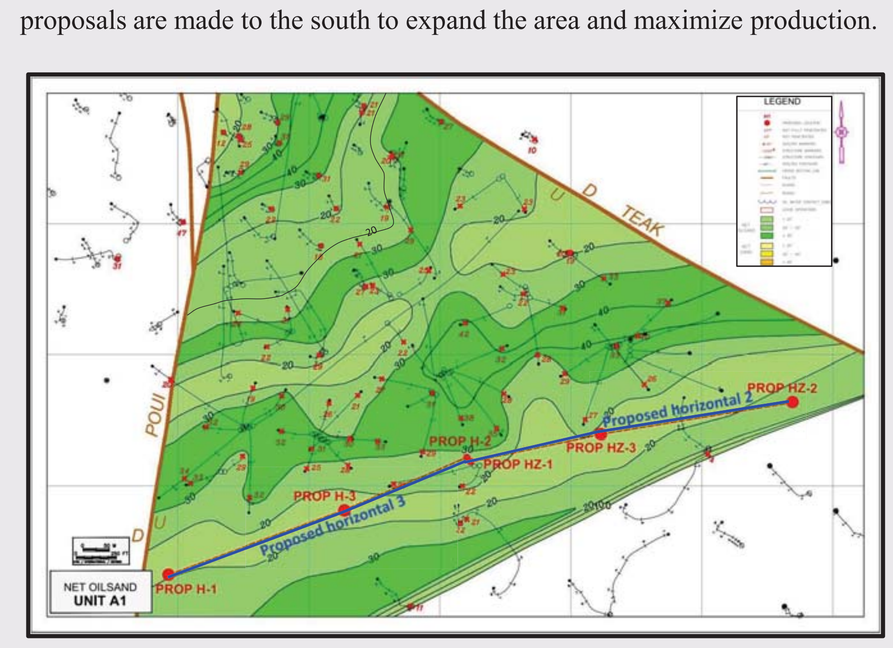


FIGURE 10: Net Oil Sand Map on A1 unit.
The net oil sand was generated using the structure and sand trends. Net oil sand thickness varies between 20-40 ft. The A1 Unit is found to be "fully oiled-up" up-dip of the -1800 ft. contour. The proposals are made to the south to expand the area and maximize production.



A Multi-disciplinary Approach for Planning a Horizontal Well in an Enhanced Oil Recovery Field, Forest Reserve, Trinidad.

Reshma D. Maharaj, Therese A. Steele & Michael Budri

GEOPHYSICAL EVALUATION

SEISMIC INTERPRETATION

The seismic interpretation on the 3D North West District (NWD) land dataset was used to validate the geological interpretation. However the interpretation of the reservoir showed subtle changes in the dip of the sand which the previous interpretations, using only well logs, was not able to discern. As a result of the 3D interpretation, changes in the well design were made so the horizontal well path remains within the reservoir interval. The chance of success has increased with the integration of the seismic data that allowed better 3D visualization of the Geological Model and more accurate placement of the horizontal well to achieve optimum results.

FIGURE 11 : Basemap showing drilled and proposed wells. Highlighted are key wells surrounding the proposed horizontal well. The water sand below the A2 sand is identified on the strip log for Well W.

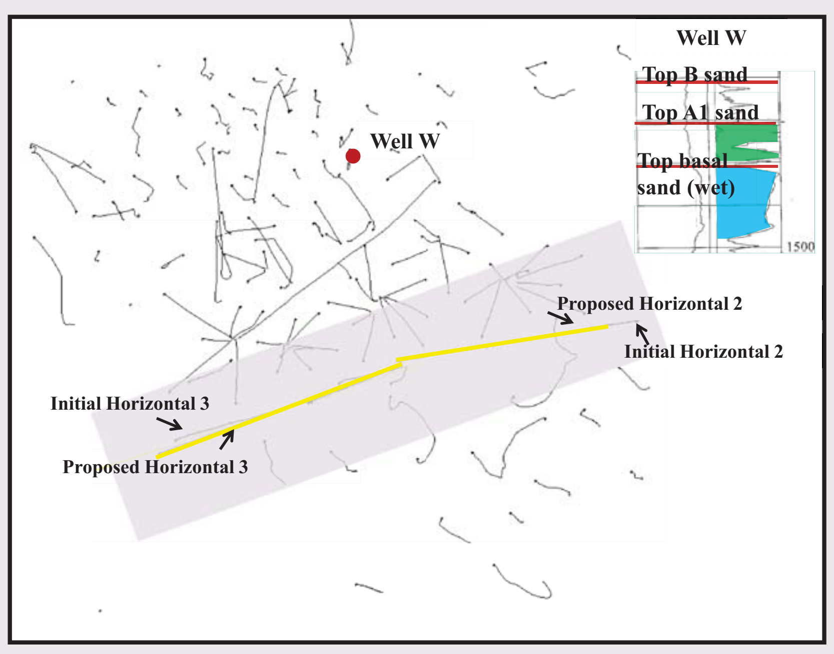


FIGURE 12 : Inline W-W' showing the UMLE A sands (A1 and A2).

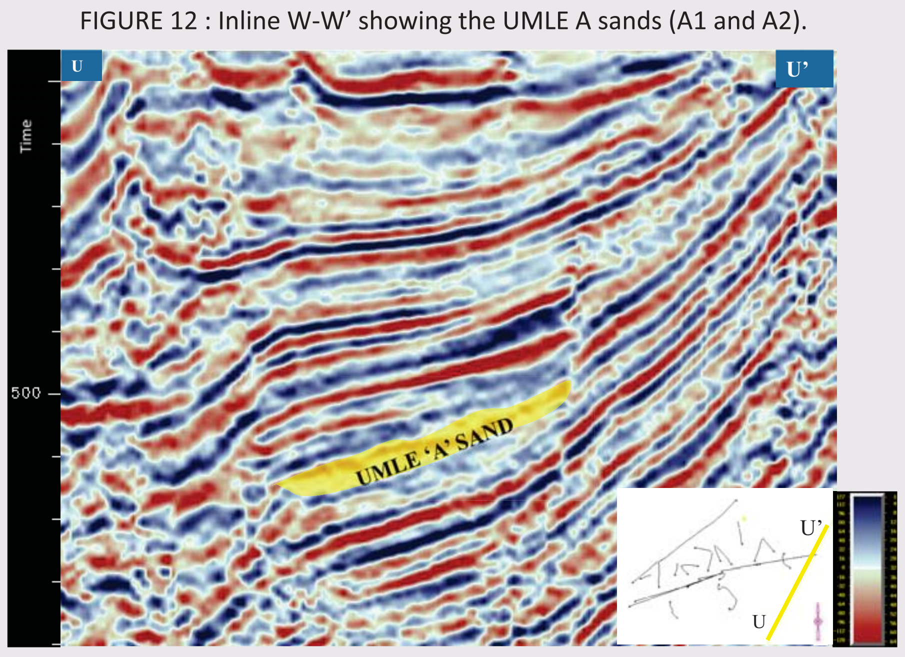


FIGURE 13 : Crossline X-X' showing the UMLE A sands.

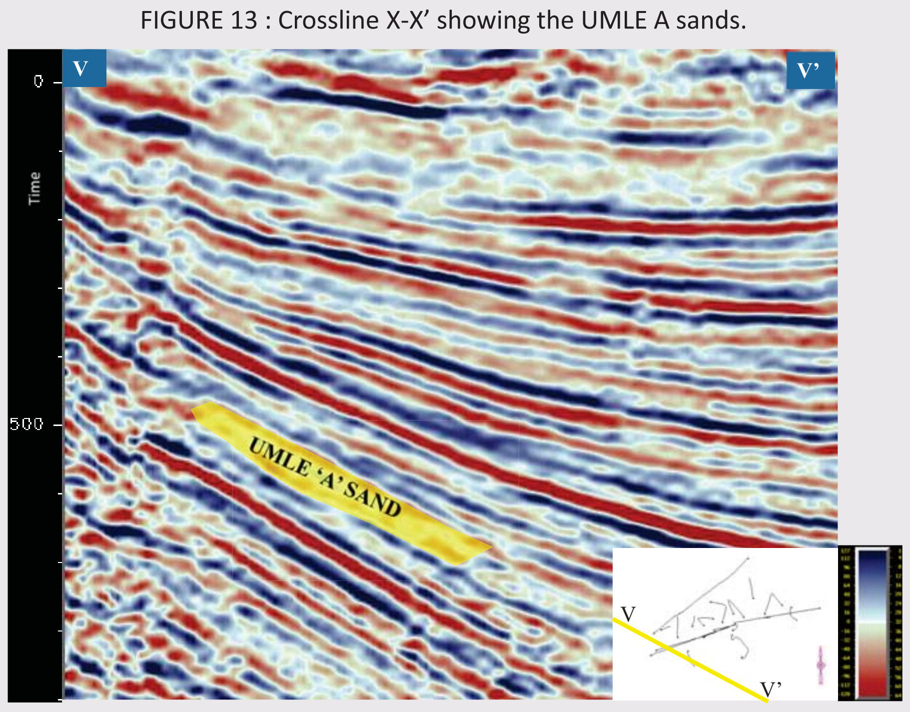
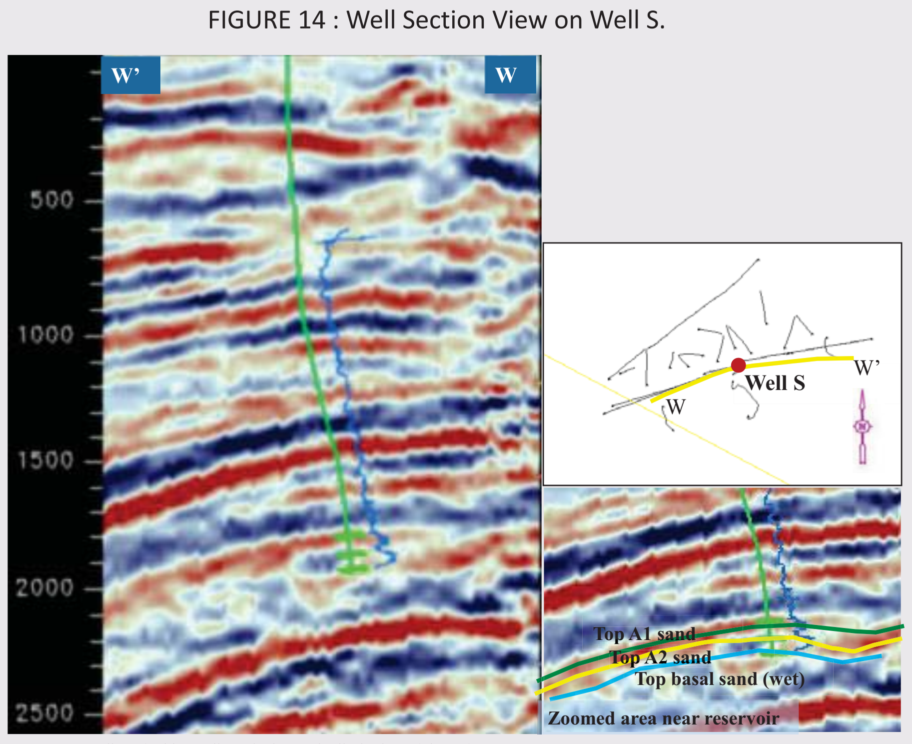


FIGURE 14 : Well Section View on Well S.

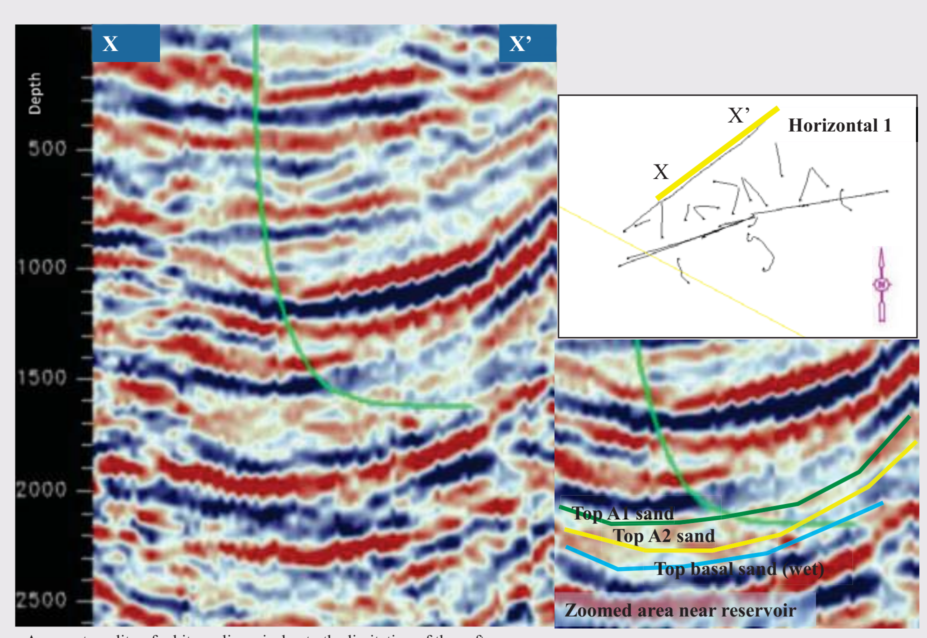


Apparent quality of arbitrary lines is due to the limitation of the software.

EVALUATION

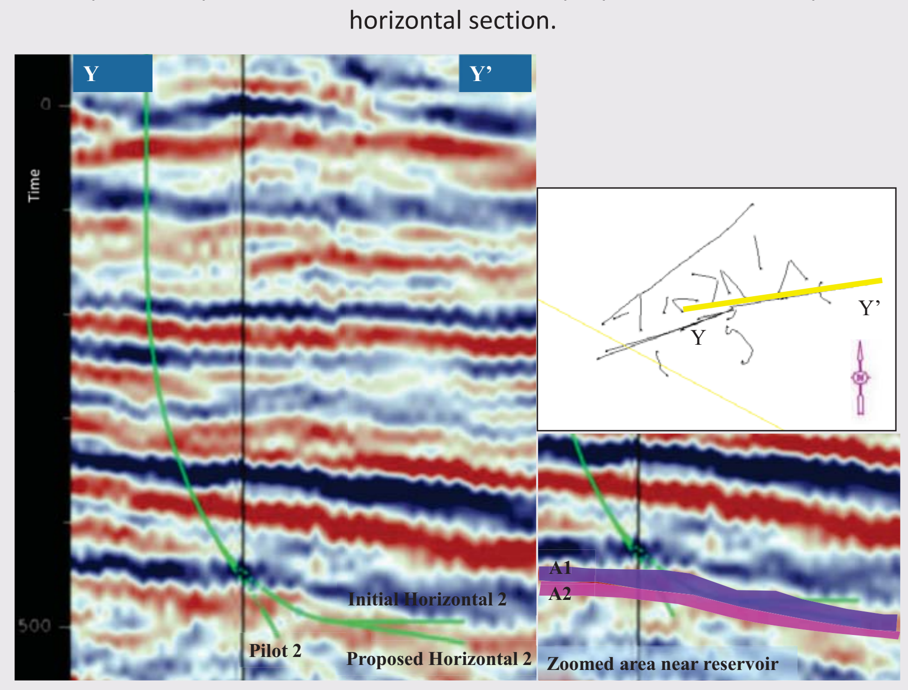
- The proposed horizontal wells were overlain on the seismic using checkshot data from a neighboring well outside the fault block.
- To validate the velocity function, depths were calculated using the TWT and compared to the depths from well log data for the key surrounding wells. For well S, the top A1 sand was calculated 10 feet deeper than the depth from the well log.
- The Top A1, top A2 and top basal sands (also referred to as the 'water sand' down dip of area) were interpreted and the surfaces interpolated and imported to Landmark's Geoprobe 3D Visualization software.
- Seismic data was not available during the planning and drilling of the Horizontal 1 well which encountered the water sand. The seismic interpretation showed that the well penetrated the water sand.
- Coordinates and depths of points for sand entry, heel and toe of the proposed wells were taken from the seismic and used to re-design the wells to meet drilling requirements and follow the geology as mapped on 3D seismic.
- The new proposed wells were designed to target the A1 sand and prevent drilling into the water sand. The seismic interpretation confirms that the new proposals will not penetrate the water sand.

FIGURE 15: Well Section View on Horizontal 1.
The previous horizontal 1 well drilled in UMLE area and penetrated the water sand.



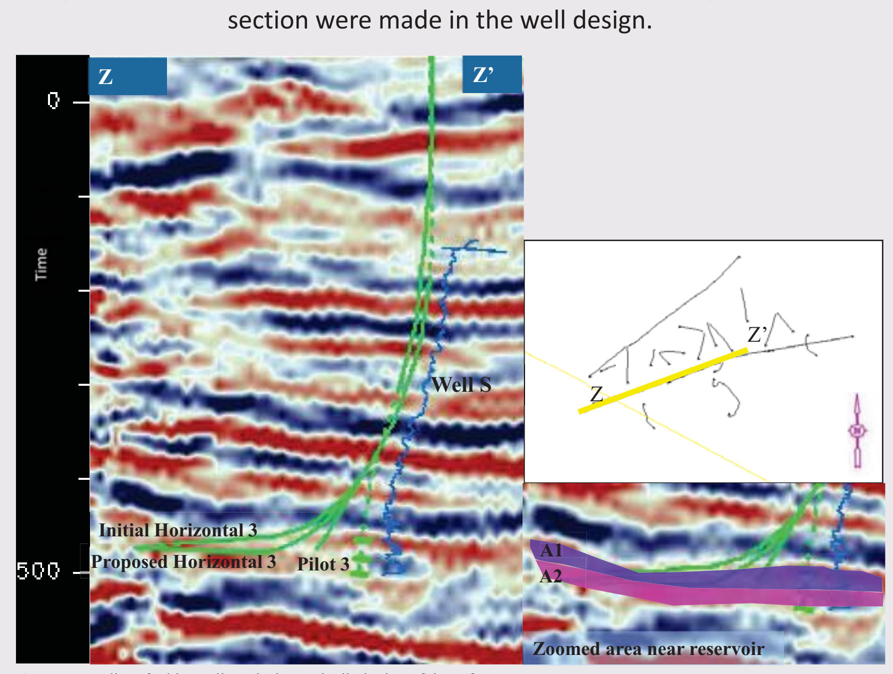
Apparent quality of arbitrary lines is due to the limitation of the software.

FIGURE 16 : An arbitrary line showing the initial horizontal well 2, the final proposed horizontal 2, and the final pilot well paths on the seismic. The initial proposal exited the top sand on the horizontal section.



Apparent quality of arbitrary lines is due to the limitation of the software.

FIGURE 17 : An arbitrary line showing the initial horizontal well 3, the final proposed horizontal 3, and the final pilot well paths on the seismic. Modifications to the heel position and horizontal section were made in the well design.



Apparent quality of arbitrary lines is due to the limitation of the software.

3D VISUALIZATION

FIGURE 18 : Proposed wells in relation to the Top A2 sand and Picks for Top A1, Top A2, Top basal sand . On the left plot the proposed horizontals do not penetrate the top A2 sand. On the right, the proposed wells are viewed with Horizontal 1 well with the picks for the respective surfaces.

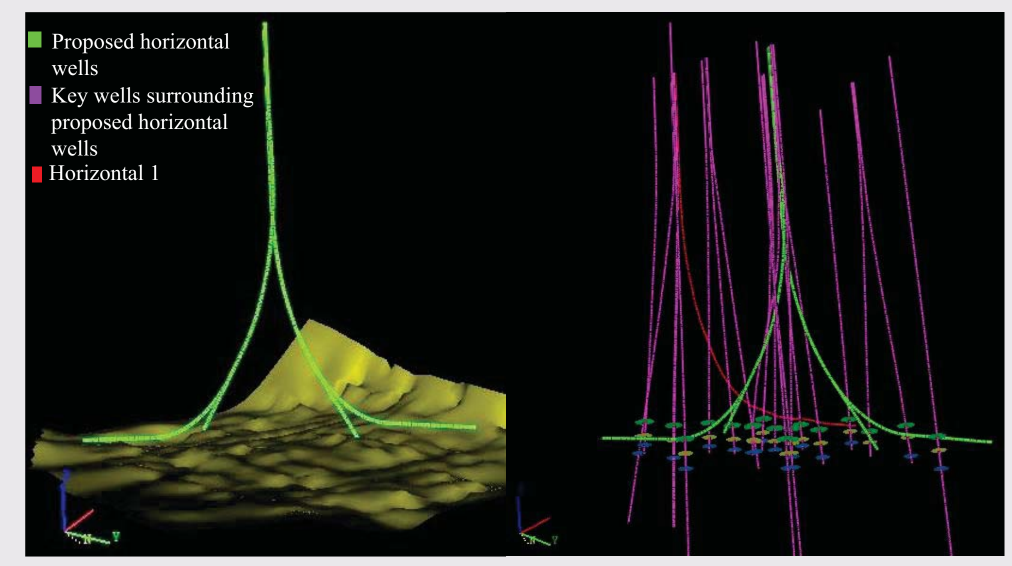


FIGURE 19: Horizontal 1 well penetrated the basal sand which is wet.

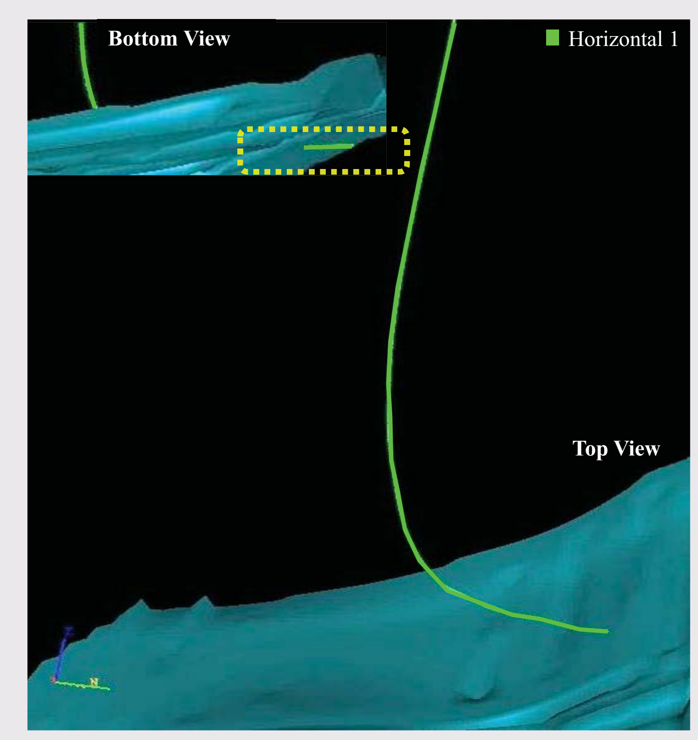


FIGURE 20 : 3D view of the initial planned horizontal 2 well and the proposed horizontal 2 well. In the top view the initial horizontal exited the top A1 sand. The bottom view shows that the proposed horizontal follows the trend of the A1 sand and is not expected to enter the A2 sand.

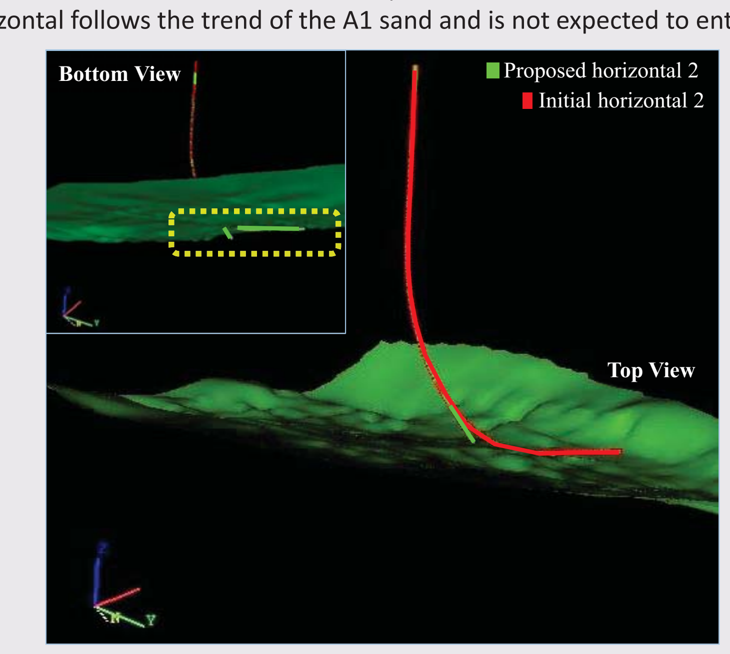
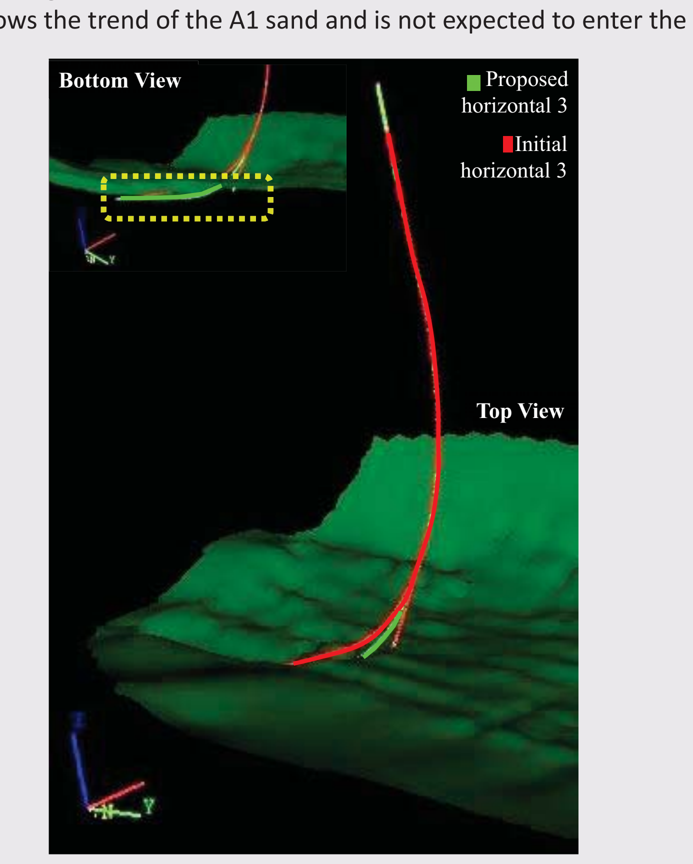


FIGURE 21 : 3D view of the initial planned horizontal 3 and the proposed horizontal 3 well. The heel point was re-designed to set in the A1 sand. The bottom view shows that the proposed horizontal follows the trend of the A1 sand and is not expected to enter the A2 sand.



A Multi-disciplinary Approach for Planning a Horizontal Well in an Enhanced Oil Recovery Field, Forest Reserve, Trinidad.

Reshma D. Maharaj, Therese A. Steele & Michael Budri

RESERVOIR ENGINEERING

BACKGROUND

- Primary production in the area began in 1969. In 2004, steam injection in the form cyclic steam stimulation (CSS), was introduced in a pilot project.
- The pilot project showed promising results and in 2007 the thermal project was expanded.
- The thermal project produces heavy oil mainly via CSS and it is intended to convert the project into a steamflood.

HISTORY

- There has been limited success in drilling horizontal wells onshore
- In this study area, the horizontal well (Horizontal 1) was drilled to 3266ft (MD). The expected IP was 145 BOPD and actual IP was 8 BOPD.
- This well entered the water sand below reservoir unit.
- The horizontal well was converted to CSS in 2007.
- After cleaning the well for sand entry problems, the well was converted to CSS in 2012 where it is currently producing ~10 BOPD.

WHY USE HORIZONTAL WELLS?

ADVANTAGES

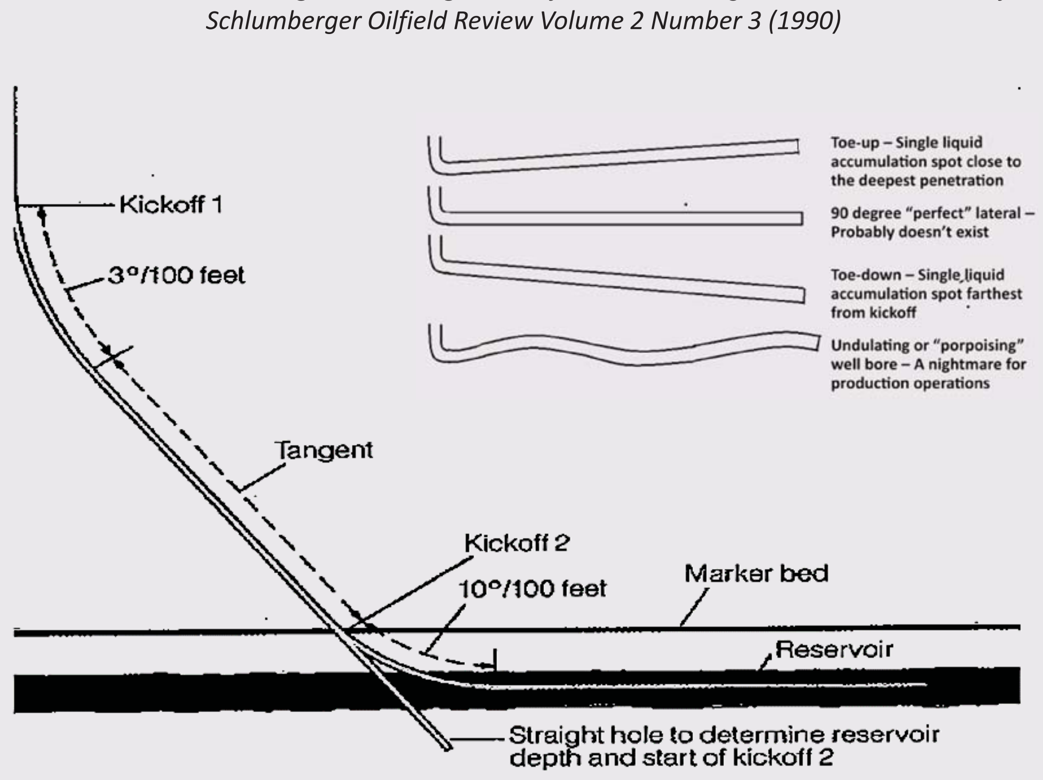
- Less water and gas coning problems
- Higher well productivity
- Larger drainage volume
- Lower drawdown near the well bore for the same flow rate as vertical wells, results in more stable flow and delaying breakthrough
- Higher sweep efficiency due to more contact with reservoir fluids
- Horizontal wells intersecting vertical fractures can dramatically increase productivity

DISADVANTAGES

- Horizontal wells are not suitable for thick reservoirs with poor vertical communication
- Horizontal wells are more difficult and more costly to drill, log and complete
- If natural fractures connect to aquifer and/or gas cap, breakthrough time may be accelerated
- Production problems for horizontal wells are more difficult to solve

TYPICAL HORIZONTAL WELL

FIGURE: Horizontal Drilling Comes of Age; *taken from Trevor Burgess & Patrick Van de Slijke, Schlumberger Oilfield Review Volume 2 Number 3 (1990)*



FIELD DATA

AREA (acres)	≈ 205
PRODUCTION RATE (BPD)	919 BOPD, 1,390 BWPD, 2,596 BSPD
CUMULATIVE PRODUCTION/INJECTION (MBBLS)	2,949 (OIL), 3,433 (WATER), 3,080 (STEAM)
POROSITY (%)	21.6 – 36.9
PERMEABILITY (md)	42.9 – 1,774.8
WATER SATURATION (%)	17.8 – 29.2
OIL GRAVITY (°API)	10.6 – 17.2
OIL VISCOSITY @ 100 °F (cp)	238.5 – 5,320
RESERVOIR DEPTH (TVDSS ft)	753 – 1,825 (OWC)
RESERVOIR THICKNESS (ft)	41 – 153 (GROSS) 32 – 99 (NS) 32 – 84 (NOS)
RESERVOIR TEMPERATURE (°F)	94 - 100
AVERAGE CURRENT RESERVOIR PRESSURE (psi)	≈ 400 - 500
ORIGINAL OIL IN PLACE (MMSTB)/RF (%)	32 (OOIP), 9.22 % (RF)

JUSTIFICATION

The two (2) proposed horizontal well candidates in the UMLE steam flood project will seek to add reserves, further expand the steamflood project and exploit high potential areas that are located downdip of the project area. The wells are programmed to penetrate the A1 sand of the UMLE Formation. This unit is highly resistive and has favorable rock and fluid properties. Production data from surrounding wells suggest that it is reasonable to expect an initial risked production of 50 BOPD per well. After the wells have been drilled and completed they will be put on primary production. After oil rates have declined they will be converted to CSS. Oil production is expected to peak to 250 BOPD after CSS and subsequently decline thereafter.

RESERVOIR MODEL

INPUT TO MODEL

- Geological data: structure maps, net sand maps, net oil sand maps and interval thickness map
- Rock Properties: porosity, permeability, relative permeability and formation compressibility

FIGURE: 3D Reservoir Model; *Captured from CMG Reservoir Simulation software suite*

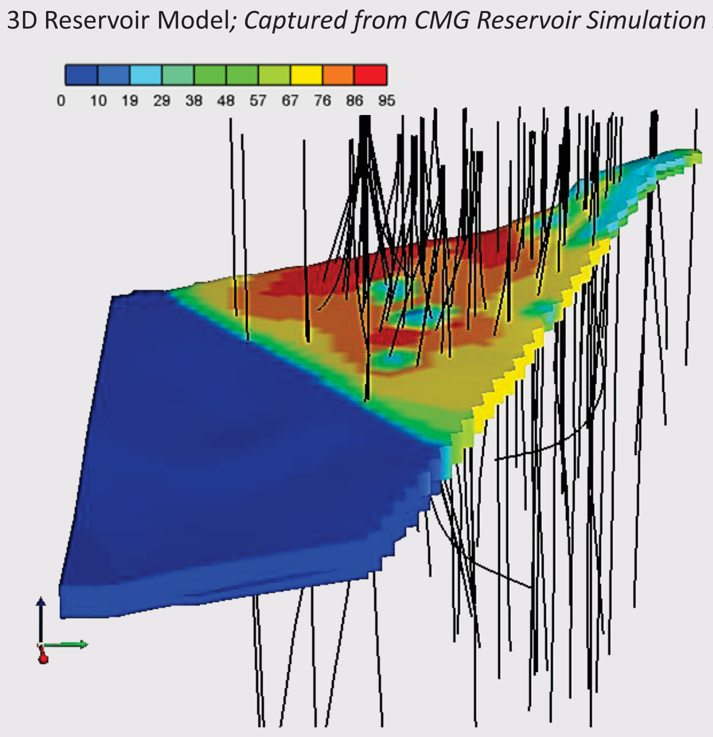


FIGURE: Side view of 3D model above showing the penetration of the past horizontal well and the two (2) proposed wells in the reservoir; *Captured from CMG's Reservoir Simulation software suite*

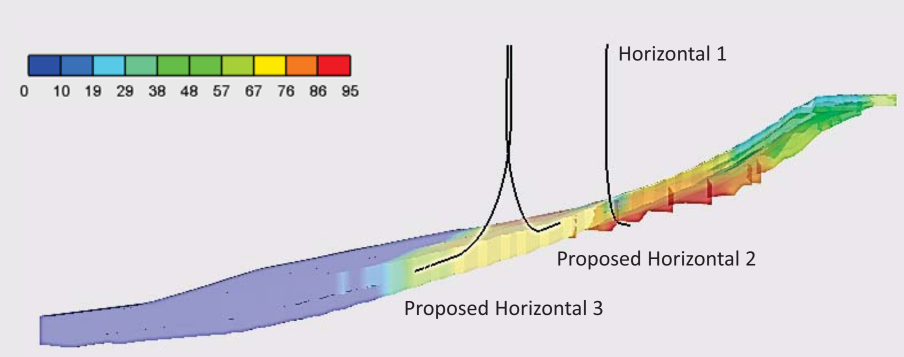
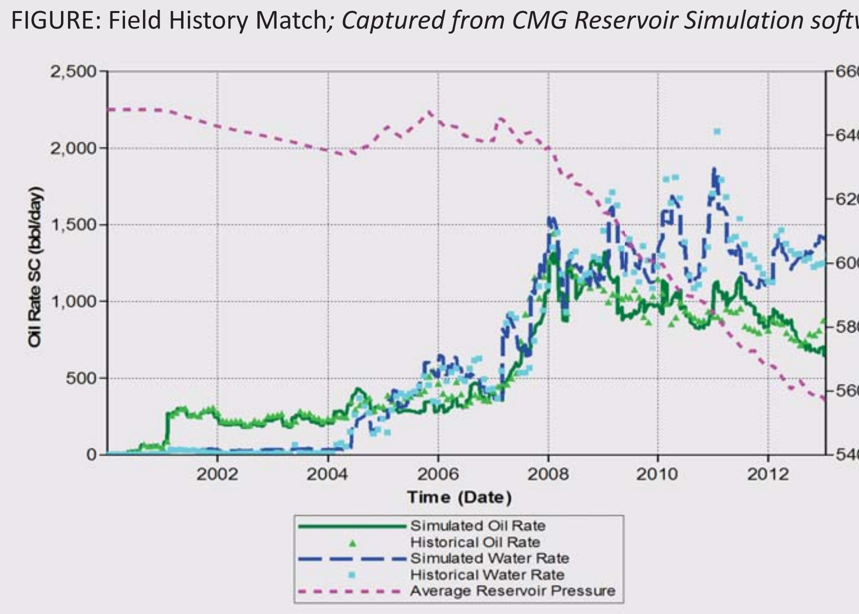


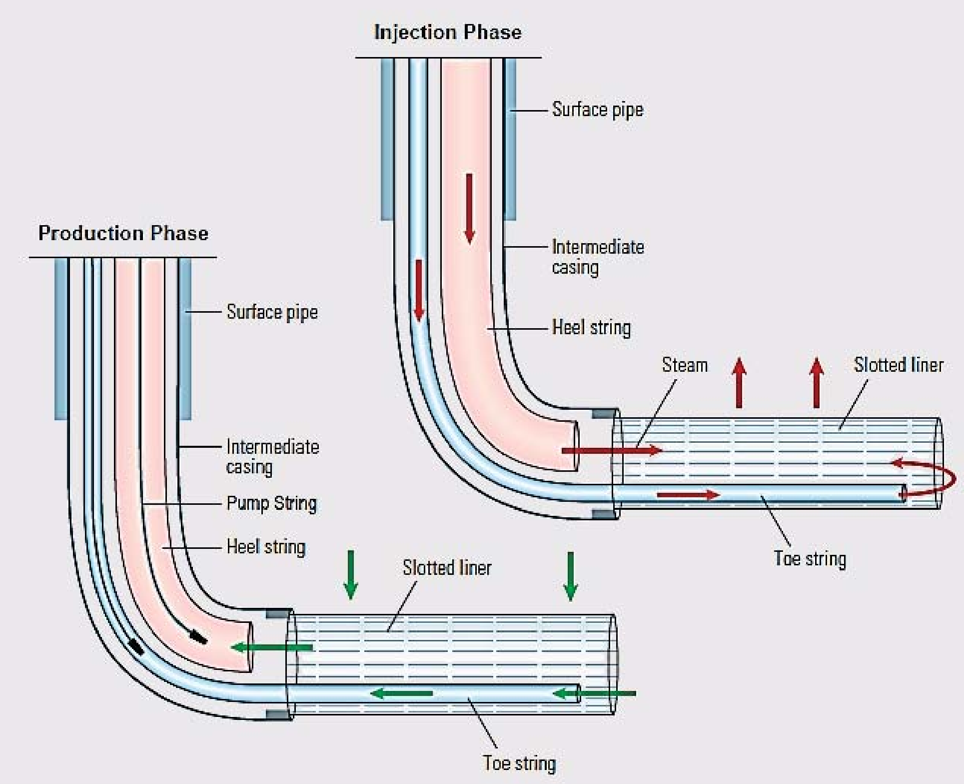
FIGURE: Field History Match; *Captured from CMG Reservoir Simulation software*



HORIZONTAL CYCLIC STEAM STIMULATION

- A method of thermal recovery in which a horizontal well is injected with steam and then subsequently put back on production.
- The process includes three (3) stages; (1) injection, (2) soak phase and (3) the heated oil is produced through the same well.
- The cycle is repeated as long as oil production is profitable.

FIGURE: *Warming to Heavy Oil Prospects; taken from Farrukh Akram, Terry Stone, William J. Bailey, Euan Forbes, Michael A. Freeman, David H.-S. Law, Glenn Woiceshyn and K.C. Yeung, Schlumberger Oilfield Review Volume 26 Number 2 (2014)*



INCREASING THE CHANCE OF SUCCESS THIS TIME AROUND…

- 3D seismic data used to confirm well paths
- The target is ONLY the A1 sand
- Sand has favorable reservoir parameters e.g. kv/kh ratio ~1!
- Sand better developed in proposed locations
- Areas are not depleted and no steam injection has occurred
- Drilling of pilot holes to confirm geology and depths
- Using state of the art MWD/LWD tools e.g. Autotrak, Zonetrak
- Well and completion design have been tested worldwide with success
- Thermal methods of production that are applicable have been readily established and proven to be successful e.g. HCSS, SW-SAGD

ACKNOWLEDGEMENTS

We would like to thank the management of the Petroleum Company of Trinidad and Tobago Limited for permission to present the work done on planning the horizontal wells in the EOR field, Forest Reserve. We are grateful for the contributions from the following departments; Exploration & Geophysics, Technical Data Centre, Geological Laboratory Services, Prospect Generation, Reservoir Engineering and Cartography during the project.

REFERENCES

- Zyndel, F., 1916, Morne l'Enfer formation, private report for Trinidad Leaseholding Ltd., p. 137.
- Kugler, H.G., 1959, Stratigraphic Lexicon of Trinidad and Tobago.
- Saunders, J.B. and Kennedy, J.E., 1968, Sedimentology of a section in the Upper Morne L'Enfer formation, Guapo Bay, Trinidad, Fourth Caribbean Geological Conference, Port of Spain, Trinidad, p. 121.
- Bower, T.H., 1968, Geology of Texaco Forest Reserve Field, Trinidad, W.I: Transactions of the Fourth Caribbean Geological Conference, Port of Spain, Trinidad, p. 75-86.
- Sinanan, B. et al., 2003, Forest Reserve Upper Morne L'Enfer Steamflood Feasibility Study, (Internal Petrotrin Report # 10078), unpublished.
- Pindell, J. L., and Kennan, L., 2007, Cenozoic Kinematics and Dynamics of Oblique Collision Between two Convergent Plate Margins: The Caribbean-South America Collision in Eastern Venezuela, Trinidad and Barbados: Transactions of GCSSEPM 27th Annual Bob F. Perkins Research Conference, p. 458-533.
- Wach, G. and Hasley Vincent, H., 2007, Reservoir Heterogeneity and Characterization in Deltaic Depositional Systems - Outcrop Analogs for Heavy Oil and Oil Sand Developments, Search and Discovery Article #50064 Posted March 24, 2008.