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FROM MULTI-WELL DATA HUBS TO DUAL LAYER DEVELOPMENT PLAN: CASE STUDY FOR SIERRAS BLANCAS AND CRUZ DE LORENA BLOCKS, NEUQUEN BASIN, ARGENTINA

Raul Notta[1], Kristen Boyd[1]

1: Shell, raul-carlos.notta@shell.com, kristen.boyd@shell.com

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RESUMEN

De los centros de datos con pozos múltiples a un plan de desarrollo con dos capas: Caso de estudio en los Bloques de Sierras Blancas y Cruz de Lorena, Cuenca Neuquina, Argentina.

Shell ha estado estudiando el *play* de Vaca Muerta en los bloques de Sierras Blancas y Cruz de Lorena desde el año 2012. Durante ese tiempo, mediante la perforación de 5 pilotos verticales, 9 side tracks horizontales y la implementación de locaciones de pozos múltiples con adquisición multidisciplinaria de datos, se lograron identificar 2 objetivos para la navegación de pozos horizontales que ofrecen las mejores perspectivas para el desarrollo de ambos bloques.

Un factor clave para un desarrollo económico es asegurarse que la interferencia entre pozos sea mínima. El punto fundacional para estudiar esta interferencia fue la primera locación de pozos múltiples del bloque Sierras Blancas, compuesta por un pozo horizontal navegado en cada objetivo, un pozo inclinado que atraviesa toda la formación Vaca Muerta con un ángulo de 3 grados, y un pozo vertical, heredado de un operador previo. En esta locación se llevaron a cabo distintos estudios que incluyeron microsísmica, trazadores no radioactivos de agua y petróleo, perfiles de producción y análisis geoquímicos del petróleo producido. El análisis conjunto de estos datos fue clave para identificar barreras de fractura dentro de los 2 objetivos y determinar las ventanas de navegación optimas, que permitirán acceder la mayor cantidad de hidrocarburos evitando interferencia.

Para extender los resultados anteriores al resto del área, fue necesario subdividir la interpretación estratigráfica en secuencias de cuarto orden, lo que permitió mejorar la interpretación paleoambiental y su relación con el espesor del pay, la heterogeneidad, las barreras de fractura y los sweet spots. Este modelo fue constatado mediante la implementación de estudios geoquímicos del petróleo producido en todos los pozos perforados por Shell desde el inicio de sus operaciones, los cuales permitieron identificar la zona de proveniencia del petróleo en el contexto estratigráfico secuencial mencionado. Estos resultados, al contrastarse con geo-navegación de los pozos horizontales, permitieron derivar el volumen vertical efectivo de roca estimulado y observar la variación en la efectividad de las barreras de fractura con respecto al paleoambiente y a su separación vertical desde el pozo, lo cual es clave para generar un plan de desarrollo conjunto de ambos objetivos sin erosionar valor debido a interferencia vertical entre pozos. Dado que para obtener esta información solo es necesario contar con muestras de petróleo y perfiles de rayos gamma en el pozo horizontal, este método es de gran relevancia ya que puede ser aplicado en cualquier pozo con mínima adquisición de datos y bajo costo.

INTRODUCTION

The Vaca Muerta-Quintuco system is part of the Lower Mendoza Group and represents a rapid and widespread transgression following the deposition of the continental Tordillo Formation (Legarreta and Gulisano, 1989). These time equivalent formations represent different physiographic sectors of the Neuquén basin: Vaca Muerta Formation represents the distal sector (bottomset and foresets) characterized by fine grained sediment; Quintuco Formation represents the proximal sector (topset) and is characterized by coarser-grained sediment with indications of relatively higher-energy currents. Based on regional seismic data, the Vaca Muerta-Quintuco system records a second-order cycle with at least seven third-order transgressive-regressive cycles that deposited in 11 Ma, from mid Tithonian to late Valanginian (Fig. 1). This stratigraphic scheme, adopted by Shell, is consistent with, and complements the work of, Mitchum and Uliana (1985), Reijenstein *et al.* (2014) and finally Dejardins *et al.* (2016). The afore mentioned seven Sequences are then grouped in three Sequence sets (1-3; 4-5; 6-7), based on clinoform geometry, stacking pattern, shelf break trajectory evolution and boundaries, all of which can be related to major events that affected the evolution of the basin (mainly relative sea-level fluctuations). This study focuses on the first 2 3rd order cycles of the first Sequence set (1-3), comprising the Vaca Muerta-Quintuco transition in the Cruz de Lorena (Cdl) and Sierras Blancas (SB) area (Fig. 1), subject of this paper.

This first Sequence set (Seq 1-3), records the first progradation cycle bounded by two major flooding events. Internally it is characterized by a relatively thin transgressive systems tract (TST), composed mainly of bottomsets (Lower Vaca Muerta), followed by a thin progradation event or highstand systems tract (HST) capping Sequence 1. A second, thin, transgressive cycle is recorded at the base of Sequence 2 followed by progradation of several clinoforms included within a HST (Upper Vaca Muerta). Finally, the top of Sequence 2 at CdL/SB area is defined by truncated reflectors and the development of Quintuco's Formation continuous topsets.

Within this context, Vaca Muerta Formation can reach an average of 120m thickness. Around 45m correspond to the homogeneous Sequence 1, whereas the Sequence 2 quickly varies from 30m to 100m depending on its position with respect to the slope. The exploration stage carried out by Shell, from 2012 to 2014, was able to identify 2 landing targets within this interval. However, due to the overall total pay thickness, the successful co-development of both targets requires careful selection of drilling windows in order to avoid vertical interference.

In 2015, the first multi-well pad was executed in SB block with the objective to assess dual layer development. It followed Shell's derisking strategy of collecting extensive selective static and dynamic data in a small area, or data hub, early in the appraisal phase (Notta *et al* 2016; Williams *et al* 2016). The pad included two horizontal wells, landed in the two high porosity/high TOC targets for Sequence 1 and 2, one slant well, traversing the entire Vaca Muerta Formation at a three-degree angle, and one legacy well that served as the pad's pilot. The bulk of the data

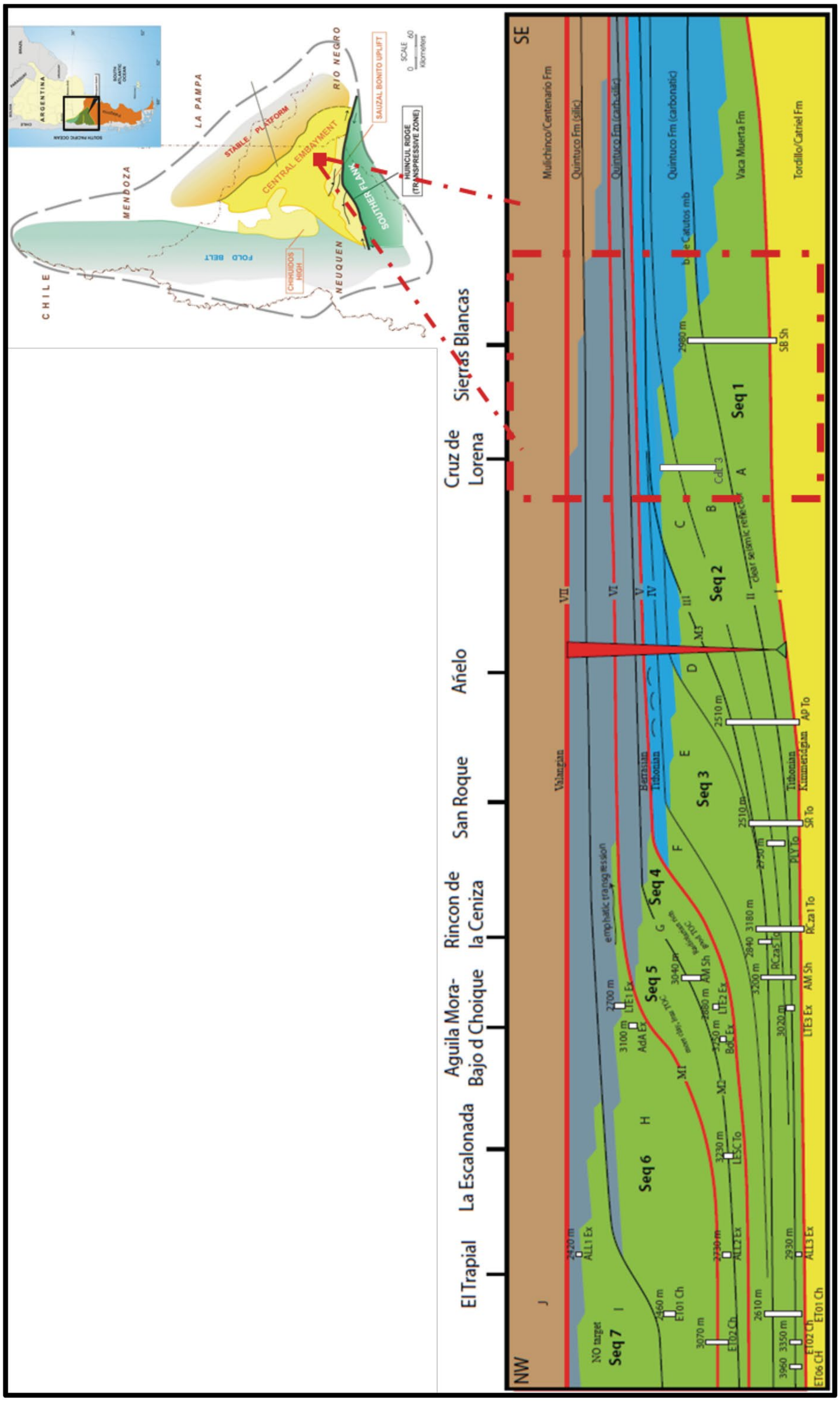

Figure 1. Vaca Muerta – Quintuco system stratigraphic scheme, adopted by Shell (modified from Davogusto *et al*, 2016). Red box highlights CdL and SB blocks position within the scheme.

acquisition took place in the slant well including: a full suite of wireline logs; microseismic, production log (PLT), oil and water based tracers and pressures. As shown in figure 2, PLT data clearly showed most of the production coming from stages at the base of Sequence 2 (overall Sequence 1 also showed good production, but specific stages couldn't e analyzed due to tool failure); microseismic showed a clear frac barrier in between the 2 targets and, finally, regularly sampled oil, tied to the 4th order stratigraphic framework picked on a nearby core by means of geochemical fingerprinting, showed that production from the horizontal wells is constrained to the Sequence they are drilled in.

The combination of this multidisciplinary data suggested the existence of 2 independent landing zones for the study area.

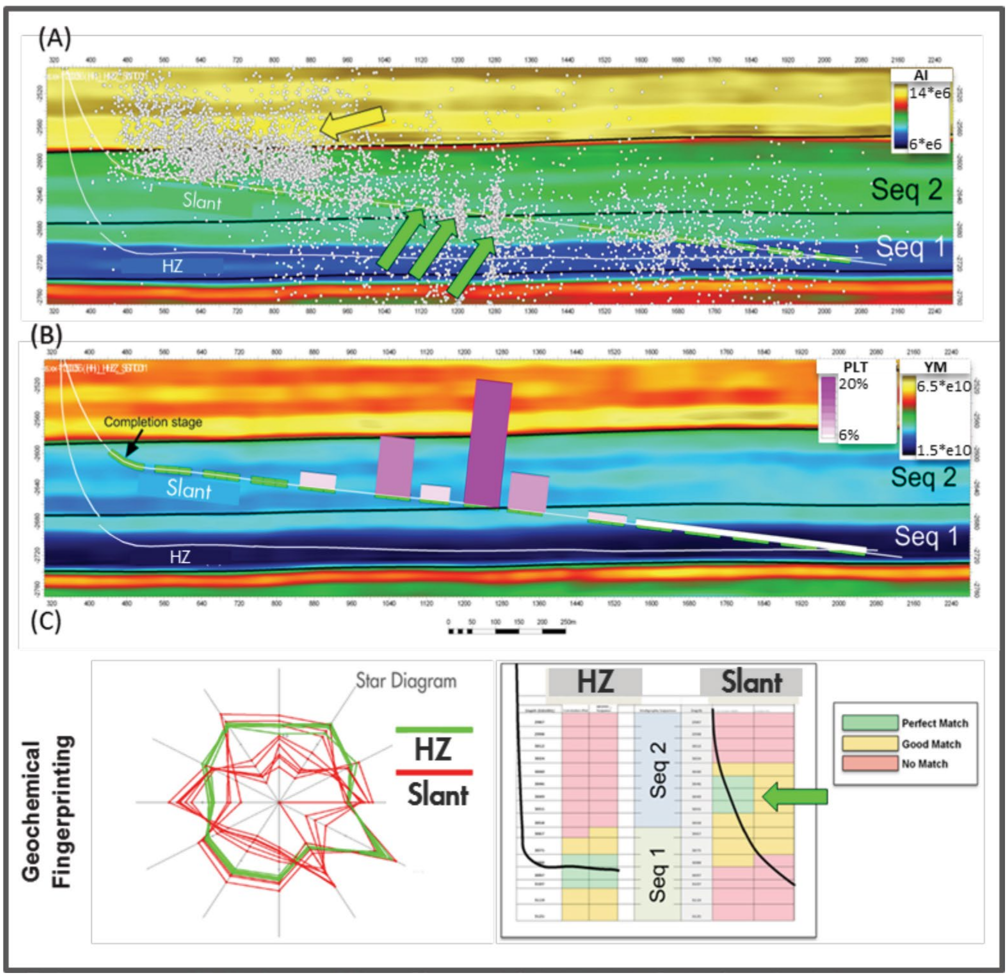

Figure 2. A) N-S cross-section through acoustic impedance (AI) volume with one horizontal well to Sequence 1, one slant well and high-confidence microseismic events. B) N-S cross-section through Young's Modulus (YM) volume with production log data suggesting that the bulk of the production is from Seq. 2. C) Geochemical fingerprinting results from multiple produced oil samples illustrate 2 distinct oil types from Seq. 1 and Seq. 2 (Notta *et al.*, 2016).

METHODOLOGY

In order to expand these results into the rest of the blocks, core data penetrating the entire Vaca Muerta was used to calibrate reservoir properties, such as porosity and TOC, with wireline data. Calibrated wireline was then used as input for seismic inversion, allowing to translate the 4th order stratigraphic framework picked on core into seismic volumes of static properties. These properties were used to model each 4th order Sequence individually, helping to better predict the continuity of reservoir facies, containment and frac barriers and, thus, extend the landing zone workflow away from control points (Davogusto *et al* 2016). This multidisciplinary approach showed that, for SB/CdL area, the best landing targets, and the frac barrier identified on SB multi-well pad, closely follow stratigraphic markers defined for Sequence 1 and 2.

Once the landing targets are selected, and considering vertical variability of the play, a 10m interval around the stratigraphic markers was chosen as a safe geosteering window to develop the play. Our ability to navigate within this interval is of great importance, as every stage completed outside of it can affect the overall production of the well by increasing chances of screen outs, decreasing the effective stimulated rock volume (SRV) or, if deviation is high, increasing the chances of vertical interference, all of which makes it difficult to compare results of different wells and reach conclusion about the efficiency of a given target. However, remaining within a 10m window while drilling 2000 m wells can be difficult as any slight change in layer's inclination can result on strong vertical deviations down the length of the lateral. To account for this issue, Shell decided to implement a 24/7 monitoring of the wells with MWD GR (geosteering) to apply corrections in real time as deviation from the stratigraphic center occurs.

Finally, geochemical fingerprinting was carried out as a standard method. Oil extracts from each 4rd order Sequence were acquired from conventional and side wall cores in different areas of CdL and SB. This allowed Shell to obtain isotopes and biomarkers signatures specific to each of them, which were then compared to the ones observed on regularly sampled oil produced from all wells.

RESULTS

2017 drilling campaign's focused on honoring the 10m window defined for Sequence 1 landing target in different areas of CdL and SB blocks. Thanks to the geosteering strategy we managed to keep 100% of the laterals inside this window and, towards the end of 2017, we were able drill the entire 2000 m within 2m around the center of the modeled target (Fig. 3C). This is of paramount importance as it allows for a high resolution comparison of different wells' production with respect to landing zone and containment.

The oil production from these wells successfully replicated the results observed at the SB multiwell pad location, which brought confidence into the modeled targets away from control

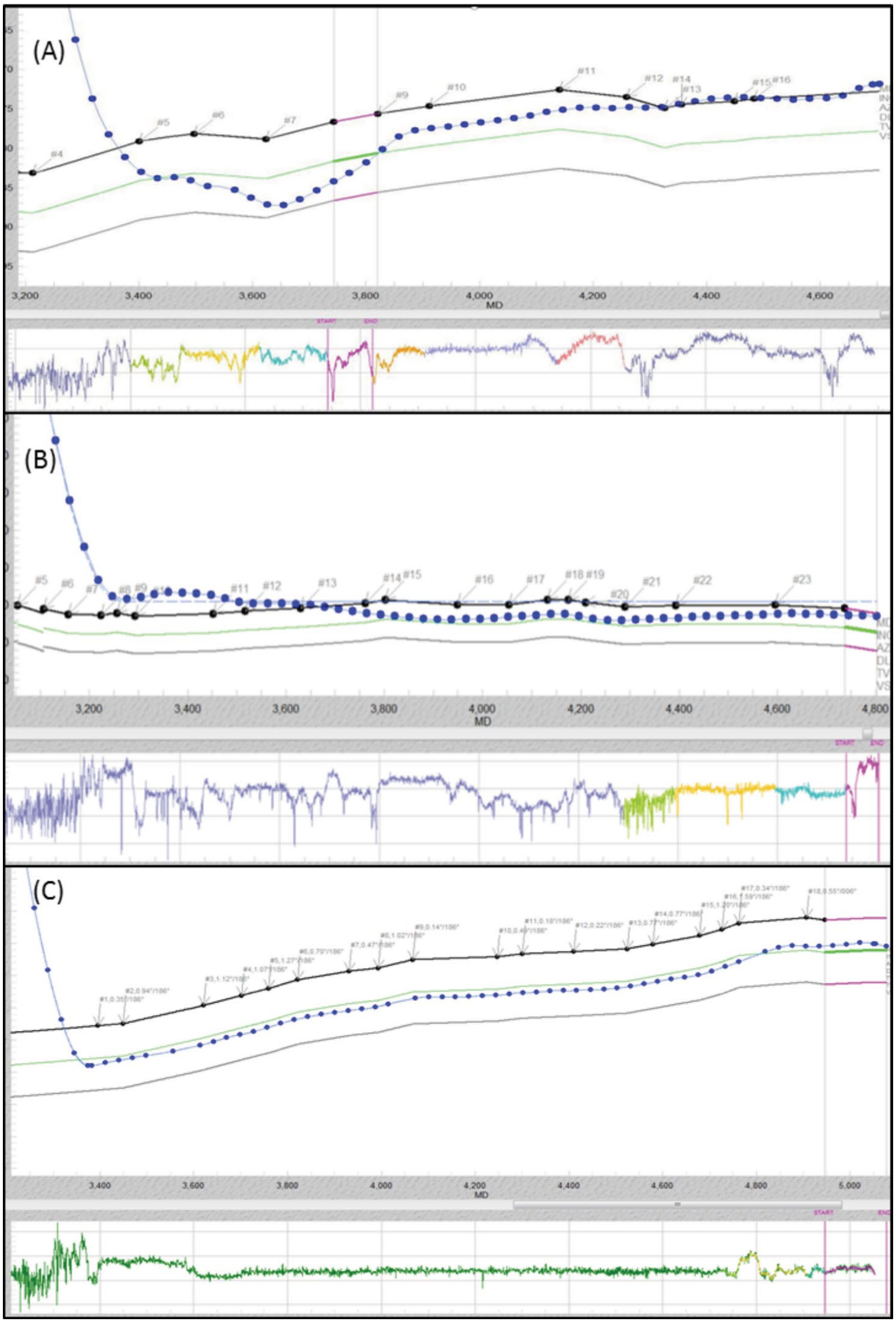

Figure 3. Comparison of well drilled without 24-hour geosteering (A&B) and well with 24-hour geosteering (C). All wells are drilled with a N to S direction, blue dotted line shows actual well trajectory; black lines denote a 10-meter target window and the green line denotes the center of target. Wells without continuous monitoring have more deviation from the target, leading to higher heterogeneity, as shown by the horizontal gamma ray log displayed at the bottom of each picture. This will result in higher uncertainty when qualifying the landing zone impact on production.

points. Also, microseismic, geochemical fingerprinting and geosteering were compared between all producing wells, showing that:

- Biomarkers contribution and microseismic show that the frac barrier efficiency between targets decreases from SE to NW. This is mostly due to the decrease in thickness and heterogeneity resulting from the transition from middle ramp facies, in the SE, to bottomset facies towards the NW.
- However, wells landed entirely inside Sequence 1 10m window (as well C in Fig. 3) show no contribution from Sequence 2 isotopes or biomarkers, even in areas where the frac barrier is thin, whereas the ones landed outside the window and closer to the barrier show contribution from Sequence 2, regardless of the area (wells A & B in Fig. 3).
- Different wells landed within the defined target showed a consistent vertical SRV derived from geochemistry. When tied to the 4th order Sequence stratigraphic framework, this SRV indicates that the entire Sequence 1 reservoir is being contacted by the induced fractures without reaching Sequence 2.
- There are fewer data points for Sequence 2 to this date, however, geochemical and microseismic results from SB area show SRVs growing upward from the frac barrier.
- Finally, geosteering has showed to have a significant impact, not only in oil production but also in the percentage of produced water, as it allows to avoid drilling near low TOC, high carbonate content deposits interfingered within the pay interval. When stimulated, this deposits can deliver wells with low estimated ultimate recovery and waters cuts as high as 45% (Notta *et al*, 2017).

CONCLUSIONS

The synthesis of this multidisciplinary data analysis suggests the existence of 2 independent landing zones for the entire study area. However, it should be noticed that the frac barrier between the 2 targets only behaves as such when the landing window is chosen and followed carefully. When deviation takes the trajectory closer to the barrier, it behaves more and more as a frac buffer which allows part of the SRV to extend into the other target.

The early acquisition of conventional and rotary side wall cores has demonstrated significant value to the long-term study and economic development of the blocks as the oil extracts acquired from them allowed Shell to implement the aforementioned geochemical fingerprinting together with the geosteering strategy as a standard method, with relatively low associated cost. Considering that Vaca Muerta Formation pay interval for the SB and CdL area is relatively thin, and that the frac barrier changes its efficiency depending on its location, the production allocation and SRV determination resulting from this method are key to avoid vertical interference when planning and testing a dual layer development strategy for the blocks.

Future work will include drilling and testing of multi-well pads targeting both objectives simultaneously. Fiber optics and tracers will be used to bring more information to de-risk both horizontal and vertical spacing on a dual-development scenario.

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