

C046

Optimum Use of Seismic Data to Reduce Drilling Risk and Improve Well Placement

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SUMMARY

The earth model obtained from seismic data is the primary input to well planning. To help place the well in the right “geological” target and to avoid drilling hazards, the earth model required for drilling often needs to be very accurate at the well location. The required accuracy and resolution for drilling purposes is typically higher than what is required by other uses of seismic data in various phases of E&P. Consequently, a best possible predrill model in a small volume around the well location needs to be built before drilling. Furthermore, while the well is being drilled, new information is obtained such as logs, vertical seismic profiling (VSP), mud weight, mud logging, and others that were not available before. These measurements are taken at the new well location and can be used to update the predrill model for a more accurate model of the earth ahead of the drill bit for better well placement and drilling hazard management. The lack of adequate technologies and measurements, and turnaround time limitations, have made this type of optimum utilization of seismic and well data (predrill and while drilling) impractical until now. With recent developments in model building, new rapid and accurate imaging technologies, and availability of new well measurements, this is now becoming a reality. In this paper, we review this process, describe the technologies that make it possible, and present a field study

Introduction

Structural images and formation properties derived from seismic data are used in various phases of E&P, from prospect generation to improved recovery. Each application has certain requirements, objectives, and cost considerations that drive the way the data are processed. For example, in a large regional-scale project for identification of possible prospects, time and benefit vs. cost considerations might dictate a workflow for an approximate, low-resolution image. Depending on the area, only a subset of the data may need to be processed, and a faster but suboptimum processing technique might be sufficient to meet the objectives of the project.

At the other end of the spectrum, when seismic information is used for planning a specific well and to monitor its progress while drilling, the best possible depth (more accurately, spatial position) accuracy, the highest resolution, and description of earth properties important for drilling, such as pore pressure and fault locations, are needed. This particular application is the topic of our paper.

The earth model obtained from seismic data is the primary input to well planning. To help place the well in the right “geological” target and to avoid drilling hazards, the earth model required for drilling often needs to be very accurate at the well location. For predrill well planning, the model must incorporate all available seismic information, offset well data, and geological information. Such models are often not readily available during drilling exploration and appraisal wells.

While the well is being drilled, new information is obtained such as logs, vertical seismic profiling (VSP), mud weight, mud logging, and others that were not available before. These measurements are taken at the new well location and, in principle, can be used to update the predrill model for a more accurate model of the earth ahead of the drill bit for better well placement and drilling hazard management.

The lack of adequate technologies and measurements, and turnaround time limitations, have made this type of optimum utilization of seismic and well data (predrill and while drilling) impractical, if at all possible, until now. With recent developments in model building, new rapid and accurate imaging technologies, and availability of new well measurements, this is now becoming a reality. In this paper, we review this process that we call Seismic Guided Drilling (SGD¹), describe the technologies that make it possible, and present a field study.

Components of a seismic project for drilling

There are three key components of a seismic project for drilling that differentiate it from other applications:

1. **Small volume of interest:** An earth model that is relevant for drilling a particular well covers a volume that includes the planned well trajectory and possibly neighbouring locations with well or geological information – we call this the drilling volume of interest (DVI). The size of this volume is typically much smaller than other seismic applications such as regional imaging. Together with other factors such as new technologies, this allows the use of sophisticated (and expensive) techniques to build the best possible, high-resolution earth model to guide drilling decisions.
2. **Integration of well information:** In a drilling project, there is always at least one well – the one being drilled – in addition to any offset wells. Availability of new well measurements, such as checkshot and VSP while drilling, and technologies that can optimally integrate them with seismic information to constrain the local earth model, such as well-constrained tomography, are critically important.

¹ A mark of Schlumberger

- Fast turnaround time – “in-time” for drilling decisions: Typical seismic processing projects take a long time compared with a seismic drilling project where turnaround time is tuned to the driller’s time scale. The baseline predrill model must be in place in time to enable well planning and the earth model updates, while drilling information must be turned around in time to make real-time drilling decisions. High-end imaging algorithms, such as beam migration, that can handle complicated geology and can produce rapid updated remigrations are required.

Drilling challenges that could be addressed

Seismic information cannot address all the challenges drillers face, but there are a number of important ones that seismic data can help with. We can highlight two areas:

Better well placement

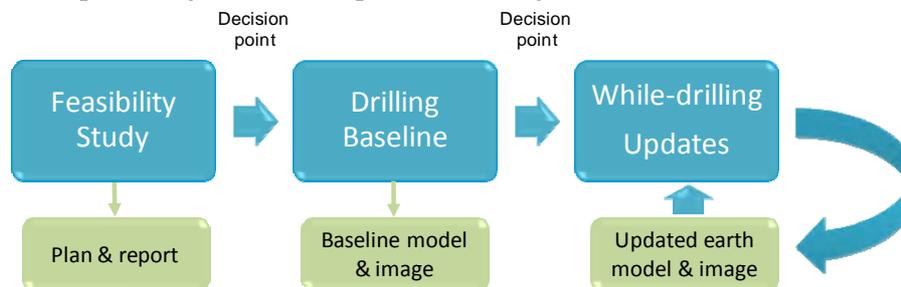
- Reduce uncertainty of drilling target locations including casing points, faults, and target reservoir(s). This is achieved primarily by building a velocity model (anisotropic) that better represents the local geology at the well location. This model is then used with fast and sophisticated imaging in the DVI.
- Quantify uncertainty of drilling target locations.
- Improved reservoir property and structure definition through inversion.

Help avoid drilling hazards

- Shallow hazard identification.
- Pore-pressure and fracture gradient estimation; reduce and quantify uncertainties in estimates.
- Identify other regional hazards such as tar and gas hydrates.

Workflow and technologies

A seismic project for drilling goes through three phases. Here, we describe the type of work that is performed in each phase, together with required technologies.



Feasibility Phase

The purpose of the feasibility phase is to explore and evaluate candidate solutions and technologies to reduce risk. Drilling and geophysical and geological (G&G) teams must understand the key drilling challenges and drilling hazards expected. This is followed by a preliminary look at the data to assess quality and to determine whether data, illumination, and other reference information are appropriate for the proposed techniques. Uncertainty regarding structure, fault locations, and drilling hazards is evaluated (Osypov et al., 2010); required measurements and technologies (what type of migration and/or inversion) are identified.

In addition to seismic data, the latest prior earth/velocity model, interpreted horizons, and hazard predictions are used to carry out this phase:

Drilling Baseline Phase

The workflows and optimized parameters from the feasibility study that have shown to provide improvement over existing images and information that help address risk elements are applied to the DVI.

The drilling baseline earth model includes an anisotropic local velocity model, depth-migrated high-resolution image, interpreted horizons and faults, and drilling hazard estimates (pore pressure, geomechanics, and others). This is the best possible model with predrill information and serves as the starting point for while-drilling updates.

The following information and data are used to carry out this phase:

- Information on area geology; basin model if available.
- All offset well information: logs, borehole seismic data (checkshot, VSPs), mud weights, kicks, and others.

While-Drilling Updates Phase

As the well is being drilled, new information become available, including checkshot, VSP, well logs, cuttings description, and actual mud weights. This new local information is used to update the local earth model at the well location. This is particularly valuable in exploration cases where limited or no nearby offset well data are available.

Updates, including pore pressure and fracture gradient estimates, are done on a predetermined schedule or as required. Real-time logging while drilling (LWD) data (checkshot and logs) are used for real-time while-drilling updates. Recorded-mode LWD and intermediate wireline VSP and logs are used to update the model and the image between bit runs.

Local anisotropic velocity updates are obtained using reflectiontomography with checkshot or and/or well tops used as constraints such that the model is consistent both with well data and seismic information (Bakulin et al., 2010). The structural depth image is updated by rapid remigration enabled by massively parallel computing. More recent developments in algorithms such as Gaussian Packet Migration (Zacek and Klime, 2004) have further speeded up the turnaround time.

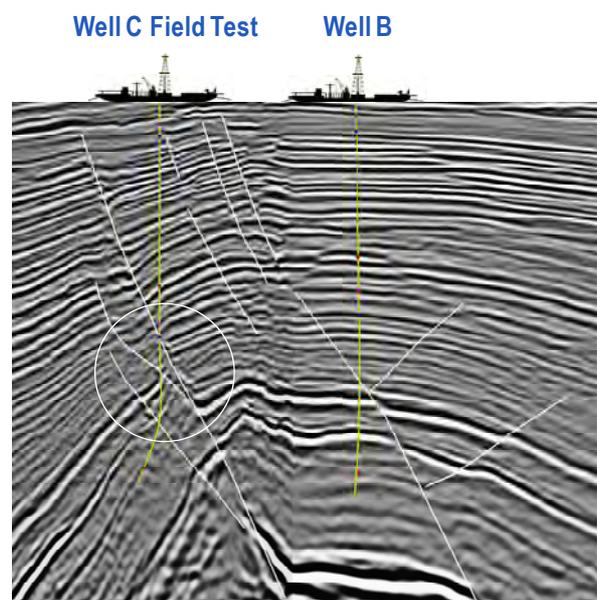
The following information or data are used to carry out the updates:

- Baseline model.
- Borehole seismic data. Either LWD, checkshot, or intermediate wireline VSP as described above.
- Logs. Either LWD or intermediate wireline logs (sonic, density) as described above.

Field test

The SGD process was tested during the drilling of a well in the Gulf of Mexico (Well C).

The primary challenge was to place the 13-5/8 inch casing below a secondary fault. This was necessary for the hole size requirements in the final well completion. Locating both primary and secondary faults accurately was deemed critical. Data from one offset well (Well B) were limited to the deeper section and could not be used to build a reliable predrill anisotropic model in the shallower sections. Large uncertainties were expected in positioning of events with existing seismic data. It was important to improve the velocity model and reimage while drilling to reduce the positional uncertainty of the fault locations.



LWD, checkshot, and wireline data were acquired all the way up to the mudline to complement the offset well for a good velocity model. Anisotropic velocity models were created in several stages by seismic tomography where the vertical velocities were constrained by well data. The volume for velocity models included the offset well to ensure a proper tie to that well, in addition to the new well.

For each updated model, the surface seismic data were reimaged with an updated model during drilling, enhancing fault location accuracy in time to impact drilling and casing decisions. The desired casing location was accurately predicted within +/- 50 ft. The prediction was performed using reimaging performed at approximately 1500 ft above the planned casing depth.

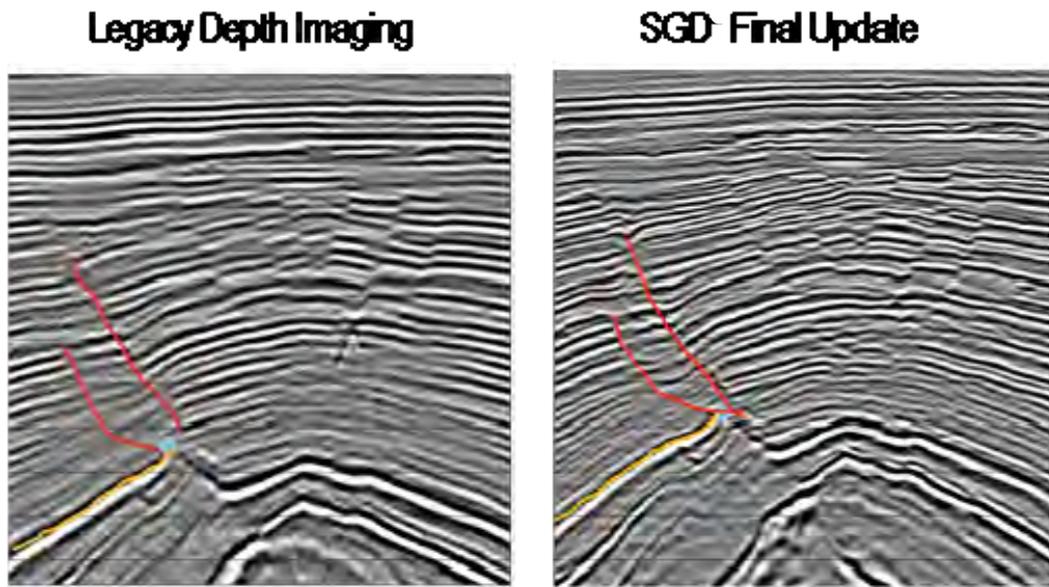


Figure 1 Left: The seismic image that was available before; Right: Seismic image after the final update. Red lines show fault interpretations.

Conclusions

Successful drilling planning can greatly benefit from an accurate high-resolution earth model obtained from seismic data integrated with well information. Using the recent developments in rapid and accurate imaging technologies, and the availability of new well measurements, this earth model can be updated while drilling the well, enabling optimum well placement and drilling hazard management.

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