OPTIMAL WELL PLACEMENT TECHNIQUES IN LOW CONTRAST CLASTIC RESERVOIRS UTILISING INTEGRATED TECHNOLOGIES AND REAL-TIME DATA TO MINIMISE UNCERTAINTY IN CHALLENGING LOW CONTRAST CLASTIC RESERVOIRS

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Summary

Nong Yao is an oil field with complex geology setting: the extent of aquifer support, faulted and compartmentalised reservoirs, lateral sand connectivity, thin oil columns, fluid contact, and low contrast pays. It is very challenging to develop the field with conventional methodology by drilling highly deviated or slanted wells. Utilising and integrating technology and real-time data geo-steering was enabling the success of development plan by minimising those uncertainties, landing the wells and geo-steering the horizontal well precisely as desired. As the result, the production increased significantly and it becomes the potential to unlock more reservoirs in the Gulf of Thailand for development in the current cost pressure and oil price environment.

Key words: *Low contrast, thin channel sand, horizontal geo-steering, field development, production, real-time.*

The Nong Yao field is located in the southern Gulf of Thailand, approximately 145km off the coast, in approximately 75m of water. The Nong Yao field covers the southern margin of Pattani basin and the north west border of the Malay basin. It was discovered by Nong Yao-1 exploration well in 2009 (Figure 1). The key subsurface challenges and uncertainties in the Nong Yao clastic reservoirs were: limited exploration and appraisal data, the extent of aquifer support, faulted and compartmentalised reservoirs, lateral sand connectivity, thin oil columns, fluid contact, low contrast pays and geological structure. The strategy to develop the Nong Yao field was via horizontal wells in order to maximise the reservoir exposure in thin sand reservoir to optimise the field production. This paper will cover some of the techniques used in placing the horizontal wells, which include utilising technologies to overcome difficulties, minimising uncertainties, dealing with reservoirs of low contrast and integrating and using data in real-time for better decision making.

All of the planned well trajectories were based on the depth converted seismic, inversion porosity cube and available appraisal well data. However, the appraisal well data was limited thus the planning phase had to heavily rely upon seismic. Due to the seismic depth uncertainty, landing wells in the target sand is always a challenging task for the Nong Yao subsurface team. The first challenge was the thin sandstone reservoir targets, some with gradational resistivity profiles changing from shale to shaly sand, to sand. Others with low contrasts between oil pay sand and surrounding shales, and other with gas bearing sands had a similar resistivity to oil filled sands. This can make differentiating the oil sand pay from either shaly wet sand

Figure 1. *The Nong Yao field location map*

or gas bearing sands difficult. Additionally, many reservoirs having either oil on water or gas on oil on water, the depth and reservoir identification become critical to the success of landing and placing the horizontal well. If the well was landed too shallowly, critical pay footage would be missed. Conversely, if the well was landed too deep, it would lead to early water break-through. None of those scenarios are desirable for long-term production outcomes. Therefore, if the wells are not correctly landed, the consequences would be a costly plug back and side-track would be required.

The first case study from the Nong Yao field is the drilling of well A into C sandstone reservoir. Well A was a horizontal development well to optimise the production of the C sandstone reservoir. Figure 2 illustrates that the fault separates the C sandstone reservoir into two sand bodies located in different fault blocks. In the left side fault block, the appraisal well D shows the sand C thickness approximate 20ft TVT. The reservoir has a thin gas interval on top of oil, with a gradational transition from the shale into the clastic reservoir. The gamma ray (GR) reduces from 160 GAPI in the shale to 90 - 110 GAPI in the shaly top, and down to 60 - 80 GAPI in the cleanest part of the sand. Similarly, the resistivity profile is more gradational from 4Ω.m in shale, to 12Ω.m in gas, gradually increasing to between 20 - 40Ω.m in the oil pay. Sand C in well D could only be used as a guide as to what to expect in well A, as there were not any control or pilot wells in the right fault block. Therefore, landing the well was challenging because of the depth uncertainty of the top sand reservoir. Moreover, there was also uncertainty on fluid types and contacts (gas on oil, oil, or oil

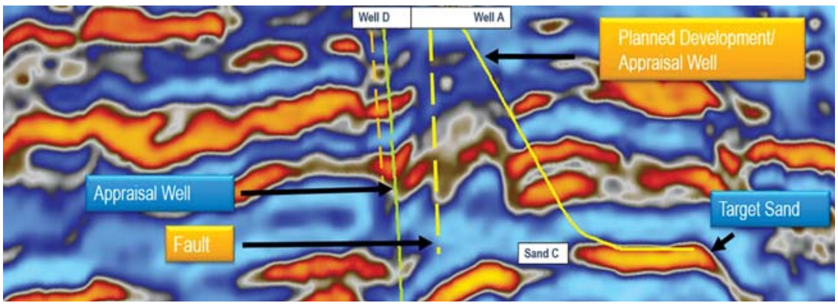

***Figure 2.** Seismic cross section for well A planning*

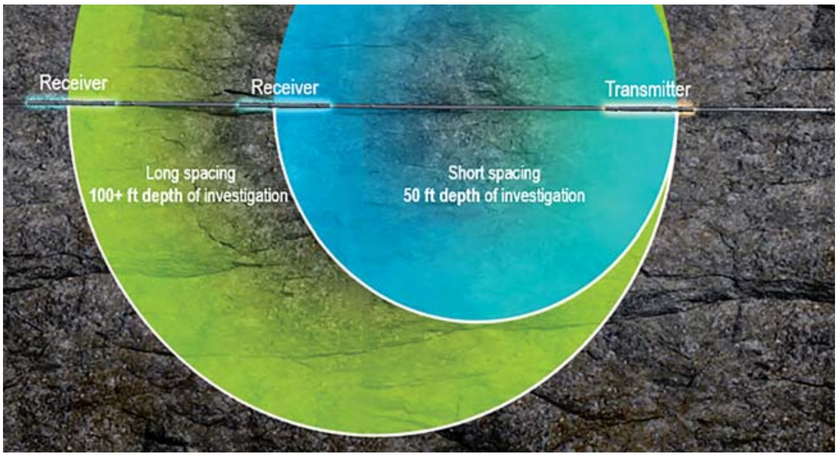

***Figure 3.** Ultra-deep azimuthal resistivity tool's depth of investigation*

on water) that were found in well D but were unknown in well A.

Following traditional development and well placement techniques, it was proposed to drill a separate pilot hole first through sand C in the right fault block in order to understand the structure and contacts inside the reservoir before drilling the development horizontal well A. However, separate pilot holes can be very costly. Understanding the situation, a solution was proposed to use a new well placement technique, utilising new technology in order to accurately land the well in real-time utilising a single well. The technology is a reservoir-mapping-while-drilling tool that uses ultra-deep azimuthal electromagnetic propagation measurements through a complex inversion that can map resistivity contrasts and boundaries in the formation at a distance of up to 100ft TVD. This deep mapping can help to detect boundaries well before the drill bit enters, which enables the depth uncertainty of formation tops to be reduced in real-time to optimise the landing point. In addition, a high build rate hybrid rotary steerable (RSS) tool was chosen to enable swift trajectory changes when required, combined with triple combo integrated logging-while-drilling (LWD) tool, just behind the RSS for differentiation between oil and gas via neutron-density cross over.

Pre-job planning is essential to success and critical to using ultra-deep resistivity tools is to model the inversion result based on the best available data, and the possible scenarios expected. Well A was modelled by using the offset well logs properties (well D) and structure from seismic data. The modelling result showed that the top of the C sandstone reservoir could be mapped at approximately 40ft TVD below the well trajectory when the well approaches the top C at 83 - 84deg inclination, based on the expected resistivity contrast between shale and reservoir. It is equivalent to 300 - 350ft MD before hitting the top C target. By mapping the top C in advance, it gave the team adequate time to revise the well plan and land in the updated top C target. The landing of well A was executed successfully. Ultra-deep azimuthal resistivity inversion mapped the top C sandstone reservoir at 7XXXft MD/2XXXft TVD, approximately 45ft TVD below the well path. The top sand was 20ft TVD deeper than the prognosed top based on seismic. The detection range was 5ft TVD greater compared with pre-job modelling. Finally, well A was landed successfully inside the C sandstone reservoir as desired.

In addition, the reservoir mapping while drilling also detected the lower boundary of the sand, which was then used to provide the thickness of the pay interval in real-time. This could quickly be used to perform volumetric calculations, to help determine well economics and enhance decision making, in real-time, which could not be achieved with seismic and traditional LWD alone.

The second case study is the horizontal well A1 drilling into reservoir C1. The sand C1 reservoir is thin (approximately 8 - 10ft TVT) and has low resistivity contrast with surrounding shaly sand. Figure 5 illustrates the resistivity and GR profile of the sand C1 reservoir. There is a low contrast between the shale resistivity and sand resistivity (shaly sand is 6 - 8Ω.m and sand is 9 - 12Ω.m) thus it is easy to place the well into the shaly sand layer instead of good sand layer. A deep azimuthal resistivity tool with distance to boundary mapping was proposed for horizontal geo-steering in order to stay in the reservoir as much as possible. Pre-job modelling was performed before each horizontal well to confirm that the boundaries could be mapped even in challenging low contrast conditions. A real-time inversion provided valued information of the boundary distance to the well bore and we can geo-steer the well confidently and precisely.

The distance-to-boundary inversion was used for the entire horizontal interval of well A1. It mapped the upper boundary for the first half of the horizontal section approximately 3 - 5ft TVD above the well path and the well was precisely placed under the top. For the second half of the horizontal section, it mapped the reservoir profile clearly with the shale and shaly sand layer. The sand quality changed, approximately two-thirds along the horizontal and the well penetrated the shaly sand layers and followed the shale boundary. Finally, well A1 was placed close to the top of the reservoir as desired. Without the "distance-to-boundary mapping" tool, there would not be a clear reference point to geo-steer and steering would be reliant on seismic data and basic real-time data. If so, well A1 would not be placed precisely within 3 - 5ft of the top of the structure. The result would be early water breakthrough and less oil production, which clearly shows the benefit of using distance-to-boundary technology to optimally place the horizontal well. Applying the same methodology, all the horizontal wells for Nong Yao development were placed successfully by using distance-to-boundary

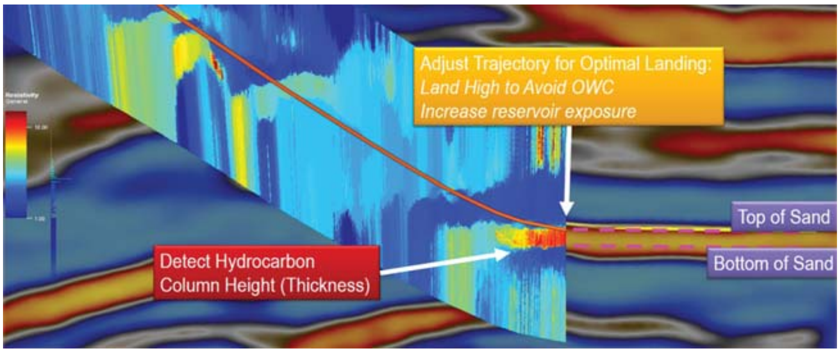

***Figure 4.** Ultra-deep azimuthal resistivity inversion mapped the top of sand C reservoir when landing well A*

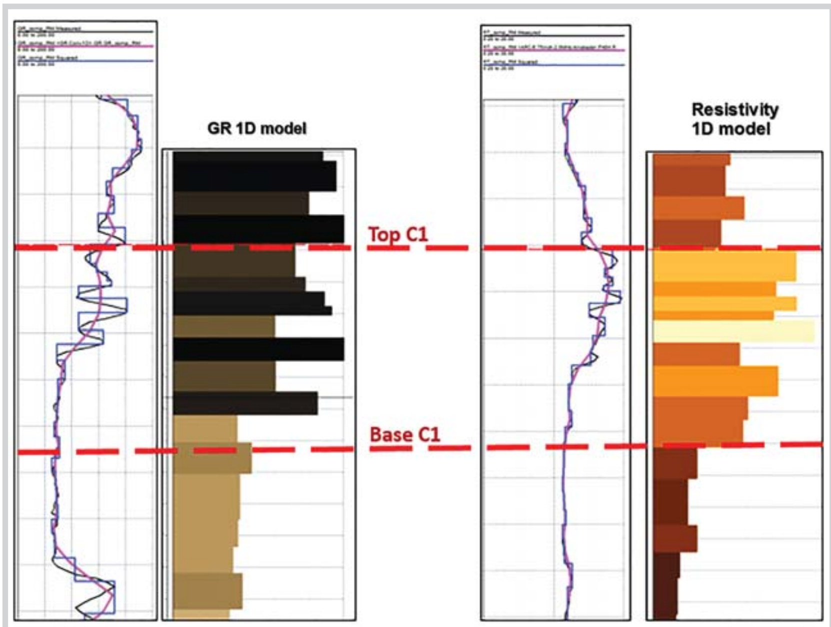

***Figure 5.** Offset well log properties*

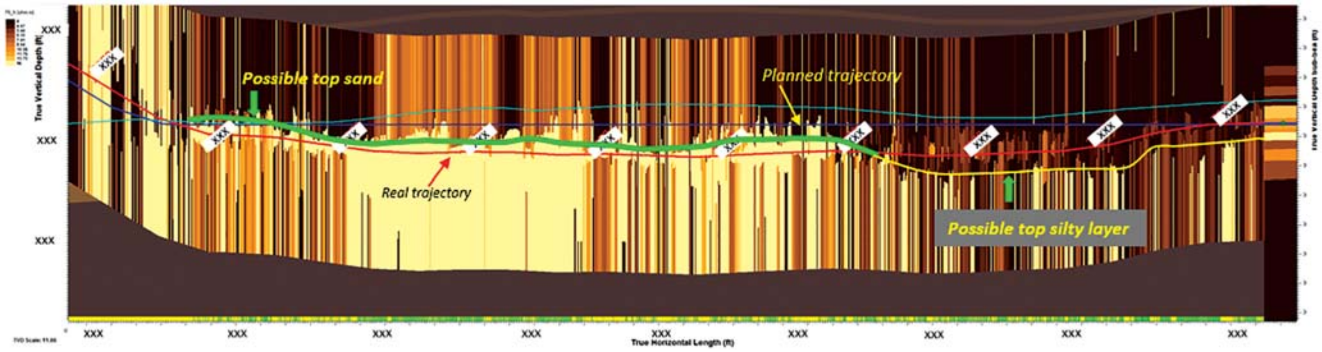

Figure 6. *Horizontal section of well A1*

mapping for optimising horizontal well position and improving the production.

The well A case shows that innovative use of ultra-deep azimuthal resistivity combined with LWD near-bit triple combo enabled Mubadala Petroleum to save the cost of a separate appraisal well. Key LWD data was used to make real-time decisions, changing the well path and landing point and reducing the structural and volumetric uncertainty. While the well A1 case shows that the right selection of technology will help to optimally drill and place horizontal wells to optimise the production and the well lifetime. For the whole Nong Yao development project, this methodology in overall reduced 25% development or drilling costs while developing additional resources, and achieving target production:

Appraisal while drilling optimised well locations, leading to cancellation of multiple water injection not required, resulting in substantial well cost savings;

Distance-to-boundary LWD geo-steered wells in sands and also mapped top and extent of structures, improving volumes and drainage areas;

Ultra-deep azimuthal resistivity, the first use of the technology in Thailand, with LWD triple combo enabled reservoir mapping and the elimination of a separate pilot well.

Conclusions

The Nong Yao development methodology and well placement techniques provide a model strategy for how development can be approached in order to reduce overall development costs, in turn making reservoirs more viable to develop. The integrated approach to the use of technology, planning techniques and well placement techniques in challenging environments sets a benchmark for clastic reservoir development in the Gulf of Thailand. The value and impact to Thailand's Oil and Gas Industry is significant, as it has the potential to unlock more reservoirs in the Gulf of Thailand for development in the current cost pressure and oil price environment.

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