Integration of seismic data and while-drilling logs to reduce drilling uncertainty

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Abstract

Seismic is used as a primary input in planning and execution of drilling projects. However, it is not always used to its full potential.

An earth model consisting of structural information with geological targets, faults, and with relevant formation properties such as pore pressure and fracture gradient guide drilling decisions to help place the well in the right "geological" target and to avoid drilling hazards.

The best possible accuracy and resolution at the well location is required; therefore all available information needs to be optimally combined and used with the latest model building and imaging technologies. This information includes the while-drilling well logs from the well being drilled as well as any offset wells and other local geological knowledge.

The lack of adequate technologies, measurements, and turnaround time limitations, has made this type of optimum utilization of integrated seismic and well data impractical until now. Recent developments in model building, rapid and accurate imaging technologies, and the availability of new well measurements have made this optimum combination a reality. This new approach has been used in a Gulf of Mexico well, demonstrating the potential value it can provide to drillers.

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 project for identification of possible prospects, processing time and benefit vs. cost considerations might require 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.

For drilling purposes only a relatively small area containing the well trajectory and any significant local geological structures need to be imaged and formation properties estimated. This we will call the drilling volume of interest.

Before the drilling and detailed well plan is completed a "pre-drill" earth model is built in the drilling volume of interest. The model incorporates all available seismic information, offset well data, and geological information. Such models are often not readily available for exploration and appraisal wells.

While the well is being drilled, new information is obtained such as logs, vertical seismic profiling (VSP), mud weights, mud logging, and others that were not available before. These measurements are taken at the new well location therefore they provide the best well-based information about the local velocities, geology, and rock physics for the new well.

The while-drilling well information is used to update the initial 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 hardware and software technologies, while-drilling measurements, and turnaround time limitations, have made this type of optimum utilization of seismic and well data (pre-drill 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 while-drilling measurements, this is now becoming a reality. In this paper, we review this "new process" that we call Seismic Guided Drilling (SGD[1]), describe the technologies that make it possible, and present a field study.

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[1] A mark of Schlumberger

Method

In this section we show how this new process works using a simple example. Pre-drill planning of a well is made using the seismic image and estimated properties important for drilling such as pore pressure, frac gradient, geomechanical properties etc. Figure 1 shows a seismic image, and a velocity model, that typically would have come from the processing of a large exploration data set. After a target has been identified a well plan is made including trajectory, casing locations, mud plan, etc. The better this initial pre-drill model is the better drilling and completion plan can be made.

The new process helps in this stage by producing best pre-drill model possible with as high resolution image and as accurate velocity (therefore pore pressure etc.) estimates as possible. This is made possible by taking only a small volume around the well location and producing an image only in this drilling volume of investigation using advanced, typically computationally intensive, techniques that may not be practical for large data sets. Furthermore, localization of the process allow the creation of a velocity model representative of the local geology.
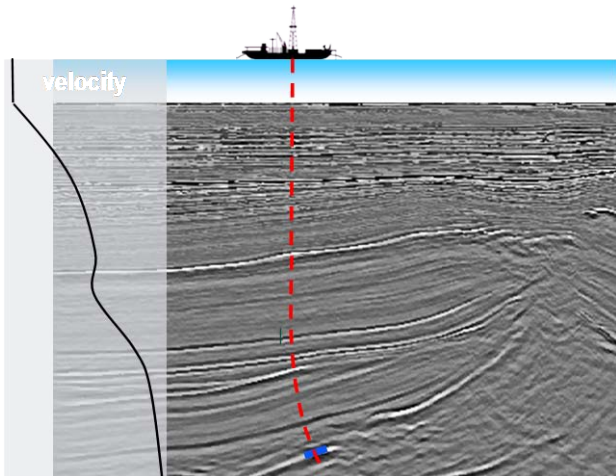

Figure 1. *Pre-drill planning of a well with the new process. The local seismic data are re-processed for best local high-resolution pre-drill image, and pore pressure and frac gradient estimate. Benefits are improved pre-drill plannin of well trajectory, casing points, and mud weights.*

As the well is being drilled new information become available from well logs, checkshots, mud weights, drilling events, etc. These could come from LWD (logging while drilling) or intermediate wireline measurements. This new information represents the local properties of the formations.

Seismic data are completely re-processed by using this local information as constraints. Checkshot-constrained local tomographic inversion is used to get new velocities (Bakulin et al., 2010). This is followed by a full depth migration. Figure 2 shows updated velocities (in red) and updated image. Note that the drilling target (in blue) now

has moved in depth and lateral position. Well logs are used to update the local rock model used in pore pressure prediction ahead of the bit as indicated with the black arrow.

It is important to point out that velocities – and therefore the pore pressure, frac gradient, and image accuracy – are re-estimated and improved ahead of the bit. This is not possible to accomplish by any other technique that only uses well data for model updates.
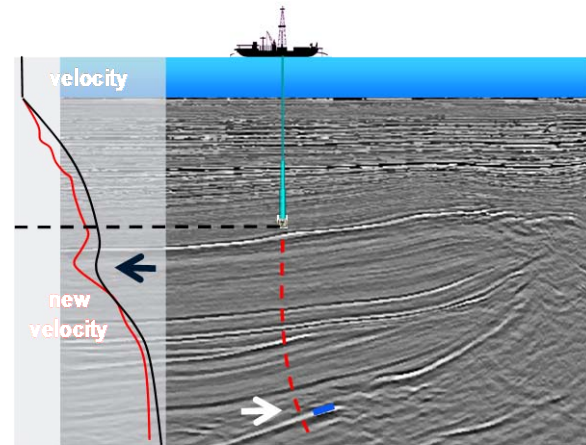
Figure 2. *Using new well data as constraint seismic data are completely re-processed and structural and velocity – and therefore pore pressure and frac gradient – uncertainty ahead of the bit is reduced. Note that the depth and lateral position of the target (blue box) has moved.*

Finally, changing predictions ahead of the bit allow for adjustments in the drilling plan. Well trajectory is adjusted to intersect the target. Casing point and mud weight plans are adjusted according to the new desired casing locations and new predictions of pre pressure and frac gradient ahead of the bit (Figure 3).
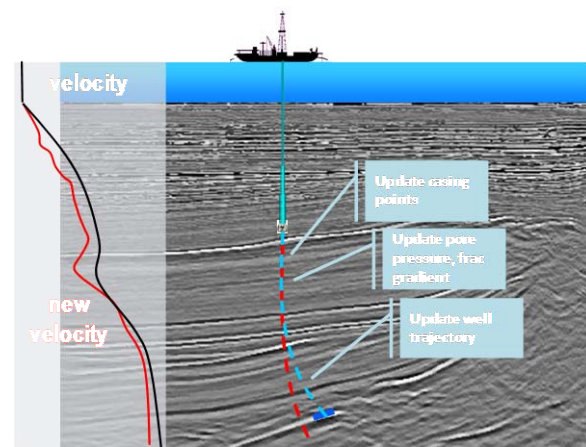

Figure 3. *Well trajectory, casing points, and mud weights are modified based on the new image and predictions ahead of the bit. Benefit is reduced risk and/or elimination of unnecessary casings.*

using re-imaging performed at approximately 1500 ft above the planned casing depth.

Examples

The new process was tested during the drilling of a well in the Gulf of Mexico (Well C in Figure 4).

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 in Figure 4) were used to build a local anisotropic model extending into the new well location. However, Well B data were limited to the deeper sections and could not be used to build a reliable pre-drill model in the shallower section in the drilling volume of interest. Large uncertainties were expected in positioning of events with existing seismic data. It was important to improve the velocity model and reimage while drilling using well information from Well C to reduce the positional uncertainty of the fault locations.
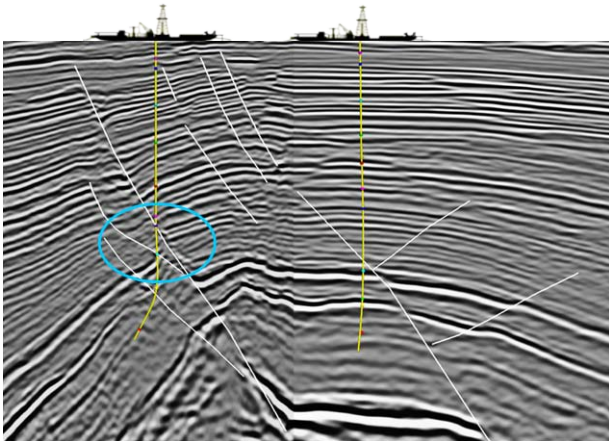

Figure 4. *In a Gulf of Mexico well (Well C) a primary challenge was to place the 13-5/8 inch casing below a secondary fault due to hole-size requirements in the final well completion. Locating both primary and secondary faults accurately was critical. Large uncertainties were expected in the positioning of events using the existing seismic image. While-drilling data from Well C was used to improve the velocity model and reimage 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 velocity model, the surface seismic data were re-imaged 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
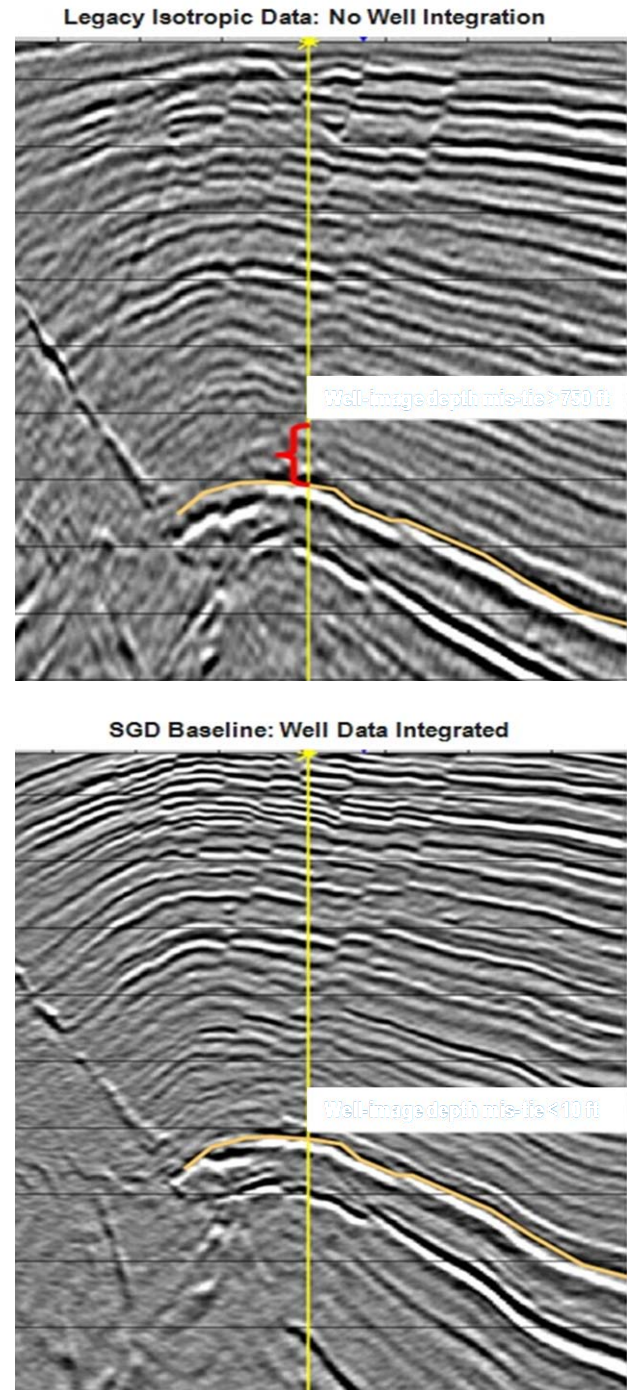

Figure 5. *The top panel shows the legacy image that existed prior to the project. An anisotropic velocity model was built using the offset well (Well B) data and seismic data were depth migrated. The bottom panel shows the result giving the best possible predrill image at the baseline stage. We observe a significant (>750 ft) depth shift in the new image compared with the legacy image. Drilling showed that the new image for this horizon was within 10 ft of the prediction.*
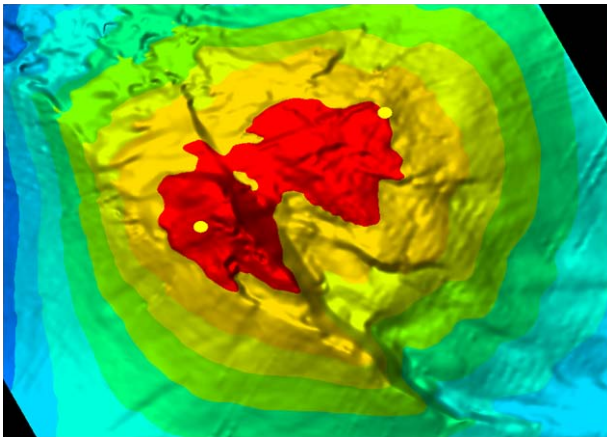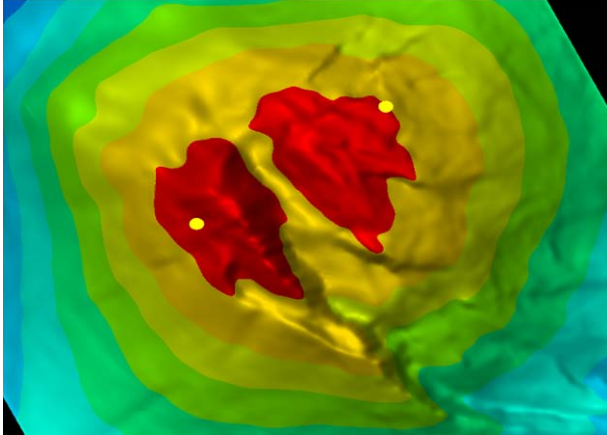
Figure 6. *The same comparison as in Figure 5 in plan view. The top panel is the legacy image that existed prior to the project. The bottom panel shows the new image. The updated image shows a better description of structure and faults becasue of the utilization of all available data and better focusing provided by the new anisotropic local velocity model.*
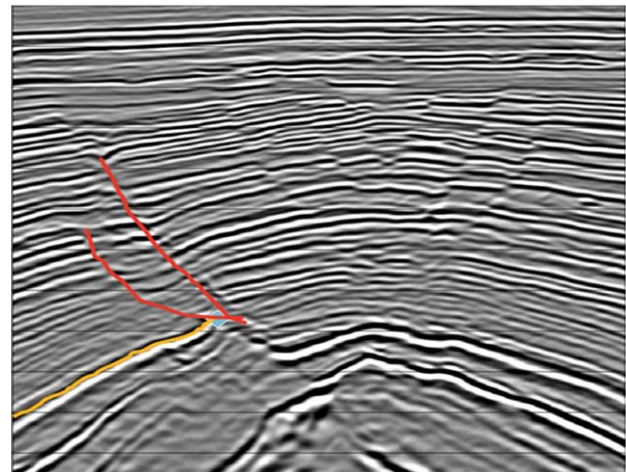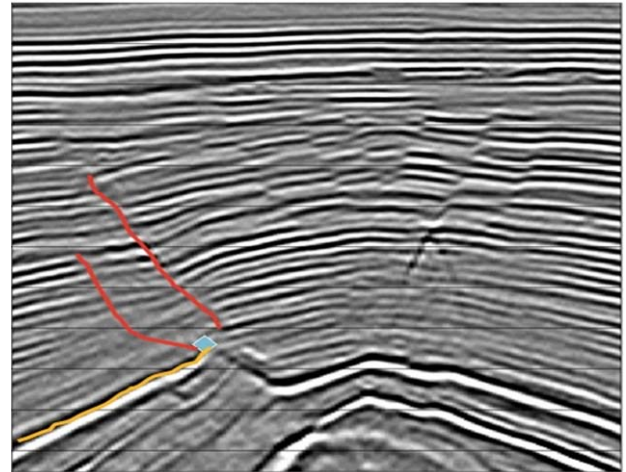
Figure 7. *The panel on top is the legacy image that existed prior to the project. The panel on the bottom is the seismic image after the final update.Both shhow faults interpretations. There was a significant shift in the spatial locations of the faults targeted for casing point.*

Conclusions

Successful drilling planning and execution 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.

Acknowledgments

References

Bakulin, A., Woodward, M., Nichols, D., Osypov, K., and Zdraveva. O., 2010. Building tilted transversely isotropic depth models using localized anisotropic tomography with well information. Geophysics, 75, D27–D36.