LITHOLOGICAL ANALYSIS THROUGH INTEGRATION OF CORE, LOG AND DRILLING DATA LEADS TO IMPROVED STEERING PERFORMANCE IN HORIZONTAL WELLS TARGETING VACA MUERTA FM.

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RESUMEN

El presente trabajo busca identificar la causa detrás de ciertos problemas de navegación comúnmente observados en la perforación de pozos horizontales con objetivo a la Secuencia 1 de la Formación Vaca Muerta; en los bloques Cruz de Lorena, Coirón Amargo Sur Oeste y Sierras Blancas.
En algunos de los pozos estudiados se observaron cambios bruscos en dirección horizontal y/o de inclinación, que no respetaron la trayectoria planificada, lo que resultó en menor tasa de penetración debido a las correcciones que fueron necesarias aplicar, y que se tradujeron en menor eficiencia total de la perforación. No realizar dichos ajustes tendría consecuencias negativas, tales como que el pozo no estaría dentro de la ventana objetivo, lo que a su vez se traduciría en interferencias con pozos vecinos, perjudicando la producción.
Este estudio proporciona una correlación entre los problemas de navegación y ciertas características litológicas y geomecánicas de la formación, establecidas a través del análisis de datos de corona y de perfiles eléctricos. Este flujo de trabajo permite la identificación de litologías que, al ser atravesadas durante la perforación del pozo, pueden generar desviaciones horizontales y de inclinación. Además, tiene como consecuencia una optimización de la zona de aterrizaje y de la ventana de perforación, lo cual podría ayudar a reducir los tiempos operativos. Si bien este análisis puede ser aplicable solo localmente, la metodología expuesta puede ser utilizada en cualquier área dentro de la cuenca, siempre que el operador disponga de suficientes datos de pozo.

INTRODUCTION

Several Vaca Muerta targeted horizontal wells drilled in the Cruz de Lorena, Coiron Amargo Sur Oeste and Sierras Blancas blocks (Figure 1) experimented azimuth swings of the directional tool in undesirable direction. If the push is big enough, the well can leave the pre-defined lateral window parameters resulting in detrimental effects on production because of interference with neighboring producers. Another commonly observed issue is the difficulty to correct the vertical placing of the well when going through certain layers, commonly attributed to the “hardness” of the rock above, or below the current level being drilled. Both effects affect the optimization of the drilling operation because of the time required to correct the trajectory.

The objective of this paper is to show that both problems are related to lithological heterogeneity inside the target vertical window, with some layers, mainly tuff and limestones with concretions, that seems to be more prone to causing these drilling issues, as opposed to the marl levels, which are typically drilled much more efficiently.

In order to arrive to such a conclusion, a detailed analysis was carried out on multiple pads within the Cruz de Lorena, Coiron Amargo Sur Oeste and Sierras Blancas blocks, linking different Gamma Ray log responses to problematic drilling zones, and correlating these responses to lithologies via core data of the target zone. The information was linked to geomechanical analyses that showed the different characteristics of these levels that highlighted the contrast between lithologies.

With that information at hand, a "traffic light" classification was performed of the vertical window levels, which is currently being used by the Geosteering team to target certain lithologies and to help avoid undesirable outcomes.

Future geomechanical work will be needed to properly explain the effect on the bit that causes the deviations.

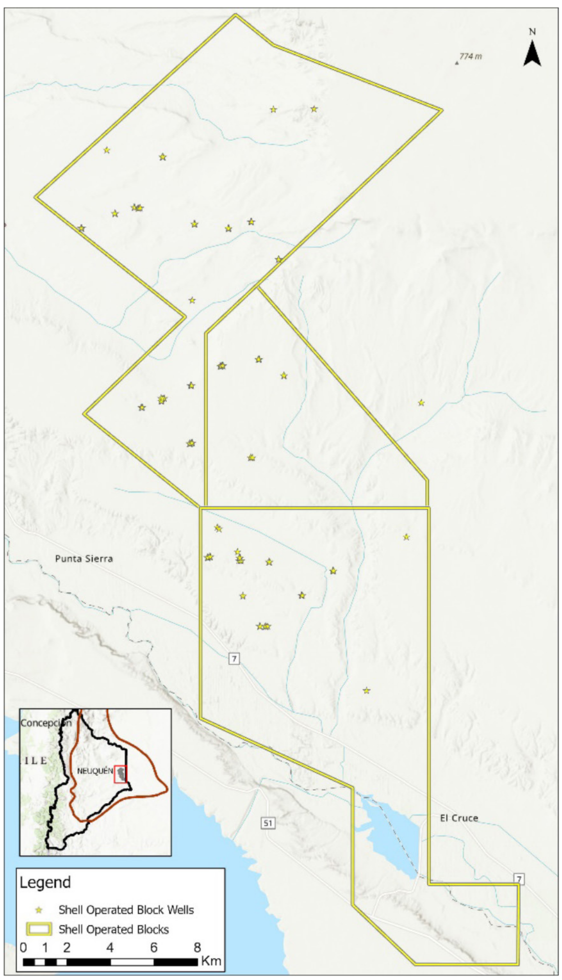


Figure 1. Location map including Cruz de Lorena, Coiron Amargo Sur Oeste and Sierras Blancas blocks, where the work was performed.

PROBLEM DESCRIPTION

Figure 2 illustrates PAD 1, composed of 4 wells (A, B, C and D). All wells were drilled in the same direction and targeted the same interval. Well C had directional tool steering problems, as the tortuosity of the trajectory suggests, but on the other wells the tool worked properly. Wells B and D were not as impacted by the same trajectory issues observed on Well C, and Well A showed an almost perfectly straight trajectory.

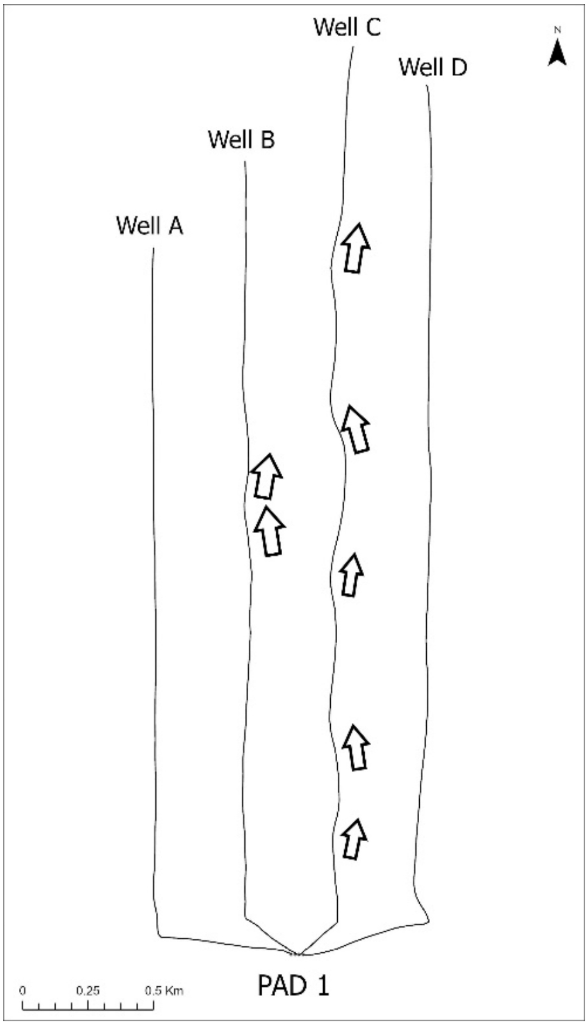


Figure 2. A top view of PAD 1, composed of 4 well (A, B, C and D) showing the azimuth swing (arrows) along wells B and C.

In summary, on PAD 1, one well faced very hard azimuth swings that needed important corrections, resulting in high tortuosity which can be observed in Figure 1 (Well C), and on the other end of the spectrum, is a well drilled following almost perfectly the planned trajectory and without issues (Well A) (Figure 3). The remaining two wells being in the middle of the spectrum. Well C's trajectory could easily be dismissed as a result of the directional tool not working properly.

However, upon closer inspection of the Geosteering model, it becomes clear that the well was also drifting within the vertical window. It can be assumed then, that the directional tool failure was making the well more susceptible to the swings.

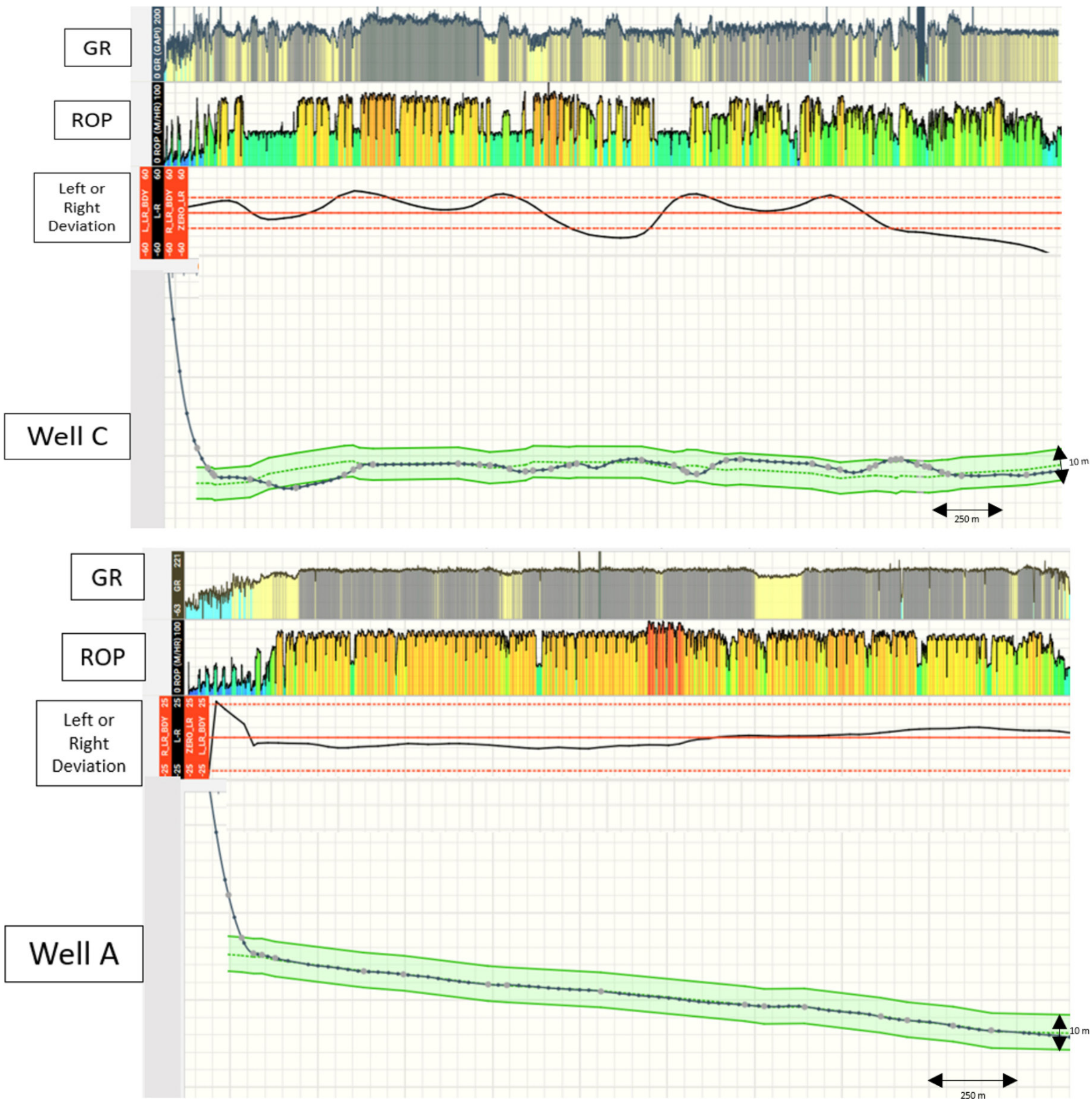


Figure 3. Geosteering models for wells C (Top) and A (bottom). The vertical placing of Well C varies greatly along the trajectory, while Well A's was at the center of the window the entire lateral.

PAD 2 (Figure 4), composed of wells E, F, G and H, also has a good spectrum of results. Like PAD 1, the wells are all targeting the same level and drilling in the same direction, and some had more trouble than other staying inside the lateral window, with the most notable being Well E. The difference with the previous example is that in PAD 2 the tools were working properly, so the tortuosity in well trajectory is a direct cause of drilling issues.

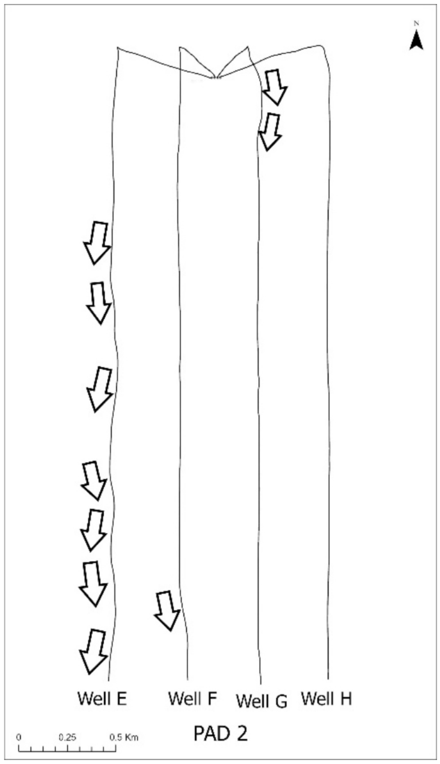
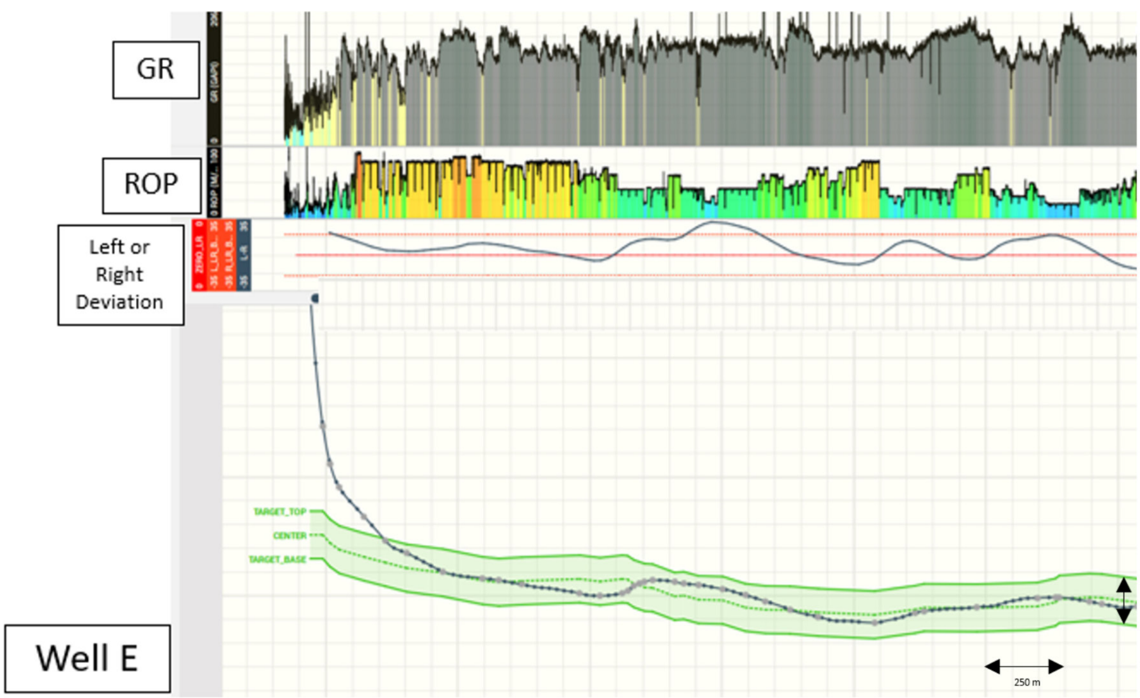


Figure 4. Top view of PAD 2, composed of 4 well (E, F, G and H) showing the azimuth swing (arrows) along wells E, F and G.

Like Well C, Well E's trajectory is not only changing in the horizontal but also within the vertical section (Figure 5). On the other hand, Well H has almost no issue staying in both targets (except for the last few meters of lateral on which the directional tool reported a failure).



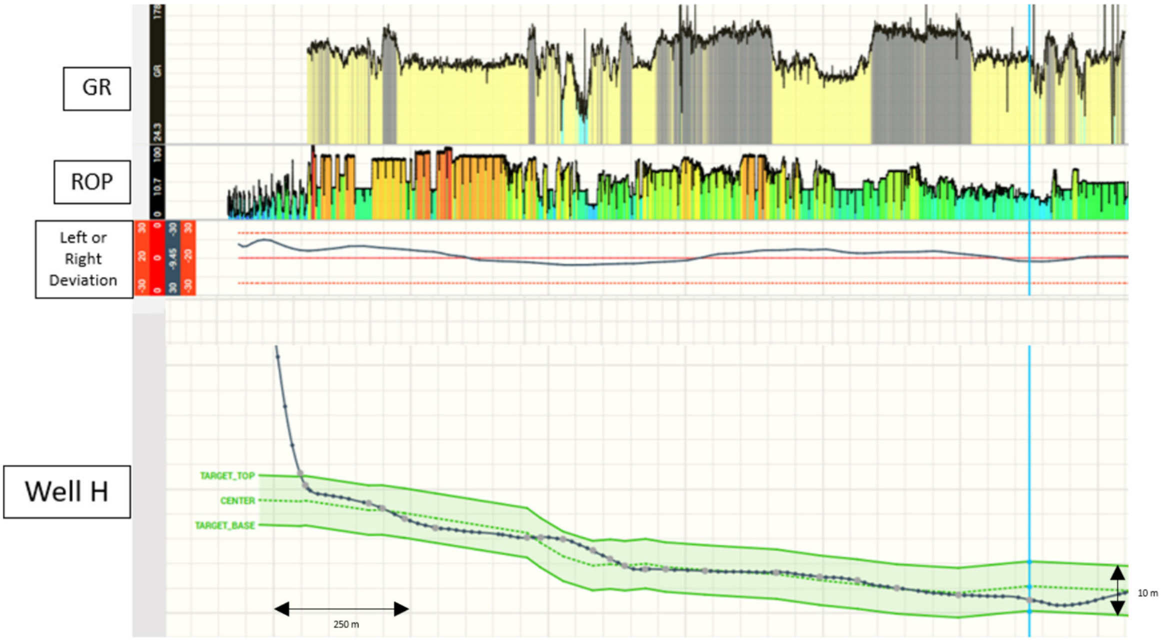


Figure 5. Geosteering models for wells E (Top) and H (Bottom). The vertical placing of Well E varies greatly along the trajectory, while Well H was closer to the center of the window along the entire lateral.

PAD 3 (Figure 6) had a different behavior than the other two. The wells were perfectly drilled inside both lateral and vertical windows.

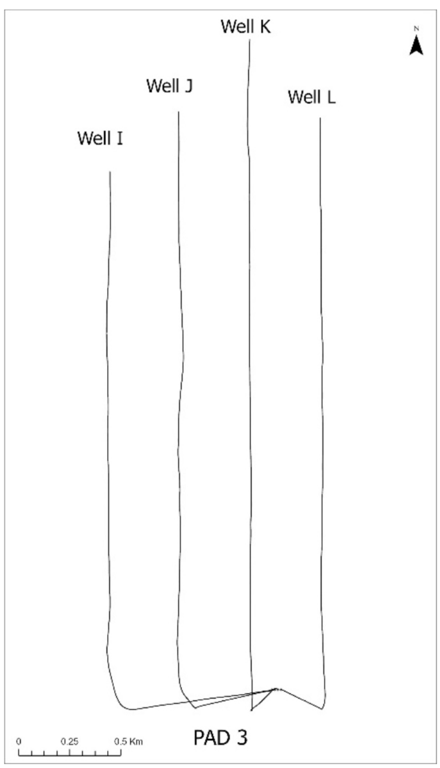


Figure 6. A top view of PAD 3, composed of 4 well (I, J, K and L).

METHODOLOGY

To identify the main cause of the observed vertical and horizontal trajectory deviations, a detailed analysis was conducted with the Geosteering and Directional teams. The outcome of this analysis was the identification of certain gamma ray log responses that were prone to azimuth swings.

The identified levels are shown in Figure 7 with blue arrows. There were also mentions of gamma ray responses tied to very good ROP's, and very responsive to adjustments in trajectory. Those are shown with green arrows. It is easy to conclude that the more problematic levels are characterized by low value gamma ray responses, while the zones drilled with fewer issues correspond to high gamma ray zones. To help with the identification, the blue arrows were named from top to bottom as Low Gamma Ray (LGR) 1, 2, 3, 4 and 5, and the High Gamma Ray (HGR) levels as 1 and 2.

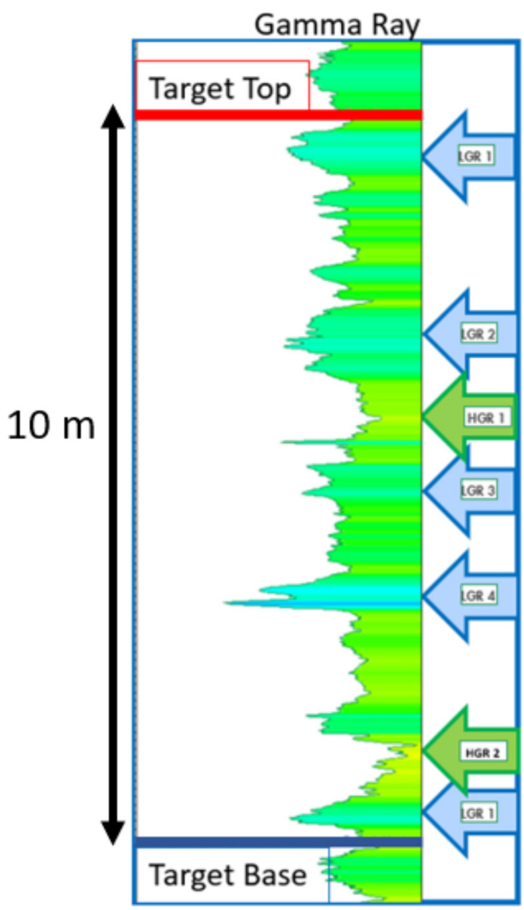


Figure 7. Type correlation log of the 10 m window utilized for Geosteering showing the Gamma Ray log response of the identified harmful levels (LGR) and the helpful ones (HGR) on blue and green arrows respectively.

In order to identify the lithologies causing the problems a correlation between the log response of the target window and a core obtained from a pilot well was conducted. On Figure 8 the amount of lithological variation inside the window can be observed, with marl, calcareous mudstone, limestone, and tuff present.

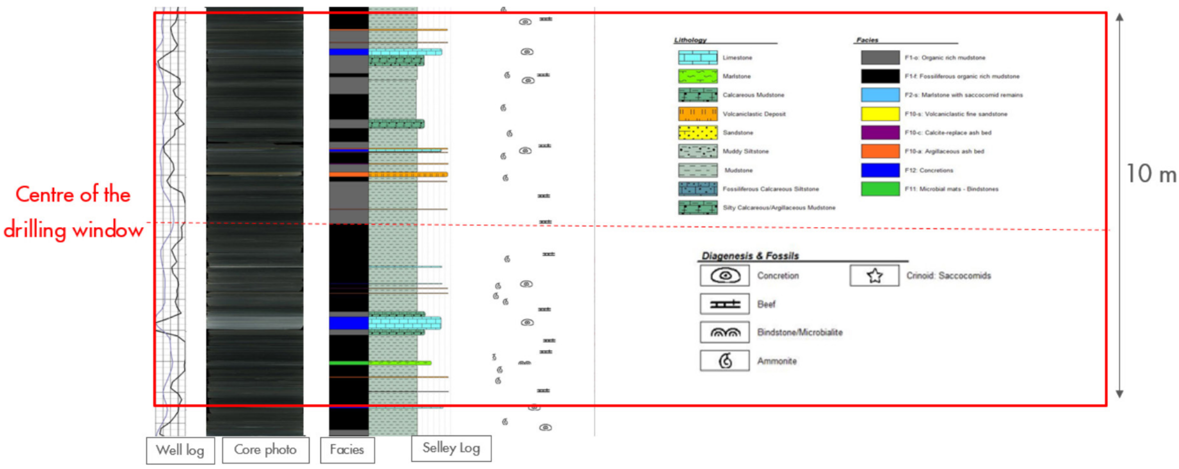


Figure 8. Core description showing the lithology, Selley log, picture scan annotations and facies of the 10 m window utilized to drill the horizontal wells analyzed on this paper.

Figure 9 shows that the Low Gamma Ray levels 1 through 5 correlates to either limestones or tuff levels. Also, the limestone layers have concretions. These concretions, because of their genesis, tend to align themselves with layers rich in carbonate, which can have a big impact on the bit during drilling because of the alternation between harder and softer lithologies, and especially when drilling through a layer with a high concentration of these features, or very close to it.

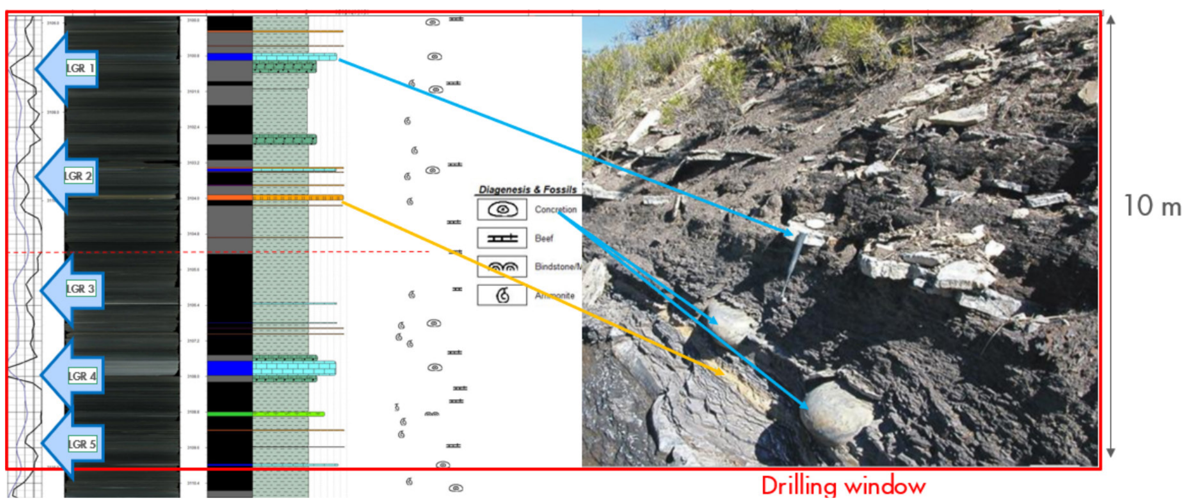


Figure 9. Core description showing the interpreted lithology, Selley log, picture scan annotations and facies of the 10 m window utilized to drill the horizontal wells analyzed on this paper, with blue arrows indication the 5 Low Gamma Ray (LGR) zones that cause problems, with an outcrop picture (not to scale) showing the distribution of concretions, tuff levels, and limestones.

On the other hand, the High Gamma Ray (HGR) levels 1 and 2, are mainly composed of clean marl (Figure 10) which helps explain why these zones are easier to drill. Another hypothesis can be made about well placement in HGR zones: since both HGR zones (1 and 2) are located between "harder" layers, it could be inferred that the bit tends to stay inside this zone "bouncing" back and forth between the upper and lower LGR zones, which could help maintain the direction of the tools.

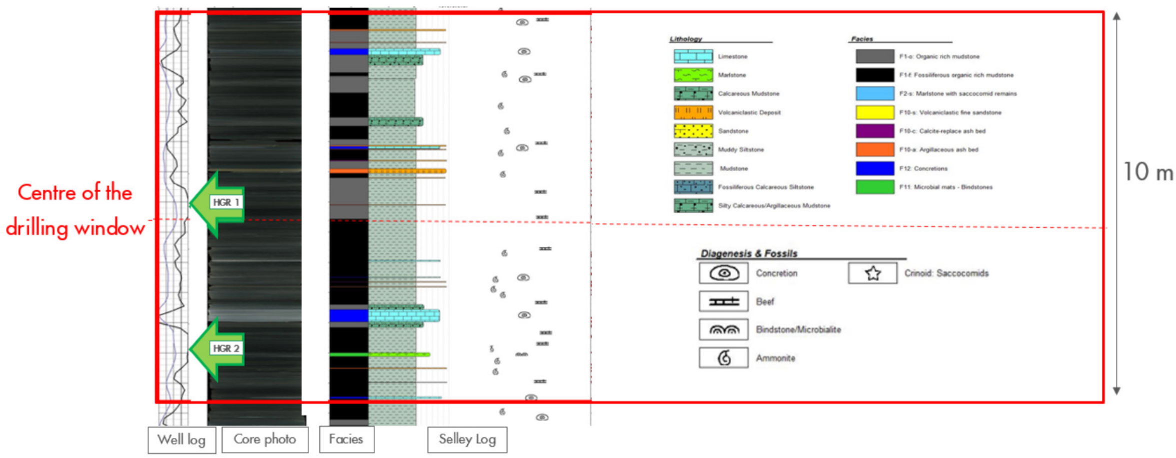


Figure 10. Core description showing the lithology, Selley log, picture scan annotations and facies of the 10 m window utilized to drill the horizontal wells analyzed on this paper, with green arrows indication the 2 High Gamma Ray (HGR) zones benign to drilling operations.

A simple geomechanical analysis, shown in Figure 11 also highlights the contrast in Young's Modulus, Poisson's Ratio and HOOP stress between the rest of the window and the LGR zones. This contrast could be enough to cause the deviations observed, and the difficulty to go through some of these levels.

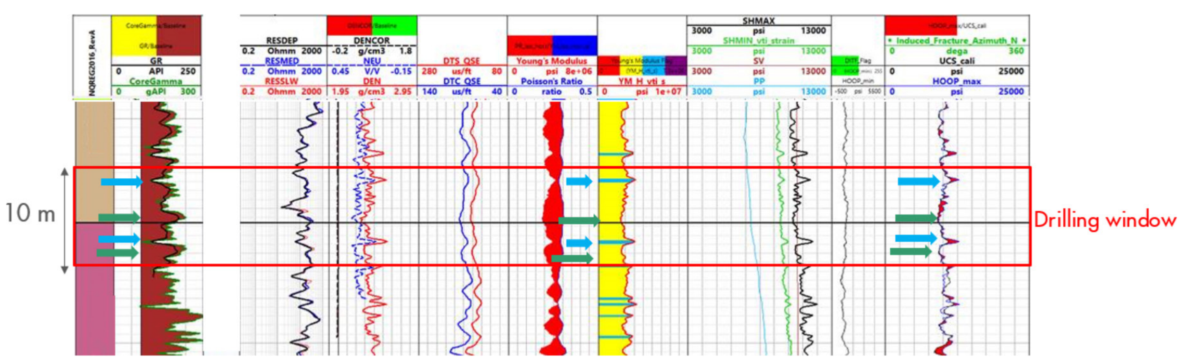


Figure 11. Geomechanical interpretation of the 10 m drilling window with different properties including Young's Module, Poisson´s Ratio, and Hoop Stress. The green and blue arrows show the positions of LGR and HGR levels. Note the variations over these levels on the formerly described geomechanical parameters.

Going back to the examples shown in the previous section, a new interpretation was undertaken over the original geosteering model, with the intent of projecting the Low Gamma Ray (LGR) levels along the wellbore, and see if they matched the lateral deviations observed, starting with Well C from PAD 1 Figure 12. The image correlates changes on the vertical positioning of the well with azimuth swings. Although the "cause and effect" aspect is not immediately obvious (mostly related to the tool malfunctions), the link between the LGR layers and lateral swings can be observed. The strongest swings seem to be tied to LGR 4 and LGR 1 layers (located a couple of meters from the top and the base of the window, respectively).

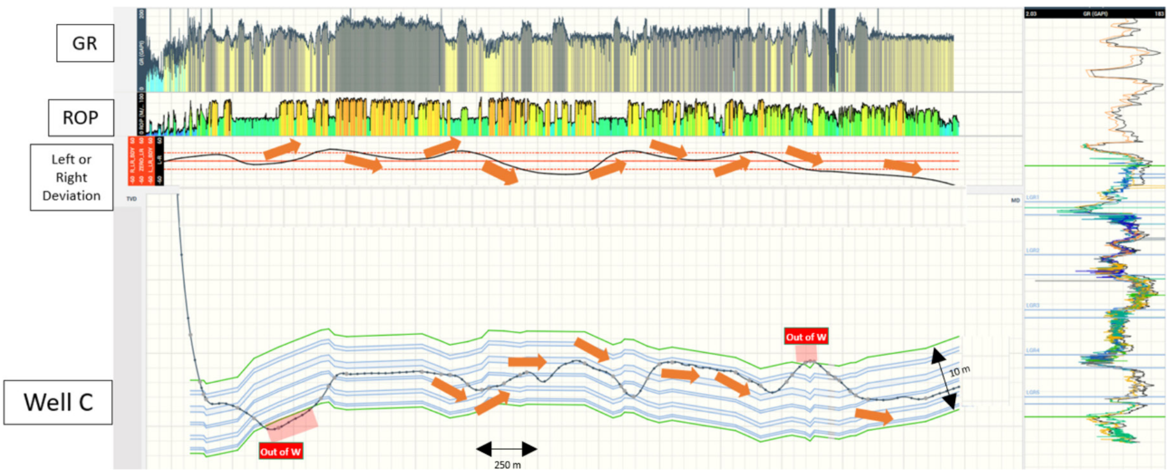


Figure 12. New geosteering model of Well C, from PAD 1, highlighting the position of the LGR layers along the trajectory. The track on the tops shows the left and right variation of the lateral window, the track on the right is a correlation log. The orange arrows indicate abrupt changes both in vertical positioning, and in lateral one. Note the strong correlation of both changes when the well gets close to LGR levels.

Well E, from Pad 2, (Figure 13), also had similar issues staying within the lateral window, and, because there are fewer vertical changes in position than in Well C, the link between the azimuth pushes and the LGR zones becomes clearer.

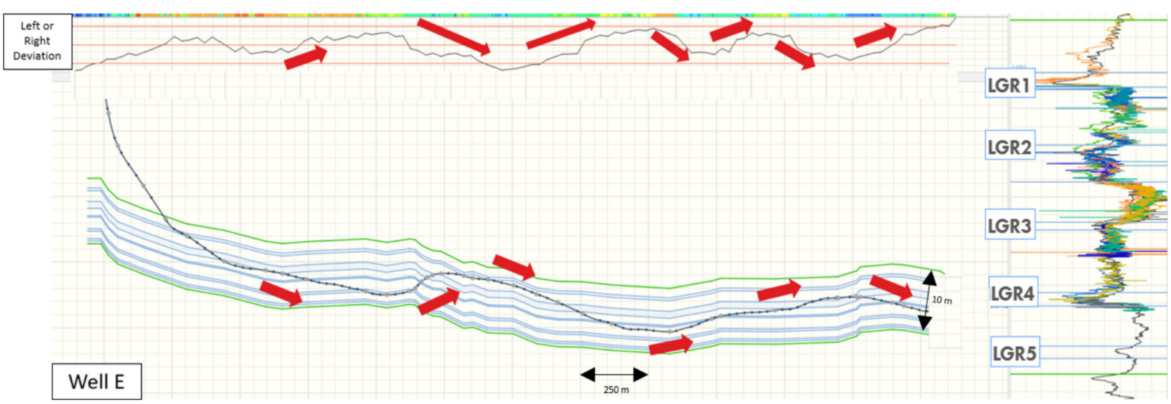


Figure 13. New geosteering model from Well E, PAD 2, highlighting the position of the LGR layers along the trajectory. The track on the tops shows the left and right variation of the lateral window, the track on the right is a correlation log. The red arrows indicate abrupt changes both in vertical positioning, and in lateral one. Note the strong correlation of both changes when the well gets close to LGR levels.

Taking an example from PAD 3, Well L shows very small changes on the lateral trajectory, related to contact with the LGR2 and LGR3 layers, but mostly staying at the center of the window (HGR1) which translated in a very smooth trajectory.

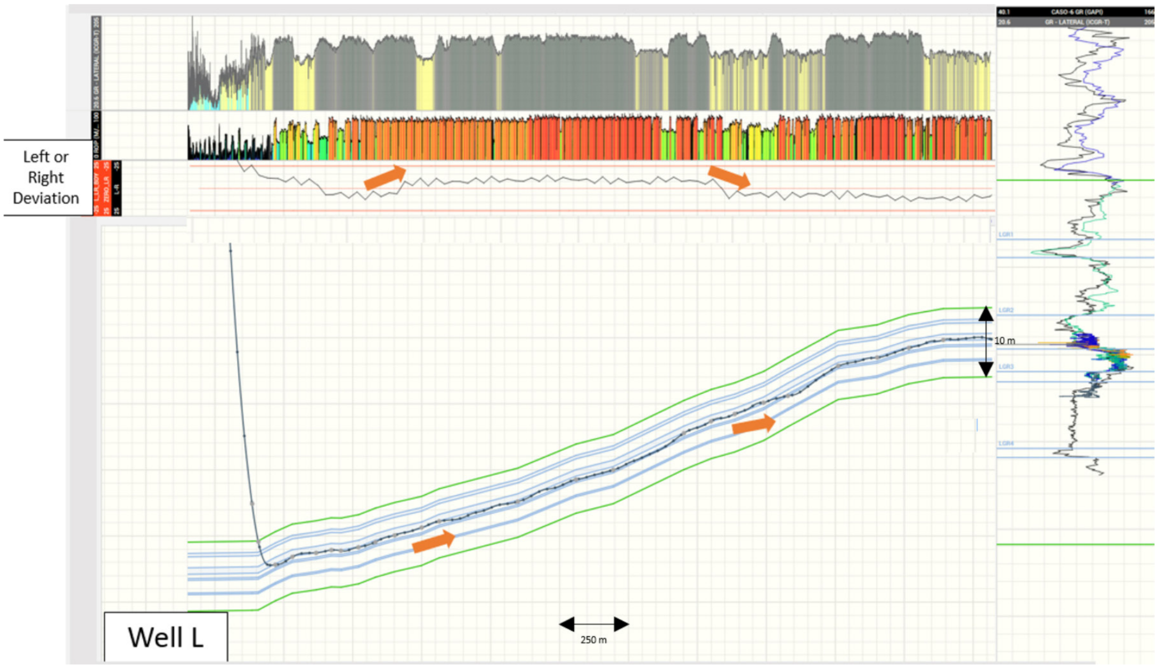


Figure 14. New geosteering model from Well L, PAD 3, highlighting the position of the LGR layers along the trajectory. The track on the tops shows the left and right variation of the lateral window, the track on the right is a correlation log. The orange arrows indicate abrupt changes both in vertical positioning, and in lateral one. Note the strong correlation of both changes when the well gets close to LGR levels. This well seems to be “bouncing” up and down between LGR 2 and 3.

Going back to the comparison between wells of the same PAD, like PAD 1, it is clear that Well A correctly targeted a HGR zone and stayed there for the entire lateral section, while Well C could not do so because of a tool failure that made the well very susceptible to the effects of the azimuth swings caused by the LGR layers. Similarly, on PAD 2, Well E also drilled a LGR level, which caused a lot of steering problems, while Well H had a much straighter trajectory. PAD 3, on the other hand, correctly targeted the center of the window in all 4 wells and was drilled very efficiently.

RESULTS

Taken the previous analysis into account, a “traffic light” classification was performed. The already mentioned “problematic” zones, defined as the Low Gamma Ray levels, mostly composed of tuff and/or concretionary limestones, are assigned a red classification. One thing that has been noted is that not all LGR zones have the same effect on the trajectory, as some are worse than others, in particular LGR4 and LGR1. The High Gamma Ray zones are assigned a green classification and are the main targets during the operation. Anything that does not fall inside one of these two categories is assigned a yellow classification, meaning that it does not have a detrimental effect but is also not an ideal zone to be targeted. While drilling through these zones, the tool will tend to maintain its trajectory.

Because the landing zone classification utilized on this well is easily correlated on a semi-regional scale, the findings can be applied to the entire field, which is what is currently happening, with the geosteering and directional teams using this classification to improve operational efficiency.

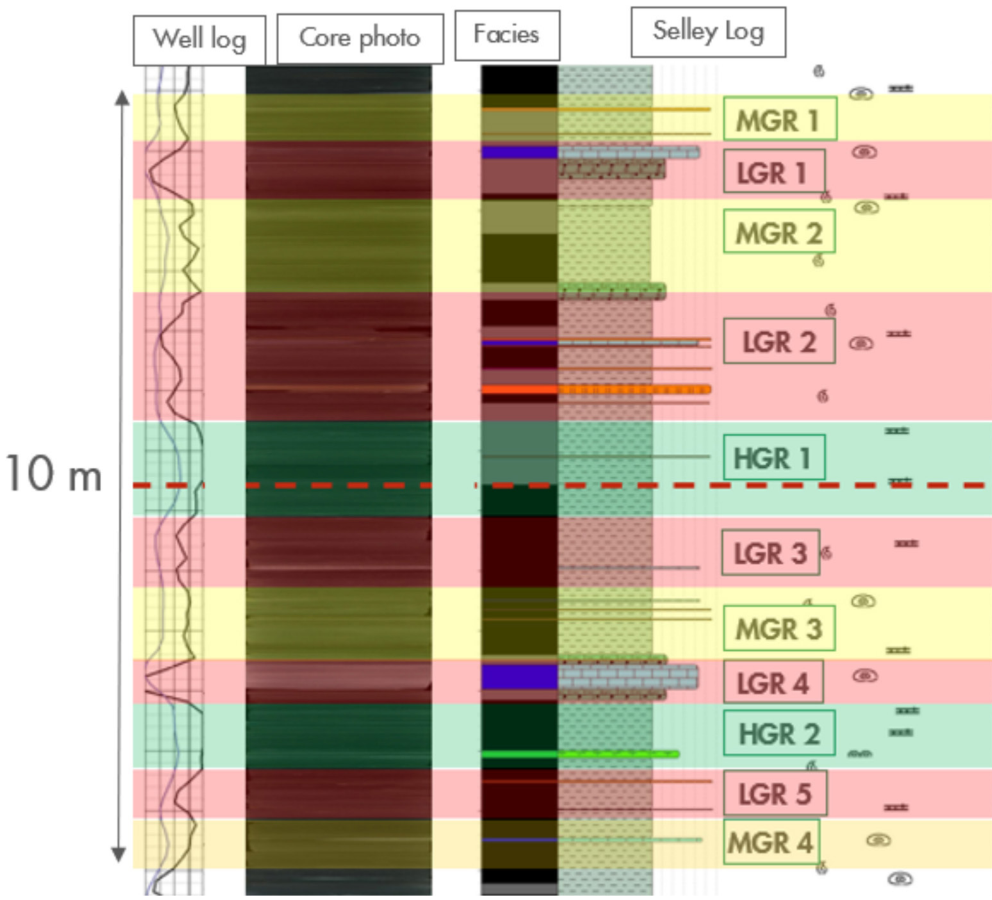


Figure 15. Core description showing the lithology, Selley log, picture scan annotations and facies of the 10 m window utilized to drill the horizontal wells analyzed on this paper with the "traffic light" classification over imposed. Red layers are Low Gamma Ray zones, green layers are High Gamma Ray zones, and yellow layers are Middle Gamma Ray zone, or intermediate lithologies with no great effect on the drilling operations.

CONCLUSIONS

The detailed analysis performed on Vaca Muerta pads with a great variety of horizontal well trajectory performance has allowed for the identification on lithologies with detrimental effects on the wellbore positioning, both laterally and vertically. These are concretionary limestones and tuffs easily identifiable by their low gamma ray responses. The same analysis has also allowed for the identification of more benign layers (marls characterized by high gamma ray values) that, if targeted, can help with the overall quality of the drilling operations by making geosteering easier. With that information, a straightforward classification of lithologies based on a traffic light system was conducted to help operators better place and navigate horizontal well trajectories targeting the Vaca Muerta Fm.

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