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Surface Seismic While Drilling - Imaging of Well Bores in Seismic Context

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Summary

Conventional methods for positioning of the well bore during drilling are based on using down hole logging. Measurements from these tools are used to compute the well path. To get an understanding of where the well is in the subsurface the well path is projected onto the seismic image from the particular area. This procedure is, in general, problematic as there are uncertainties in the measurements, the seismic image and methods, and differences in accuracy between the methods in use. The surface seismic while drilling (SSWD) method is a new method that uses surface seismic to image well paths. The advantage of SSWD is that no down hole tools are needed to image the well. There is also no need for stopping the drilling operations to image the well. We discuss the SSWD and conventional methods for well bore positioning and show examples on how the SSWD method is used to home-in a relief well to stop a blowing well.

Introduction

To avoid hazardous and unwanted sections during drilling operations it is important to know the position of the well trajectory. Loss of well control can lead to a blowout which is by far the most severe and disastrous event that can happen in a drilling operation.

The conventional methods for measuring the well position are based on a number of tools installed in the drilling equipment (Jamieson, 2012). The challenge with the conventional methods is that they claim an absolute position of the well and the well path is normally projected onto the seismic image. Absolute well positioning based on conventional tools is difficult to correlate to seismic images due to uncertainties in the migration velocity model and the imaging algorithm itself. The uncertainty of the well position relative to the geological unit identified on the seismic section is much larger than the error in the absolute position of the well. In settings with complex geology a small shift in depth for a reflector in the image may result in entrance into unwanted geological units. Furthermore, in areas with many well trajectories, it is essential to not intersect existing well bores. Because of this, much attention has been invested in directional drilling and measurements of the well position during drilling operations (Jamieson, 2012).

One may ask why there are well failures when the conventional positioning methods claim high accuracy in the absolute position of the well. One answer is that the high level of accuracy has limited relevance when compared to the relatively low accuracy of structural positioning using seismic data and imaging. In other words, there are only minor benefits of the high absolute accuracy of the conventional methods when used together with seismic imaging methods. Hence it is important to develop methods that image well bores using seismic principles.

Under certain circumstances vertically aligned objects with a diameter smaller than the seismic wavelength may be visible using seismic imaging methods (Løseth et al., 2011; Raknes and Arntsen, 2014). Surface seismic while drilling (SSWD) is a new method utilizing this fact, and the seismic diffraction response from the borehole in particular (Evensen et al., 2014). The method is used for imaging well paths using surface seismic data (Moser et al., 2016a,b). The benefit of this method is that the well is imaged in *seismic context* meaning that the well path is imaged using the same imaging methods as the seismic image removing the uncertainties in projecting the well onto the seismic image. In other words, the SSWD method is giving the position of the well relative to geological surroundings in the seismic image. Furthermore, no extra tools are needed in the well during drilling to use the SSWD method, thus the drilling operations can be run without interruption using SSWD.

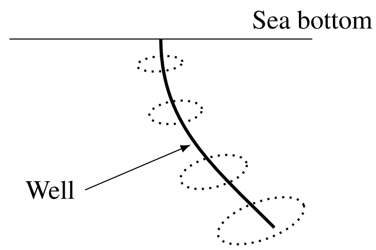

Figure 1: Uncertainty ellipsoids in conventional drilling methods.

The main application for SSWD is in relief well drilling operations where the method potentially may reduce the associated drilling time as well as increase the accuracy for intersecting the blowing well. In this paper we discuss the conventional methods for well bore positioning and the SSWD method. We demonstrate how the SSWD method can be used in relief well drilling where it is used to home-in the relief well for intersection of the blowing well without the need of any other tools in the well.

Conventional borehole positioning methods

There exist different methods for measuring the absolute position of the well with high absolute accuracy (see Jamieson (2012) where further references are found).

Conventional borehole positioning methods are based on introducing a tool in the well that can measure azimuth, inclination and toolface angle. At given intervals these values are measured and a vector giving the direction of the well head is obtained. To create the well path the vectors from the different positions are summed together. The length of the well is found by measuring the length of the drill sections before they are run into the hole. It is important to emphasize that the length of the well can change as a result of stretch in the steel, temperature changes or other environmental effects. This results in an uncertainty of the total well length.

The tool in the well can be either a magnetic tool or a gyroscope. The magnetic tools are used in combination with accelerometers to find the azimuth, inclination and toolface angle. The magnetic tools are used to measure the local magnetic field in the well and use the magnetic field as a reference point for the well position measurements. They are sensitive to any disturbance from the environment (i.e. any steel in the well, crustal anomalies or magnetic storms). Furthermore, the magnetic tools have problems when used in near vertical boreholes as the horizontal component of the earth's magnetic field becomes small and hence difficult to measure properly. Furthermore, due to changes in the magnetic field to the earth these tools have problems in polar regions. The gyroscope, on the other hand, consists of a balanced spinning wheel mounted on a gimbal. When used as positioning tool the wheel is spinning at a given initial position. The resulting moment of inertia of the wheel will keep the initial position fixed regardless of the position of the well. The initial position for the gyroscope is used as a reference point for measuring the position of the well in the subsurface. Even though gyroscopes traditionally are accurate and elegant tools there are uncertainties using them for well positioning. The gyroscope is sensitive to mechanical shocks and vibrations that may knock the wheel out of its initial position. Furthermore, there may be friction forces between the wheel and the gimbal resulting in drift when running the tool. One of the benefits of gyroscopes is that they are not affected by magnetic disturbances and may therefore be used when steel is present in the well.

The uncertainty in the well position is the accumulated sum of the uncertainties from each measurement from the tool (i.e. magnetometer or gyroscope) and external sources from the environment from the surface down to the drill bit. The uncertainty is typically larger in the lateral direction than in the vertical direction. Instead of determining an absolute position in space, the wellbore position is determined by an ellipsoid of uncertainty (Figure 1). The accumulated uncertainty ellipsoids may be large for long wells (Buchanan et al., 2013).

Surface Seismic While Drilling (SSWD)

Surface seismic while drilling (SSWD) is based on using seismic data acquired at the surface to image the well path (Evensen et al., 2014; Moser et al., 2016b). The method uses conventional seismic equipment (receivers and sources) together with specialized setup, procedure and processing to accurately display both wells on the seismic image. The method is based on the principle that the wellbore represents a reflective and diffractive object for the seismic waves, and therefore is not dependent on the presence of steel in the wells (Figure 2).

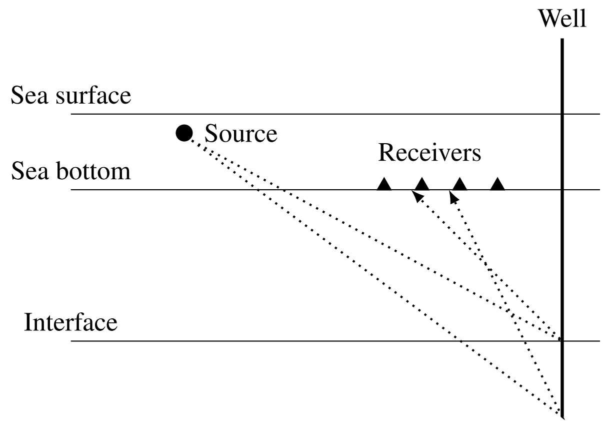

Figure 2: Overview of the wave events (dotted arrows) used in the SSWD method.

The applications of SSWD are in regular and relief well drilling operations. The advantage of the SSWD method is that as the method uses geophysical principles, no tools or steel are required in the well. The blowing wells can be intersected by the relief well at deeper depths than normal where there is no steel casing present. A deeper intersection point is favourable as this increases the hydrostatic head, increases the frictional pressure drop, and allows a lower density kill fluid to be used. In situations where steel is present, SSWD can be used to maneuver the relief well close to the blowing well such that conventional magnetic ranging tools can be used on the last part of the drilling operation. This may reduce the time associated with conventional relief well drilling. Moreover, SSWD does not require interruption of the drilling operation.

A favourable property of the SSWD method is that the well path is imaged directly into the seismic image. Hence, the position of the well path is imaged relative to the geological surroundings. This means that the drill bit is imaged in relation to and consistently with the structural geology. Thus, if the drill bit is imaged outside a target geological unit, then the drilling team can be sure that the drill bit has not entered the particular structure. Furthermore, any other wells in the particular area are also imaged with SSWD giving important information on the position of them relative to the well to be drilled. To sum up, the uncertainties in the mapping of the well path into the seismic image are removed since both the well and the sediments are imaged simultaneously and consistently with the same imaging method.

Examples

The SSWD method has been used to image vertical well bores (Evensen et al., 2014; Moser et al., 2016a) and an already drilled relief well using streamer field data (Moser et al., 2016b). To illustrate how SSWD may be used during relief well drilling we use a synthetic model based on outcrop data from the Kvalhovden area, east-Spitsbergen, Norway (Johansen et al., 2007). In this model we simulate a reservoir in one of the rotated fault blocks with a vertical production well (Figure 3a). The pre-stack depth migrated (PSDM) image is given in Figure 3b. Now, assume that due to some external reasons the production well develops into a blow-out and needs to be stopped. The procedure for doing this is by drilling a relief well that intersects the blowing well at the bottom (dotted line in Figure 3a).

We simulate four seismic surveys at different stages of the relief well drilling. Receivers with a spatial spacing of 10 m are placed at the sea surface and 401 shots with a shot distance of 5 m are used in each survey. The seismic data at each stage is generated using ray-Born modelling. For each of stages SSWD is used to image the relief well.

In the first stage the well is drilled down to approximately 425 m depth and position 720 m. In the SSWD image (Figure 3c) both the relief and the production well are clearly visible. Diffraction responses from the wells are visible at the interfaces in the geological structure. This image in combination with the PSDM image (Figure 3b) can be used to identify in which geological unit the drill bit is located. In each of the next stages the relief well is drilled about 50 m until it intersects the blowing well (Figure 3f). The SSWD images from each of the stages are given in Figures 3d–3f. Note that we have used time-lapse data to only image the newly drilled section of the relief well in the figures. We observe that the newly drilled sections are clearly visible in the images by their intersection with geological interfaces and the drill bit itself.

Conclusions

SSWD is a method that is used to image well bores using seismic data at the surface and without the need of down hole tools and interruption of the drilling operation. Examples presented here show how the SSWD method can be used to home-in a relief well and intersect a blowing well at the bottom. The advantage of SSWD compared to the conventional methods is that the well bore is imaged in *seismic context* and thus the well path is not projected onto the seismic image. For relief well drilling, the uncertainty of the relative distance between the two wells is an area for further assessments. In cases where steel is present in the bore hole, SSWD may be used, in addition to conventional logging tools, to guide the relief well so that conventional magnetic ranging can be used for the final alignments and interception of the blowing well. This may reduce time and leaks to the environments.

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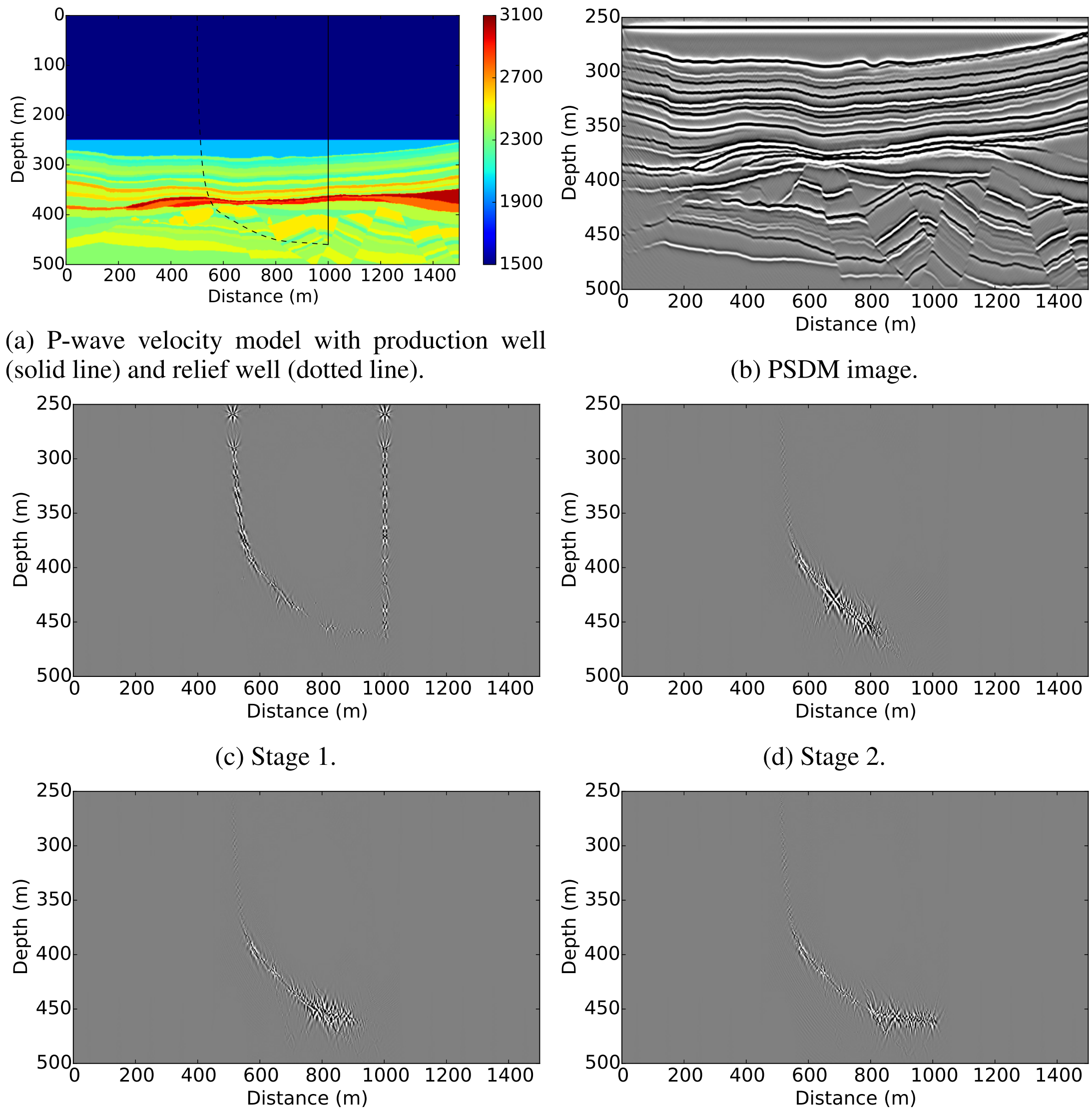

(a) P-wave velocity model with production well (solid line) and relief well (dotted line).

(b) PSDM image.

(c) Stage 1.

(d) Stage 2.

(e) Stage 3.

(f) Stage 4.

Figure 3: The P-wave velocity model and the migrated images using SSWD. Note the imaged diffractions from interface intersections and the drill bit.

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