Post-Drill Pore Pressure Study for Infill Well Design to Uncover Deep Gas Potential Left Behind Primary Drilling Campaign (Gulf of Thailand)*

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Abstract

The area of study is located in the southwest of the Pattani Basin, characterized by complex structural trend of multiple North-South trending graben systems. Highly faulted and stratigraphically complex reservoirs in this area are commonly overpressured and can exhibit significant differences in formation pressure gradients between the shallow and deep formations, adjacent fault blocks, and over some distances within individual fault blocks.

The new platform wells were planned along several normal fault trends, 500 m – 4500 m from the existing wells. The drilling program was divided in two batches. Project pore pressure profiles were generally defined by fault block using formation tests from the nearest platform to the north.

First several wells drilled during the campaign encountered well control events due to high formation pressures, resulting in shorter TDs and considerable NPT. New formation tests indicated that some intervals had pore pressures more than 1.5 ppg EMW higher than predicted, leading to underbalanced drilling. Pore pressure regimes appear to change over a distance of 1-1.5 km along delineated fault blocks within previously tested stratigraphic intervals.

Starting from the first well control event the project team had to make changes to the drilling order strategy, selecting less risky wells to acquire maximum data for the rest of the program. Acquired data revealed considerably higher magnitude of overpressure and its steeper ramp, which led to change all pre-drilled pore pressure profiles after the five first wells were drilled.

Early investigation identified that elevated structure away from the offset platform acts as a considerable size gas trap with potential pressure communication across the faults. Pre-drill pressure profiles show clear difference between the fault blocks; however, in this area normal faults

make a complex East-West dipping fault junction and pressure trends become less predictable. Although the team expected and accounted for this communication, it was eventually observed at a wider area, extended to shallower stratigraphic intervals, and with higher overpressure.

Most of the new wells showed higher pay counts, so it was important to adequately revisit pore pressures to ensure further wells can cover the pay window, but on-the-fly analysis and measures taken could not mitigate the risk for all the wells. Further well control events led to shortening TDs and deferring a number of wells to future infill campaign, because pore pressures encountered exceed the standard well design limit. Subsurface and economic analysis indicate feasibility of deferring high-risk wells to 4-string design infill drilling project, so it becomes critical to understand and predict pore pressure in the well control areas and adequately design 4-string wells.

Post-drill analysis included a number of general aspects: a) study area expansion, including RFT and mud weight data from a number of other platforms located on the same structural trend; b) seismic well tie and velocity model update; c) structure maps updated using all the new wells' information; d) detailed log correlation and determining main overpressure stratigraphic intervals/depths; and e) shared pay analysis which helps understand how much connectivity can be expected between the drilled wells.

The next key step of the study was to establish reliable correlation between known formation pressures with seismic velocities and well logs and attempt to make predictions for the undrilled sections. Interesting results were obtained by estimation of pore pressure from resistivity logs in wells drilled in this part of the field. Pressures estimated from resistivity were calibrated with formation pressure tests, kick pressures, and mud weights as appropriate. All wells used the same Eaton coefficient to estimate the pore pressure, and similar normal compaction trends.

Results show that the shale pressures line up closely with most of the kick pressures measured during the well control events. The majority of the pay sands in the field have lower pressures compared to the shales due to obviously better rock properties and lateral/vertical pressure release at faults. Sands which retained higher pressures are assumed to be less extensive, effectively sealed, and therefore have less chance to release pressure. Those observations indicate that although most of the pay zones in this area are traditionally less overpressured compared to shales, a few sand zones still contain higher pressure similar to that of the shales. So, given very limited data for the deep undrilled sections, shale pore pressure trends predicted from resistivity can provide a proxy for maximum (or most conservative estimate) formation pressure for similar localized sands in future wells.

Pore pressure estimated from seismic velocity does not show any reasonable correlation, which can be an indication of multiple mechanisms of overpressure generation (Figure 1). A number of studies in the area indicate that shales overpressured by disequilibrium compaction essentially exhibit sonic and density as in normally pressured sequences (normal porosity trend), whereas overpressures generated by kerogen-to-gas maturation (fluid expansion mechanism) will show decreasing sonic velocity with increasing overpressure and little density change. Similar relationships were observed within the current study on sonic vs. density and effective stress vs. density plots.

The post-drill study allowed us to make several key observations: a) pore pressures observed during project operations are identified as the highest on the structural trend (Figure 2); b) there is no correlation of PP with seismic velocities; c) kick overpressures correlate with shale PP (Figure 3); d) minimal shared pay between the wells, pay sands are isolated (Figure 4); and e) communication between fault blocks is limited/unclear.

Although the study is not fully complete, it helps establish more clarity on overpressure sources and make proposals for future infill pressure profiles. Given limited data, resistivity derived shale pore pressures can be used as a proxy for highest possible pressure in sands. Deep zones pressure reversal not captured by the shale trend needs to be honored using existing RFT and predicted stratigraphy. It is proposed to acquire bottom hole pressures when perforating deep zones, that likely caused well control events and are missing RFT and integrate gathered data with other nearest platforms located on the same structural trend, applying stratigraphic shift for downdip data.

Selected References

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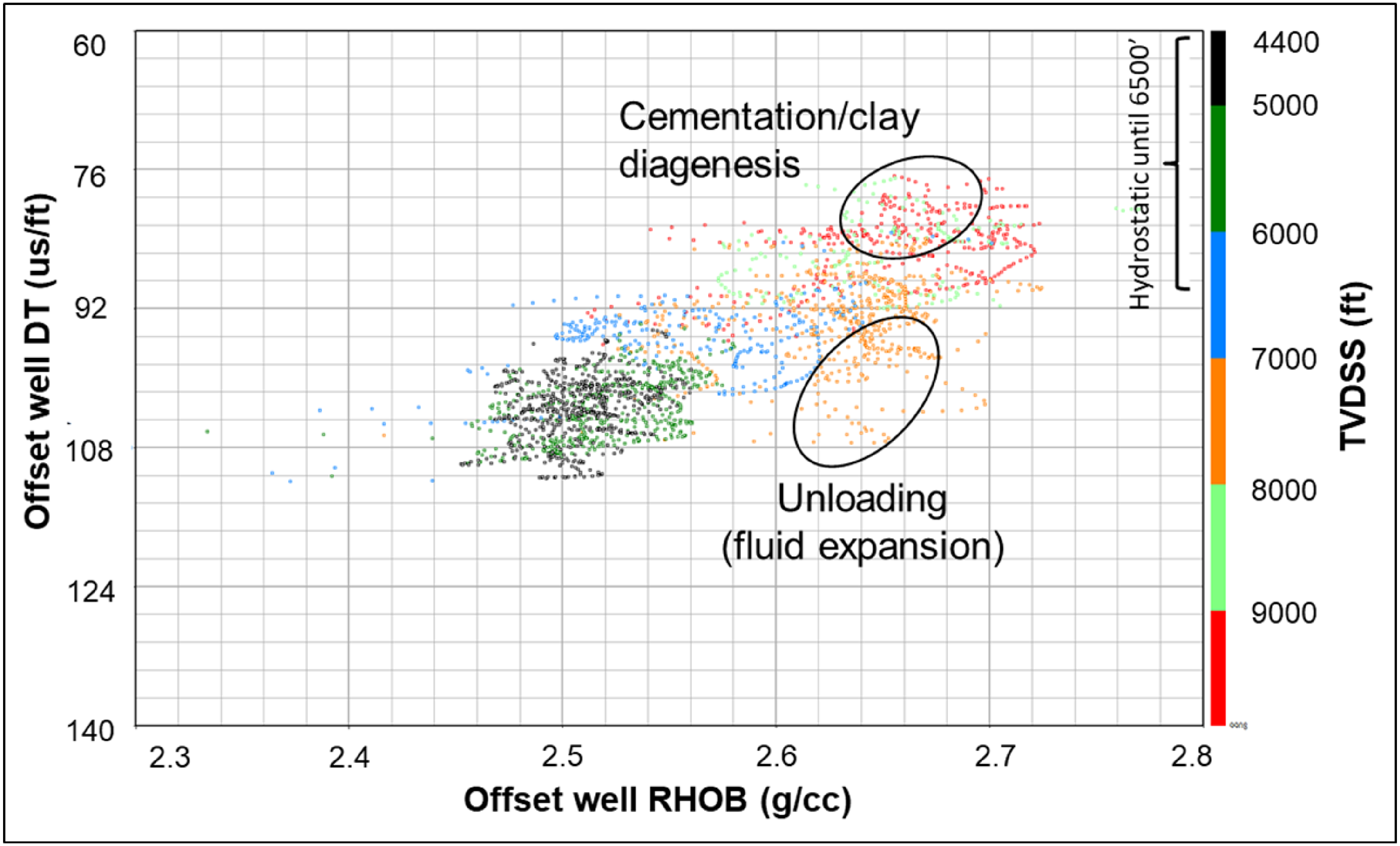

Figure 1. Nearest offset well velocity-density cross plot indicating multiple overpressure mechanisms.

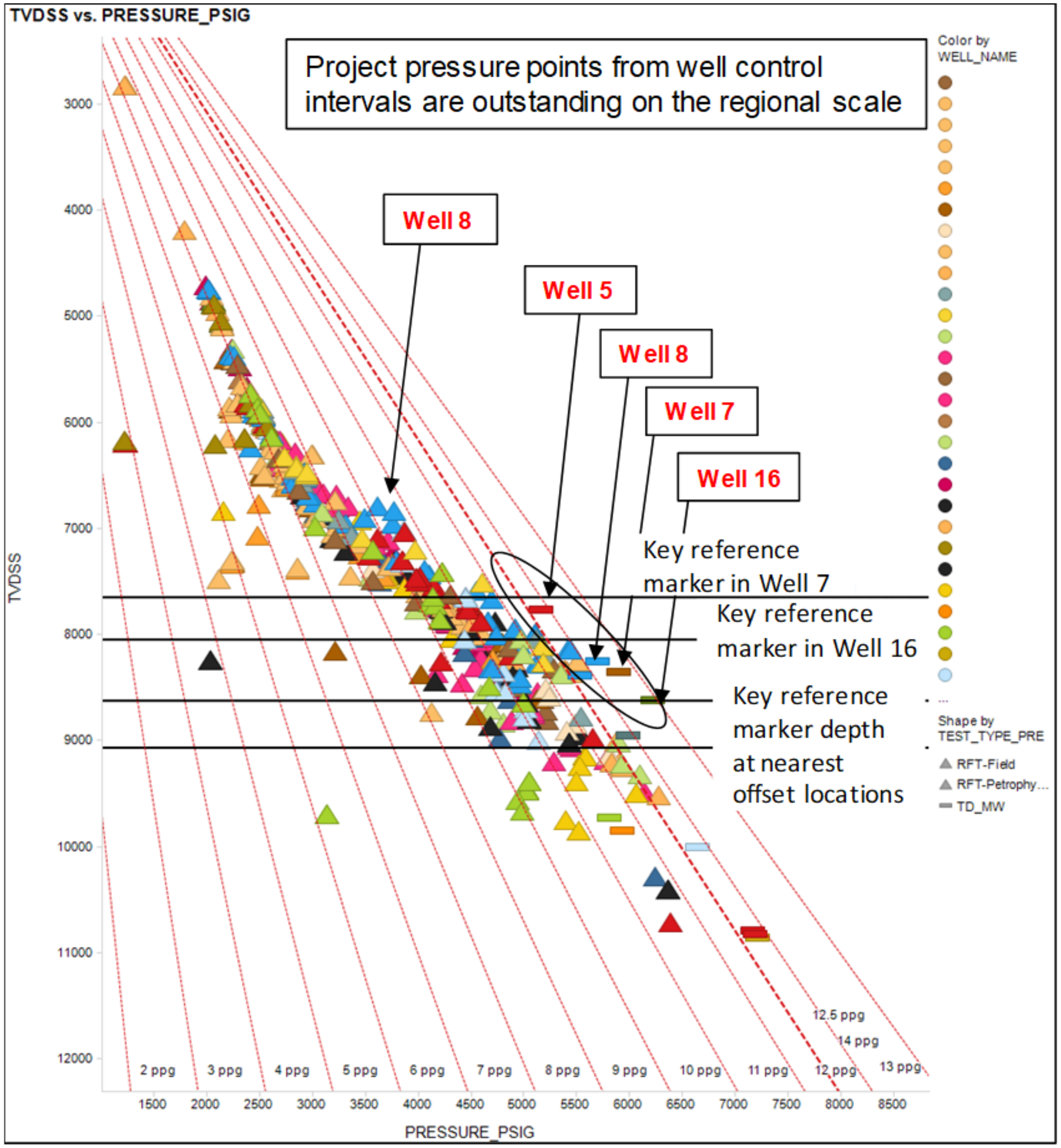

Figure 2. Project RFT data with regional RFT dataset.

- Project pressure points at well control intervals are outstanding on the regional scale.
- Some similarity with nearby trends can be observed, but it is higher.

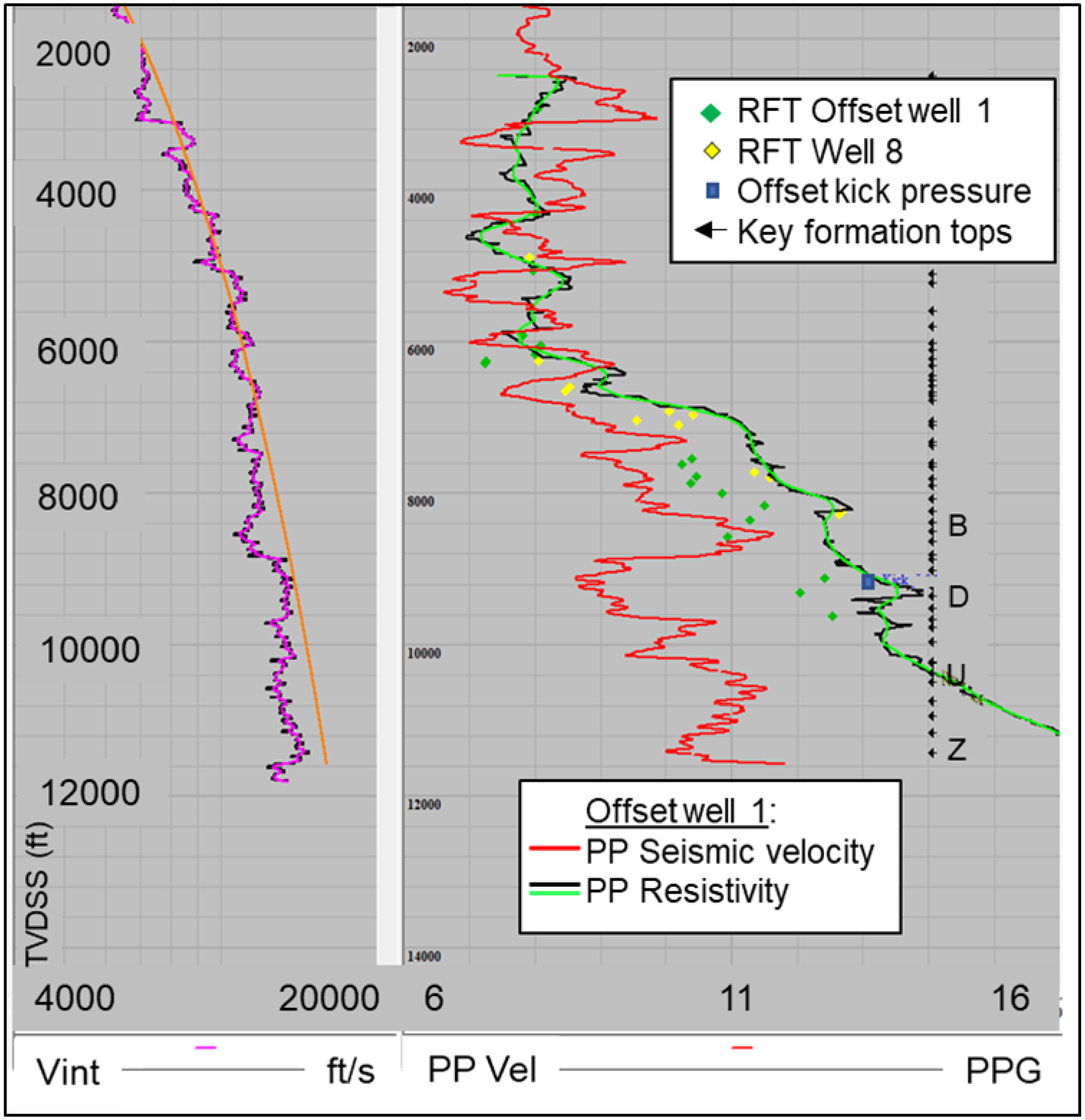

Figure 3. Offset well pore pressure prediction using seismic velocities and resistivity logs compared to RFT data.

- Seismic velocities are under predicted pressure and show considerable variance compared to the RFTs.
- Resistivity PP overpredicted in the deep section.
- Resistivity PP matches the kick pressure from the offset well.

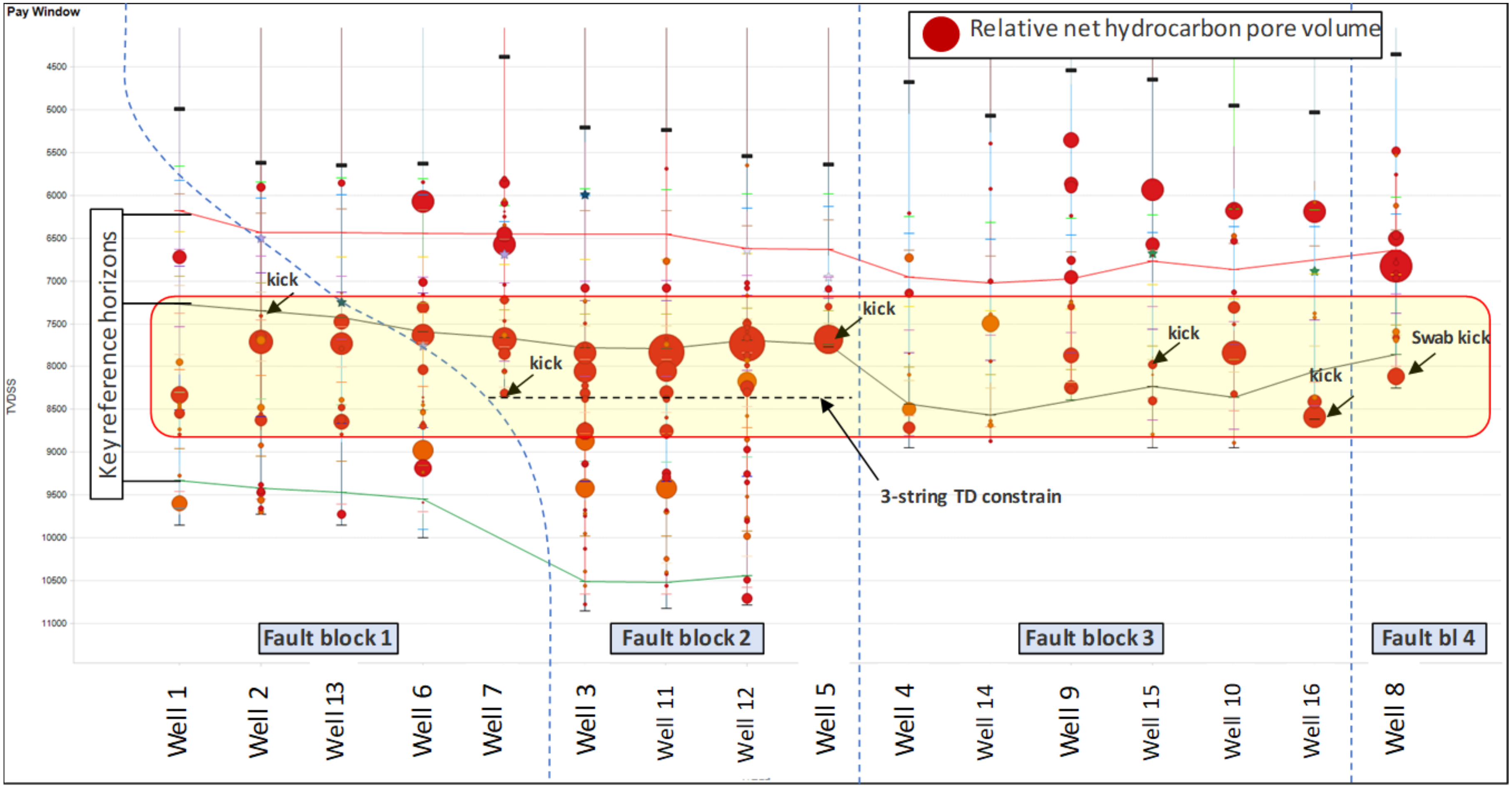

Figure 4. Post-drill pay window with well control events depths.

- Excessively overpressured intervals are observed at a limited depth interval.
- Well 7, 8, and 16 are shortened and overpressured below TD is unknown.