# Optimization of Geosteering Workflows in Unconventional Reservoirs: A Vaca Muerta Case Study

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## Abstract

In the context of unconventional reservoir exploration and development, geosteering has become a key tool for the success of horizontal drilling. This study aims to demonstrate how the optimization of geosteering workflow, supported by the integration of multidisciplinary teams, advanced technologies, and digital processes, has enhanced well placement accuracy, operational efficiency, performance, and real-time decision-making.

This research presents a case study of geosteering applied to horizontal wells in the Vaca Muerta Formation within the Neuquén Basin, with a focus on achieving operational excellence. It highlights the optimization of milestone wells, characterized by extended lateral sections and placement within minimal True Vertical Thickness (TVT) intervals. A structured methodology is proposed, consisting of three fundamental stages:

- **Pre-Job Phase:** This stage involves planning and a preliminary geological analysis to ensure that well placement and trajectory align with geological and drilling objectives. Additionally, subsurface models are evaluated to identify landing points with minimal uncertainty, predict expected structural trends, and define TVD domains within the target zone.

- **Operational Phase:** During this stage, the expertise of the geology and drilling teams is seamlessly integrated within a collaborative environment, where effective communication strategies play a crucial role. This synergy, combined with cloud-based real-time monitoring technologies, enhances overall performance and enables agile, data-driven actions to manage necessary adjustments or unexpected changes during the drilling operation.

- **Post-Drilling Analysis:** Post-drilling statistical evaluations are essential for refining and optimizing workflows, identifying opportunities for improvement, reducing uncertainty, and enhancing model predictability for future projects.

This study highlights the impact of digital transformation on workflow optimization, operational efficiency, and decision making. The results, including a detailed analysis of lateral sections placed within stratigraphic TVT thicknesses of less than 4 meters, demonstrate significant improvements in the accuracy and overall effectiveness of drilled wells. In the Neuquén Basin, top-tier operators have adopted cloud-based technologies that enable remote collaboration and faster, more informed subsurface responses, significantly enhancing operational processes and minimizing non-productive times (NPT).
These advancements contribute to successful operations in unconventional reservoirs by ensuring accurate execution of trajectories and optimizing interaction with the most productive zones of the geological window.

Finally, the study shares practical lessons and best practices for bringing cloud-based tools into everyday geosteering workflows, with the goal of improving efficiency and execution in horizontal drilling. This collaborative, digitally supported approach has not only helped optimize the development of unconventional reservoirs but also has established a valuable framework for future projects, proving its value as a forward-thinking solution in the energy industry.

## Introduction

Geosteering is a specialized technique used in horizontal and directional drilling to precisely guide the wellbore within the most productive zones of a reservoir. By integrating geological, geophysical, petrophysical, and drilling data during operations, geosteering enables operators to make continuous adjustments to the drilling trajectory. This ensures optimal well placement, maximizes reservoir contact, reduces uncertainty, and enhances hydrocarbon recovery. In unconventional reservoirs, where target formations can be thin and heterogeneous, demanding high precision and adaptability, geosteering has become a crucial tool for mitigating drilling risks, improving operational efficiency, and supporting rapid decision-making throughout the well drilling process.

Industry experience has shown that structured workflows and multidisciplinary collaboration significantly enhance decision-making and reservoir understanding. At ROGII, the methodology is structured into three phases, which will be explained in detail: **Pre-Job, Operational Phase, and Post-Drilling Analysis**. This methodical approach positions geosteering as a cornerstone of unconventional reservoir development, directly impacting both technical performance and economic outcomes.

### Fundamental Stages

1) **Pre-Job Phase:**

During the Pre-job stage, we focus on integrating all available project data in order to evaluate the quality of the information, verify the structural trend of the area, identify and estimate the correlability of the target. This stage also facilitates early identification of geological uncertainties and enables an assessment of the project, depending on the density, quality, and reliability of the data. The planned well trajectory is verified against the structural model, and adjustments are made if needed. From this analysis, we select the best landing zone and develop a

geosteering plan that accounts for possible changes in structure. At the same time, we prepare alternative well paths for different geological scenarios to proactively manage possible unforeseen drilling events.

**Factors Influencing Geosteering Strategies**

The definition of an effective geosteering strategy depends on several interrelated factors that must be carefully considered during planning and execution. These include the quality and extent of information available from offset wells, the thickness of the target interval, the structural trend of the area, and the direction in which the layers are intersected by the planned trajectory. Other relevant considerations are the planned length of the lateral section, expected variations in thickness or dip derived from the geological model, and the maximum allowable build and turn rates determined by drilling constraints. Together, these aspects provide the framework for selecting an appropriate strategy that maximizes reservoir exposure while minimizing operational risk.

**Landing Strategies**

Landing strategies are typically defined during the planning or pre-job stage, based on a thorough evaluation of the geological context and operational parameters. Key inputs to this process include the quantity and reliability of subsurface information, the proximity to trajectories of offset wells, the thickness of the reservoir target, and the anticipated dip trend of the layers.

Informed by these factors, the landing zone is optimized to ensure a smooth transition into the lateral section while maintaining the wellbore within the most productive zone of the defined geological window. In cases where the reservoir is particularly thin, it is recommended to position the landing point as close as possible to the center of the target and to align the inclination of the wellbore with values similar to the layer's bed dip. This approach increases the probability of staying within the target along the lateral section and improves reservoir contact.

Modeling Scenarios

One of the most important factors when landing a well is to build a robust pre-job model that allows us to define a landing prognosis as close to reality as possible. At ROGII, the methodology we use consists of creating a static model based on all available preliminary information, which considers 2 main scenarios, one based on data derived from seismic interpretation and the other based on the integration of validated well data + seismic data.

The first modeling scenario is based on subsurface data analyzed by the geology teams, where the regional and local structural trends are primarily defined by seismic features and the corresponding true vertical depth (TVD) domains derived from this information. It is important to note that in most areas of the Neuquén Basin, seismic vertical resolution ranges from 20 to 25 m (Chebli et al., 2015; Fantín & Bollati, 2017), introducing a similar or greater magnitude of uncertainty in the predicted landing depth. This limitation can significantly impact the accuracy of trajectory planning, particularly in thin reservoir intervals where precise placement is critical.

On the other hand, a second static model is constructed, with higher-confidence control points derived from well data. The primary inputs

include geosteering interpretations from nearby horizontal wells, as well as formation tops and horizons from offset wells, validated through drilling and mudlogging data. These inputs are integrated with the regional structural trend obtained from the seismic grid. The resulting model incorporates a set of correlated points that define the navigation level of interest, obtained through real-time or post-drill (post-mortem) interpretation of adjacent wells. As a result, the corresponding TVD domains more accurately represent the local structural configuration of the subsurface at the interest level.

The second static model is validated through 2 methodologies: the model-based and the stratigraphy-based approach.

In the model-based approach, the geological model is represented by a type log from a reference well, while the level of confidence in the interpretation is expressed through a dynamic log (which evolves as new data is interpreted). This dynamic log reflects how closely the real-time log from the well being drilled matches the pattern of the type log. The closer the match, the higher the confidence level indicated by the dynamic log.

The stratigraphy-based approach, by contrast, allows us to determine the stratigraphic position of the trajectory within the navigation window by correlating the gamma-ray (GR) signature in the wells under study. This correlation is achieved by stretching or squeezing the modeled segments representing the subsurface layers, which reveals a geometric relationship corresponding to the apparent dip interpreted for that section. These two approaches complement each other and together allow for a more precise static model.

Once the two static scenarios are defined, the vertical size of the geosteering window, typically between 5 and 10 m of True Vertical Thickness (TVD) for Vaca Muerta wells, is evaluated along with the expected dip of the layer (updip or downdip) to define the landing point by prognosis. This selection considers all the factors mentioned above, aiming to satisfy both scenarios while also accounting for operational constraints and potential risk areas, such as weak zones or undesirable lithologies within or surrounding the boundaries of the navigation window.

Dip estimation

Additionally, estimating the dip of the layers is essential for defining the landing strategy. In downdip scenarios, landing between the target level and the base of the navigation window allows for greater coverage of the window and typically requires fewer adjustments to align with the layer dip. By comparison, in updip scenarios, it can be beneficial to land between the target level and the top of the window, which facilitates building the drilling angle if the dip is steeper than anticipated, or maintaining a tangential trajectory if the dip is less than expected.

The selection of a landing point based on the criteria described above serves as the reference for projecting the navigation window, as the curve and the inclination are progressively built. To achieve the most accurate projection in Vaca Muerta reservoirs, a “shifting” or adjustment of horizons relative to the typewell is performed. This involves vertically shifting the type log (on a TVD or TVT scale) to align a common marker between the type well and the lateral well. This step is crucial, as it brings the type well data into alignment with the horizontal well data in true vertical depth (TVD), thereby correcting the differences in TVD and TVDSS that may result from variations in surface elevation, geographic distances, or regional reservoir dips.

Shifting Methodology for Landing

Each shifting value positions the projected horizons in a different TVD domain, which allows comparing the prognosis top position with the projected value to anticipate adjustments. In the ROGII methodology in Vaca Muerta Formation, once the well passes the Kick-Off Point (KOP), the shift value and the position of the target level relative to the projected landing point are systematically tracked survey by survey in a spreadsheet, at the same time the target horizons are created and projected to each shifting value, according to the correlation representing the probable position of the landing TVD point, relative to the prognosis Landing Point (LP). This approach allows the analysis of the evolution of the shift progress, stand by stand, guiding any required adjustments to the original pre-job plan. Typically, this adjustment process is limited between 40° and 60° of the well trajectory inclination, and varies depending on the requirements of the client's operational team.

Successful applications of this methodology during landing have achieved adjustments of up to 28 m TVD and as much as 40 m TVD, particularly in new development areas with limited well data, where seismic data serves as the primary input for estimating dip trends and landing depth, validating the consistency of this approach under geological and data constraints.

**Geosteering in the Lateral Section**

Once in the lateral section, geosteering must maintain a proactive and informed profile to adapt effectively to real-time geological variations. Continuous awareness of the stratigraphic position of the wellbore and the dip of the formation is essential for providing timely, accurate recommendations that keep the trajectory within the target window without compromising drilling performance.

Trajectory adjustments during the lateral section are guided by several critical variables. These include the level of confidence in the initial geological model, expected variations in dip and formation thickness., the width of the geosteering window, the difference between the layer dip and the wellbore inclination, and the distance from the current wellbore position to the target boundaries. In addition, operational considerations such as the planned length of the lateral section, well construction constraints (e.g., maximum permissible dogleg severity and build/turn ratios), and drilling parameters also inform the decision-making process.

By systematically integrating these elements into both the planning and execution phases, it is possible to design and implement robust landing and geosteering strategies that optimize reservoir exposure, ensure operational reliability, and achieve the desired well objectives.

2) **Operational Phase:**

During the drilling campaign, the geosteering workflow transitions from an structured pre-job planning, into a high‑stakes, dynamic real-time decision‑making discipline. Steering a drill bit through heterogeneous strata at depths exceeding ~3,000 m requires not only technological precision but also human expertise and continuous oversight.

In the Vaca Muerta case, this challenge is addressed by integrating geological interpretation, directional drilling control, and data science within ROGII's unified, cloud-based environment that integrates a variety of applications, including cloud-based storage, geosteering software (StarSteer), geosteering web and mobile visualizer, real-time data transmission and visualization platform, drilling parameters monitoring and analytics program, and mudlogging real time streaming software. This architecture enables seamless synchronization between field data, geological models, and steering decisions, allowing teams to respond quickly and effectively to unexpected deviations or drilling events.

During the operational phase, a fully cloud-based environment enables real-time data integration and collaborative work from multidisciplinary teams. Data from multiple sources such as Measurement While Drilling (MWD) and Logging While Drilling (LWD) is transmitted in Wellsite Information Transfer Standard Markup Language (WITSML) format. This information is aggregated through systems like ROGII's rig data aggregators and is transmitted without interruptions in Real Time (RT) through a data transmission platform and synchronized in Solo Cloud. This uninterrupted data stream updates constantly critical parameters, including wellbore position, toolface orientation, GR response, and formation properties, directly into the live geosteering model.

Geologists and reservoir engineers operate within a shared environment in the geosteering software, enabling continuous refinement of structural interpretations, dip estimation, and target proximity assessment. Directional drillers, in turn, visualize trajectory and formation data on the web, allowing for real-time alignment between geological interpretation and drilling execution. The drilling monitoring interface further enhances situational awareness by correlating geosteering updates with drilling performance metrics like rate of penetration (ROP), weight on bit (WOB), and real-time dogleg severity (DLS). This integrated digital workflow supports quick, informed adjustments and minimizes the need for reactive corrections during lateral drilling.

Also, communication between multidisciplinary teams is a key component of the workflow, and is maintained through multiple real-time channels, including phone calls, WhatsApp, Microsoft Teams calls and messages, and formal email reports. Recommendations on well trajectory and target inclinations are provided based on the geological interpretations that deliver information about the structural trend and the stratigraphic position within the geological window. These recommendations are essential to keep the wellbore within the geological window and minimize the risk of exiting it, ensuring optimal well placement and improving the overall operational performance. All interpretation changes, decision points, and directional adjustments are systematically logged in StarSteer comment boxes and documented in the corresponding email reports, ensuring full traceability and auditability throughout the geosteering process.

In some cases, the methodology also incorporates projections up to 200 m ahead, in addition to maintaining efficiency and fluent communication. This approach provides a comprehensive understanding of the geological scenarios, enabling proactive geosteering rather than merely reactive adjustments. By anticipating potential changes, teams can save time, avoid unnecessary sliding procedures or excessive dogleg corrections, preserve tool integrity, reduce wellbore tortuosity, and achieve smoother trajectory adjustments. These extended projections are especially valuable when correlations become ambiguous and alternative interpretations are possible, requiring additional data to confirm the most accurate scenario. In such situations, both the geology team and on-site personnel are promptly informed, and operational constraints and geological objectives are evaluated collaboratively in a multidisciplinary environment. This ensures all teams have a clear view of the project, work together to make informed choices, and effectively mitigate the most critical risks.

This integrated workflow, driven by seamless collaboration among geologists, drillers, and real-time operations teams, achieved precise well placement within exceptionally narrow TVT windows of 3.7 to 5.6 meters for complex wells, such as Well‑4(h) and Well‑7(h) respectively in Fortin de Piedra Field, across laterals exceeding 3,000 meters. By minimizing steering commands and corrective actions through continuous geological model updates and synchronized, multidisciplinary teamwork, this approach powerfully demonstrates how integration and collaboration lead to superior drilling accuracy and operational performance, even in complex and challenging geological environments.

### 3) Post-Drilling Analysis and Workflow Optimization

After reaching total depth (TD), a systematic post-drilling analysis is conducted to assess geosteering performance, validate geological interpretations, and refine models for future wells. This phase combines qualitative assessment with quantitative results to support ongoing workflow optimization.

Final geological interpretations are meticulous compared against pre-job plans to evaluate positional accuracy within the geological window, lateral exposure to the reservoir, and deviations from the target window. Memory logs, including gamma-ray (GR) and rate of penetration (ROP), among others, are unified, normalized, and exported in standardized LAS and polygon formats to ensure data consistency and interoperability. These standardized datasets are then imported into the geosteering project within Solo Cloud, providing a consolidated and traceable base for analysis and decision-making.

Key performance indicators (KPIs) are also calculated, including performance, hazards, and drilling mechanics analytics, which are securely preserved in the cloud centralized database. These include the percentage of the lateral trajectory's true vertical thickness (TVT) maintained within the geological window (usually in Vaca Muerta wells a 10-meter zone centered on the target, these ranges could be limited by operational or lithological constraints), number and frequency of trajectory corrections, drilling efficiency metrics such as section drilling time and overall non-productive time (NPT), and directional drilling quality parameters like dogleg severity (DLS) compliance. Together, these metrics form a comprehensive quantitative framework for assessing geosteering accuracy and operational performance.

Operational results following this workflow and geosteering strategies demonstrate exceptional precision in geosteering placement. For example, in the Rincon de Aranda field Well-1(h) had the entire lateral trajectory confined within a narrow 4.5-meter TVT interval inside the 10 meters geological window. Similarly, in the Lindero Atravesado field where Well‑2(h) achieved an even tighter placement, with the lateral contained within a 2.6-meter TVT interval inside the geological window, or extraordinary lateral lengths such as the 3500 m of Well-3(h) that was drilled within a TVT interval of only 4.3 meters. Across multiple wells drilled in the Vaca Muerta formation at the Fortín de Piedra field, including Well‑4(h), Well‑5(h), and Well‑6(h), which lateral sections extending up to 3,100 meters achieved exceptionally precise well placement, maintaining trajectories within narrow intervals of just 2.1 to 3.7 meters of true vertical thickness (TVT) inside a 10 meter geological window. This level of accuracy was sustained even in the presence of lithological risks such as interbedded tuff layers, which present significant geosteering challenges, demonstrating consistently high geosteering precision and drilling performance.

The final geological interpretations, combined with the unified memory logs, provide validated structural data that allow continuous updates to the structural grids and seismic calibrations. This iterative refinement process adjusts the regional and local geological model across multiple horizons within the productive formations of the Vaca Muerta reservoir in Neuquén, improving accuracy and predictive capability. All completed projects (including real-time data, interpretations, and analytics) are stored in the cloud and are easily accessible for future review and comparative analysis between wells. This structured data management preserves institutional knowledge and enables scalable replication of optimized workflows across future projects.

Post-job analysis further enables refinement of geological models and geosteering protocols. A detailed examination of drilling data, LWD logs, and trajectory decisions quantifies well performance metrics, including meters in zone, lateral deviations, and non-productive time (NPT). Model discrepancies are identified and addressed through updated structural interpretations, improving predictive accuracy for subsequent wells.

All geosteering data, including real-time data, user edits, trajectory adjustments, and decision records, are securely stored in the organization's cloud. This complete digital traceability ensures full tracking and auditability, enabling faster, evidence-based decisions during operations and supporting continuous workflow optimization after well completion

In summary, this cloud-based, integrated geosteering workflow enables precise well placement within narrow geological targets, maximizing reservoir contact while avoiding lithologically risky zones. By centralizing real-time data and multidisciplinary expertise, it empowers teams to make more accurate, evidence-based decisions, reducing operational risk and non-productive time. This approach accelerates learning curves, enhances operational efficiency, and preserves institutional knowledge, ultimately delivering measurable value to operators.

**Lessons Learned, Results, and Operational Impact**

The implementation of a standardized, cloud-based geosteering workflow in the Vaca Muerta Formation has significantly improved well placement accuracy, operational efficiency, and multidisciplinary collaboration. Over successive drilled wells, teams progressively adopted a fully digital approach using ROGII's collaborative ecosystem, which ensured continuous alignment and effective communication across the entire well lifecycle.

This integrated workflow begins with accurate pre‑job modeling, where seismic trends and offset well data are combined to reduce landing uncertainty and plan trajectories that maximize reservoir contact while avoiding lithologically risky zones. During operations, all disciplines work from a shared, real‑time subsurface model, which removes data silos and enables quick, informed decisions. Live LWD updates allow continuous adjustment of the wellbore trajectory to maximize exposure to the most productive zones while maintaining optimal ROP performance. This approach enables the geosteering of laterals to remain tightly restricted within geological targets, consistently achieving wellbore placement inside a 10‑meter window, with true vertical thickness (TVT) along the lateral sections ranging from 2.1 to 3.7 meters for

these milestone wells in this study. Maintaining this precision reduces non-productive time, mitigates operational risk, and strengthens the correlation between planned geological objectives and actual drilling execution.

After drilling, automated KPI monitoring and post-job analytics foster systematic learning and promote continuous workflow optimization across multiple wells. As collaboration deepened and processes matured, top-tier operators in Argentina achieved consistent precision; 97% of well trajectories remained within the 10-meter geological window, with true vertical thickness (TVT) placement along laterals ranging from 2 to 7 meters in most cases. The quantifiable outcomes of this continuous integration of real-time data and multidisciplinary expertise include the maximization of reservoir contact and optimized well placement, reduction in non-productive time (NPT) and operational risk, accelerated decision-making, and stronger correlation between geological objectives and drilling execution.

By combining strong pre-job models, cloud-based data integration, real-time model updates, and seamless team collaboration, this workflow has proven scalable and transferable to other complex, unconventional environments, establishing a high-performance operational model applicable to plays such as the Permian Basin, Pre-Salt Brazil, and Middle Eastern tight formations.

## Conclusions

This study demonstrates that optimizing geosteering workflows through cloud-based technologies, multidisciplinary collaboration, and structured digital processes significantly enhances the development of unconventional reservoirs. Applied in the Vaca Muerta Formation, the methodology integrates three key stages: comprehensive pre-job modeling to define accurate landing strategies, real-time operational monitoring to guide trajectory adjustments, and systematic post-drilling evaluations to capture lessons learned and refine future plans.

In the Vaca Muerta Formation, the implementation of an integrated, cloud-based geosteering workflow enabled consistently precise well placement—maintaining lateral sections up to 3,500 m within 2.1 and 4.5 m TVT inside a 10 m geological target window. This precision maximized contact with optimal reservoir properties, mitigated lithological risks, and significantly reduced non-productive times (NPT). By centralizing real-time MWD and LWD data within a unified subsurface model, all disciplines contributed to trajectory control, enhancing operational efficiency, and ensuring drilling execution remained aligned with geological objectives. This workflow also improved operational performance, such as ROP, minimized wellbore tortuosity, and preserved institutional knowledge, establishing a scalable, transferable framework for future unconventional horizontal drilling projects.

Post-drilling analysis, including KPI evaluation and model refinement, further enhances predictive accuracy for future wells and preserves institutional knowledge in a fully traceable, cloud-stored environment. Together, these practices establish a scalable and repeatable geosteering workflow that strengthens operational efficiency and maximizes the value of unconventional reservoir development.

## Bibliography

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