Seismic while drilling (SWD) experiences on the Peregrino field – a case study

Thiago Pinotti, Torill Andersen, Statoil Brasil Óleo e Gás Ltda

Abstract

The Peregrino field is a heterogeneous sandstone reservoir with a pinch out trap configuration. Vertical and horizontal overburden velocity variations, thin reservoir towards the pinch out, in addition to noisy seismic data in areas introduce uncertainties into the estimation of depth from seismic and well data. The field development includes drilling long production wells with up to 2000 meters horizontal reservoir section, thus accurate depth estimation is very important to land the well correctly without the use of pilot holes.

In this scenario, the seismic while drilling (SWD) technology was used to reduce depth uncertainties, by providing borehole seismic time-depth data, (checkshot information) while the well was being drilled, without adding extra rig time. Furthermore, the SWD objective was to give a detailed seismic image below the well trajectory in an area with noisy surface seismic data, but this objective was not met in this well.

Introduction

Seismic while drilling (SWD) measurements are an efficient way to obtain accurate time-to-depth information around the wellbore. Additionally, it can provide a detailed seismic image of the structures of reflecting horizons below the trajectory, and the information can be used to support drilling decisions. In terms of operations, the data is acquired while the well is being drilled without use of additional rig time, as shots are acquired during natural stops at connections. It does however require a boat operation for positioning of the seismic source.

In this case study, the SWD technology was used to reduce depth uncertainties at the top of the reservoir, optimizing the landing (the build of inclination to horizontal), and also to locate the well vertically within the reservoir interval. The velocity uncertainties in this case are mainly caused by velocity variations related to a velocity wedge located above the target area (Figure 1).

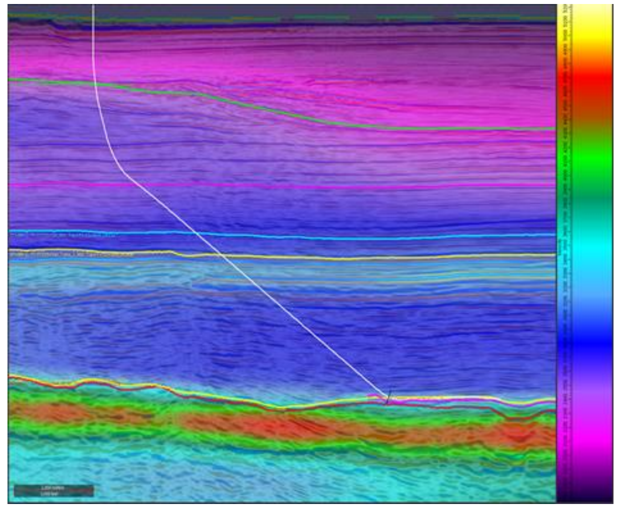

Figure 1 Seismic section along well A, showing PSDM velocities in the background.

Geological background

The Peregrino field is located in block BM-C-7, in the southernmost Campos Basin, offshore Brazil (Figure 2). The area is located 86 km southeast of the nearest coastline, approximately 100 km southeast of Macaé. The Peregrino field was discovered in 2004, and the production started in 2011. The water depth in the area varies from 95 to 135 meters, over an area of approximately 350 km2. The reservoir depth in the field is between 2150 and 2350 meters TVD. Peregrino Field is one of the heaviest offshore oil developments (14°API) in Brazil.

Figure 2 Peregrino location

The reservoir interval is the Carapebus Fm., with good quality Cretaceous sands deposited from gravity flows in deltaic and shallow marine environments. The upper and lower part of the reservoir is divided by a 5 m thick siltstone flooding surface. The caprock is a shale, the Tamoios Fm., and the bottom is the Macae Group, which is composed mainly of limestone and marls in this area.

Data acquisition method

The SWD technology uses conventional seismic source equipment at the surface, and a set of acoustic receivers in a logging while drilling (LWD) tool as part of the bottom hole assembly (BHA), (Figure 3). The receiver equipment includes a pressure hydrophone, a set of multicomponent geophones oriented orthogonally in x, y, and z directions, and a downhole clock synchronized with the surface clock to avoid biased measurements (Mathiszik et al., 2011). Since there is no physical connection between the receivers within the BHA and the rig, synchronization between both clocks is necessary. Normally calibration of the clocks starts minimum 96 hours prior to the acquisition, in order to guarantee the synchronization.

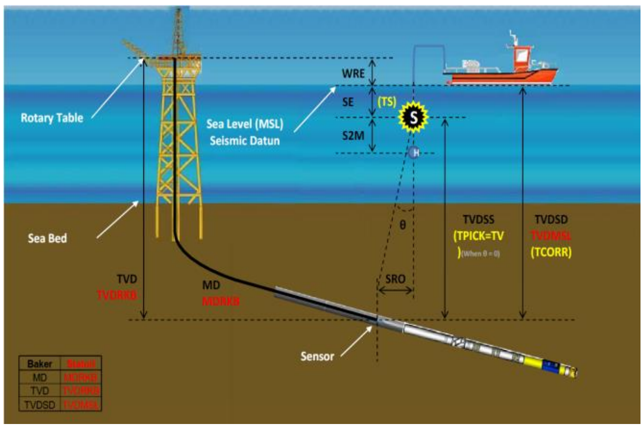

Figure 3 Overview of the SWD acquisition configuration (Baker Hughes).

The SWD measurements can be acquired during regular breaks at connections (10-30 m intervals) during the drilling process. This way, the data acquisition does not add extra rig time.

The standard SWD deliveries are checkshot information while drilling. This is achieved by transmitting 256 ms of the hydrophone data around the first break time, using the drill mud pulse system, making it possible to update continuously the drill bit position on the seismic data in real time. VSP images are available at the end of the drilling run when the tool's memory data can be accessed after retrieval to the surface.

Acquisition during pulling out of the hole (POOH) saves boat time and should be used whenever real time data is not needed. No data is transmitted to the surface while POOH due to the lack of circulation, so there are limited quality assurance possibilities. The data is recorded to memory only.

The full waveforms of all components are stored in the tools memory data and can only be accessed after the tool pulled out of the hole.

Case study

The second well (Well A) with SWD survey performed on Peregrino was planned in an area with large depth uncertainties, introducing significant challenges for the landing and geosteering strategy (Figure 1).

The SWD survey in Well A was acquired in two runs. The first run (acquired along the 12 ¼'' section) was recorded from September 30th to October 4th, 2011; while the second one (acquired along 8 ½'' section and inside the cemented 9 5/8" casing) was recorded from October 16th to17th, 2011.

In the first run, the plan was to acquire certain depth levels while drilling, in order to get a good prediction of the location of the bit towards the TD of the 12 ¼" section, to ensure that we started building angle at the correct depth. The rest of the planned depth levels were planned to be acquired while POOH. Due to a battery failure in the tool, all the traces recorded during POOH was lost from memory. This caused a large gap in data, which could only partly be filled by run 2.

The second run was planned to be recorded during POOH of the horizontal 8 ½" section, because no realtime data was needed. All data was successfully recoded to memory, but a timing issue of the data had to be resolved during processing.

Checkshot information

In the Peregrino case, the checkshot results were very useful, because it provided real-time correlation between the well data and the seismic data. Strong seismic reflectors present in the overburden were used to improve the time-depth relationship by performing a welltie using realtime sonic, density and SWD data (Figure 4). Thus, it was possible to get a good prediction of the location of the bit in the time domain, before converting it to depth. Prior to drilling, the depth uncertainties in the target area were about 35 meters vertically. Using the real-time checkshot data, this value was reduced to about 15 meters, mainly related to uncertainties in drilling and seismic interpretation.

The welltie in Well A was considered reasonable, with the best results in the overburden interval containing the strong seismic reflectors. For this reason, it was possible to confirm with high confidence that the timing of the SWD data was correct. One main advantage with this validation was the possibility to decide which velocity model would be the best to use during geosteering to optimize the well trajectory (Figure 5).

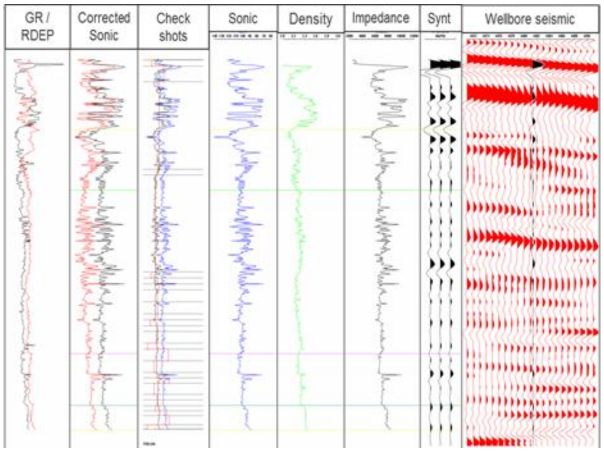

Figure 4 Welltie panel using the real-time sonic, density and checkshot data. Note that the shallow seismic events have good correlation with the synthetic seismic. Zero time shifts were required to tie the seismic.

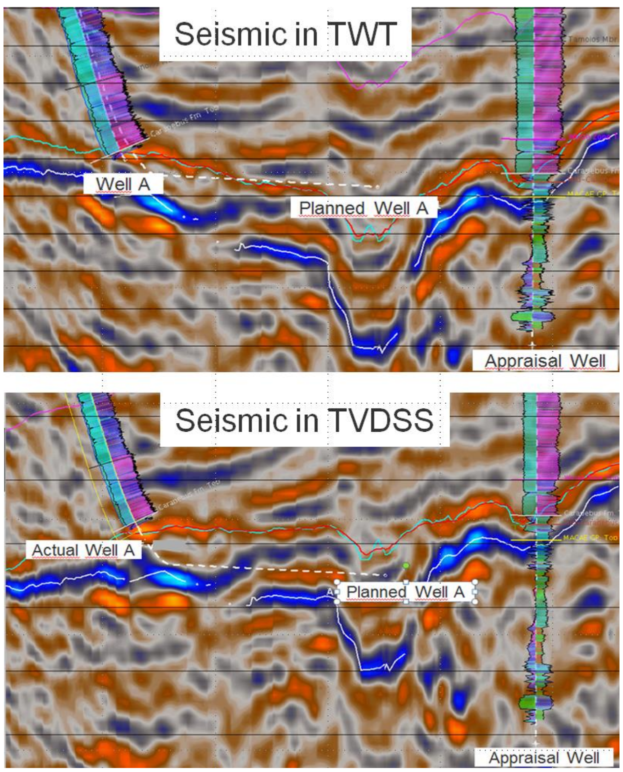

Figure 5 Bit location during landing of the 12 ¼" section in two way time (top) and depth (bottom). Note the dip change after depth converting the seismic.

SWD image data

The issues experienced during acquisition compromised significantly the SWD imaging results. Timing errors on the recorded hydrophone data and the poor data on the X and Y geophone components led to a poor SWD image quality that could not be used in further evaluations. The X and Y components were affected by a strong 15-17 Hz ringing (Figure 6 and Figure 7). The X and Y amplitude spectrum are very similar, indicating the tool orientation remains approximately similar along the whole survey.

The main challenge in processing VSP data in horizontal wells is to separate the downgoing and the upgoing wavefields, since standard separation techniques cannot be applied due to the lack of differential dip between the wavefields. For this reason, SWD data in near horizontal wells has to make use of the geophone–hydrophone summation in order to generate separated wavefields (i.e., 4C processing).

The first step in this process is to rotate the recorded components to three new components – one true vertical and two true horizontal, in order to use them in further steps during the processing. After that, the hydrophone response is matched to the geophone response and these are either summed or subtracted in order to obtain up and downgoing wavefields. However, the noise present in the X and Y components of the data, also introduced noise into the true vertical and true horizontal components, and this compromised the separation results heavily. The noisy horizontal components made this stage impossible for this well.

A seismic image in the non-horizontal part of the trajectory was created, but also this part of the data was noisy. The final SWD image spliced into the surface seismic section (Figure 8) shows that not much useful information could be extracted. The initial plan was to have a better understanding of the structure of the base reservoir, to allow for an improved mapping. However, the noise hampered any interpretation.

So far, analysis indicates that the noise could be caused by problems with the BHA configuration and stabilizers. Since the contact between the geological formation and the SWD tool is established by gravity only, the S/N ratio is dependent of the hole inclination and tool movement. It is assumed that this could be another possible reason for the imaging problem. Another cause could be vibrations on the rig.

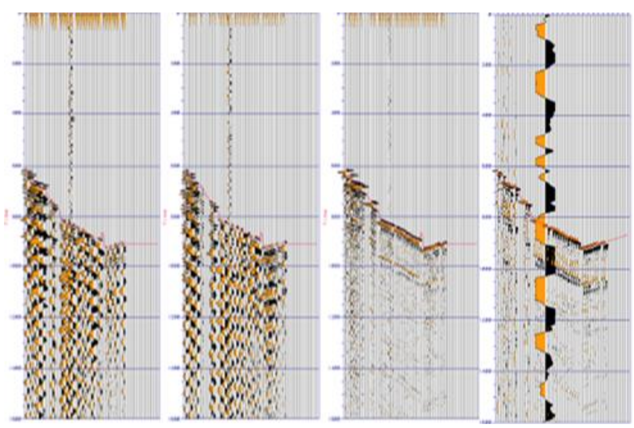

Figure 6 Run 1 X, Y and Z components – Stacked downhole geophones and downhole hydrophone. The low frequency ringing on X and Y components made the data useless for imaging.

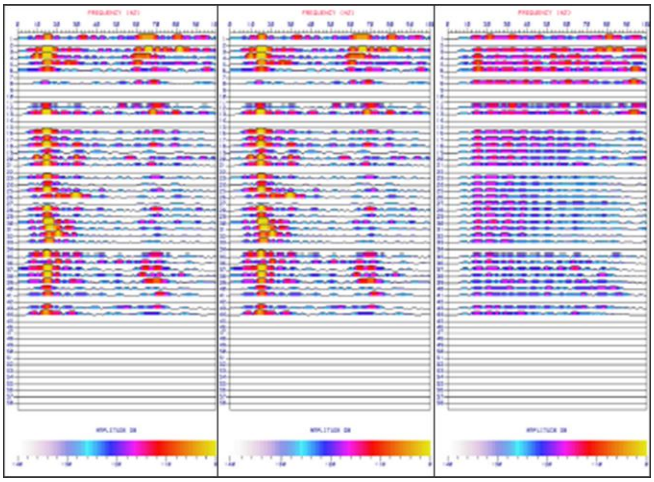

Figure 7 Run 1 amplitude spectrum in X, Y and Z components. The horizontal components are strongly affected by 15 Hz noise.

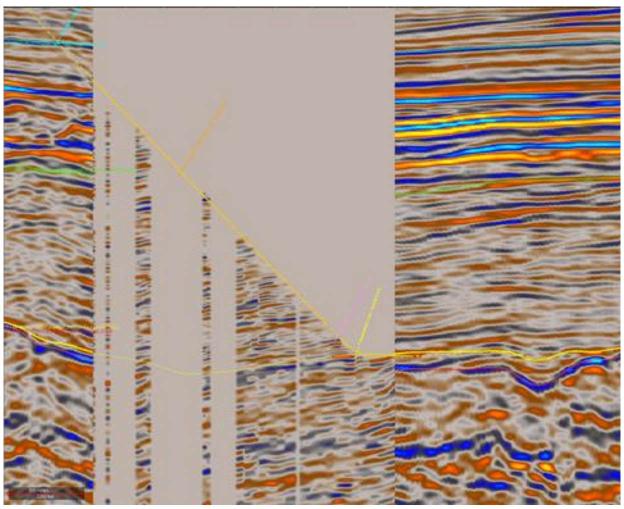

Figure 8 SWD image data spliced into the PSDM full stack data.

Conclusions

The first SWD experience on the Peregrino field sought to decrease depth uncertainties related to velocity wedges and noisy seismic data in the overburden. Although some problems were encountered during the acquisition phase, the main goal of the project was reached. Real-time checkshot data worked well as a tool to correlate seismic data and well data, and strong seismic reflectors in the overburden acted as validation points for the time-to-depth conversion. Therefore, it was possible to get a reliable prediction of the location of the bit in the time domain, before performing the depth conversion. The depth prognosis for the reservoir section could be updated, and the uncertainty in the landing strategy and the geosteering plans could be reduced (figure 5).

From the SWD imaging attempt, no useful information was extracted, since the dataset was seriously compromised by low-frequent noise.

Even with the technical problems experienced during acquisition, the potential of the SWD methodology was confirmed.

Acknowledgments

We would like to thank Statoil Brasil Óleo e Gás Ltda and their partner Sinochem Petróleo Brasil Ltda for permission to publish this study. The seismic data on Peregrino is proprietary to PGS. Additionally, we thank Baker Hughes for acquiring and processing the data, providing continuous support.

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