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REAL-TIME PORE-PRESSURE PREDICTION AHEAD OF THE BIT

FINAL REPORT
(January-September 2004)

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The project is a feasibility study on a new method for predicting pressure ahead of the bit in real time. The data requirements are surface seismic data, in the vicinity of the well, and real-time logs and check-shot measurements as the well is being drilled. The method consists of predicting the seismic velocities ahead of the bit by simultaneous use of the surface seismic and real-time check-shot information. Then, the predicted velocities are mapped to pore pressures using an equation or empirical relation appropriate for the area.

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RESEARCH SUMMARY

Title	Real-time pore-pressure prediction ahead of the bit.
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GRI Contract Number	8693 (Subcontract No. R-515)
Principal Investigator(s)	Cengiz Esmersoy
Report Type	Final Report
Report Period	January – September 2004
Objective	Predict formation pore pressures ahead of the bit while the well is being drilled in a timely fashion to help the drilling process.
Technical Perspective	Pore pressures of formations is one of the big problems facing the drillers in exploration areas. The pore pressure, together with fracture gradient, determines the amount of mud weight that is needed. Too much mud weight fractures the rock, too little mud weight allows formation fluids to come into the well and can cause blow-outs if not controlled. In this research we have studied the feasibility of a new approach to estimate the pore pressures of formations before the drill bit drills through them. Knowing the pressures ahead of time will allow the drillers to adjust mud weight or take other measures to avoid problems.
Technical Approach	Surface seismic data has been used in the industry to predict formation pore pressures before any well has been drilled. This is done by estimating the subsurface velocities from seismic and then using a number of velocity-pressure relations appropriate for a given region. We propose to combine the surface seismic data with a set of real-time well logs, acquired as the well is being drilled, to make a more reliable estimate of velocities ahead of the bit. In particular we make use of the real-time check-shot measurement (Seismic While Drilling) that was not available up until recently. To combine these two pieces of information, the surface seismic data are inverted for seismic velocities ahead of the bit while the inversion is constrained with the real-time well-log and check-shot measurements. We use a full-waveform inversion algorithm that uses an initial velocity (and density) fields as input and then modifies these fields to match the seismic

data. The log and check-shot information up to the depth point they are available are used in constructing this initial model. The objective of the research was to demonstrate the feasibility of this approach by synthetic studies and by using actual seismic data from a field where check-shot and log information were available from wireline measurements.

Results

We have demonstrated that incorporation of check-shot and well-log data significantly improves the velocity estimates ahead of a well. Field data inversion study showed that big improvements can be seen particularly in gradual changes of velocities that are typically associated with pore-pressure variations in areas like the Gulf of Mexico.

INTRODUCTION

Pore pressure of formations is one of the big problems facing drillers in exploration areas today. The pore pressure, together with fracture gradient, determines the mud weight that is needed. Too much mud weight fractures the rock, too little mud weight allows formation fluids to come into the well and can cause blow-outs if not controlled.

Pore Pressure Prediction (PPP) can provide timely warning of the potential for a gas kick so that the driller can adjust mud weight well before a kick is allowed to occur. The consequences of a gas kick are usually very costly delays in the drilling process while steps are taken to equilibrate the pressure in the well. In extreme cases a gas kick can become a blow-out with much more catastrophic consequences up to and including the loss of the well.

PPP also impacts the decision for placement of casing strings. The decision to place casing is determined by the stability of the well at a particular level or levels, and by the perceived risk of encountering a gas kick. In the case of very expensive Deep Water wells, a conservative approach is taken by the driller, in which a more than optimal number of casing strings are placed. Placement of casing requires that drilling be stopped and the drill string removed from the well. With accurate PPP one can reduce the total number of casing strings thereby dramatically reducing the cost of the drilling operation.

Accurate and timely PPP is a “Driller’s Tool”, meaning that it is an aid to the driller of a gas or oil well that allows him to optimize the drilling process for time and cost and even optimize the final executed well design. This technology will give the most monetary benefit and have the most use in Deep and Ultra-deep Water drilling for gas and oil. The cost of rig time on a Deep Water drilling platform or drilling ship can be up to $0.5M per day. Any technology, such as PPP, that can reduce or eliminate unplanned delays in the drilling process or that can provide timely input into the driller’s decision-making process can easily deliver savings to the driller on the order of $1M+ for a single well.

Most pore-pressure look-ahead is done today by one of three approaches. One approach is to observe the change in the trends of the logs combined with some geological models. For example, in the Gulf of Mexico sonic logs are used for pore pressure prediction. In areas with normal pressure, the sonic logs are expected to increase with depth due to compaction. If the Logging While Drilling (LWD) sonic log starts showing a consistent slowing trend away from the compaction curve predicted by the geological model, then it is used as a likely indicator of increased pore pressure ahead of the bit.

Aside from this type of prediction from logs, seismic is the only measurement that is sensitive to pore pressure and that is deep enough to make a direct look at pore pressure ahead of the bit. In the second approach pore-pressure maps are obtained from surface seismic data prior to drilling. For this, velocities are estimated from pre-stack surface seismic data, and then a velocity to pore-pressure transform, appropriate for the area, is applied. This map has the coordinates of shot position (horizontally) and seismic travel time (vertically). When the well is being drilled the bit location is marked on this pore-pressure map (for example by using real-time check-shot measurements), therefore providing a way of telling what pressures are expected ahead of the bit.

The third approach to pore-pressure prediction ahead of the bit is the look-ahead impedance inversion using VSP data. If the pore-pressure change is associated with a sharp change in acoustic impedance, then the look-ahead imaging could work well. However, this approach does not work in cases where the pore pressure builds up gradually and it is not associated with a sharp impedance change. In this case there would not be a seismic reflection event from the pore pressure zone and there would not be a well-defined pore-pressure "target" on the look-ahead image.

THE BASIC IDEA

The main idea behind our approach is to get "look-ahead velocities" in near real-time by using surface seismic data and real-time logs and check-shots together (Esmersoy and Clark, 2003). These velocities are related to pore pressure by the transforms in use today giving a PPP ahead of the bit. Since we are using the velocities to predict the pore pressure and not relying on sharp impedance variations, this approach will work with gradual pore-pressure variations.

Surface seismic data are routinely used for estimating velocities of subsurface formations (Yılmaz, 1987). These velocities are then used for depth migration of seismic data or for estimating some formation properties such as pore pressure. The velocity estimates from the surface seismic measurement become less accurate with increasing depth. For drilling purposes the velocities obtained from surface seismic are known as the pre-drill velocities as they are obtained during the planning stage before any wells are drilled. As a well is being drilled, the accuracy of the pre-drill velocity estimates ahead of the bit can be improved in real time by incorporating the Seismic While Drilling real-time check shot information. As shown in Figure 1, the idea is to re-process the surface seismic data acquired in the vicinity of the well by using the velocities measured by Seismic While Drilling up to the bit depth B. For a simplified model in Figure 1, where we represent the formations down to the bit depth with an average velocity Vo, and the formations between the bit and a reflector by Vp, the reflection travel time observed by a surface source-receiver pair is given by

$$T(V_p, R) = \frac{\sqrt{R^2 + X^2}}{V_p} + \frac{\sqrt{B^2 + (H - X)^2}}{V_o}; \quad X = \frac{RH}{R + B}$$

where,
H: source/receiver offset; is known, several values of T are measured for several offsets
B: bit depth; is known
Vo: average velocity from the surface to the bit depth; is measured by real-time Seismic While Drilling
R: reflector distance from the bit; is unknown
Vp: average velocity in the zone between the bit and reflector; is unknown

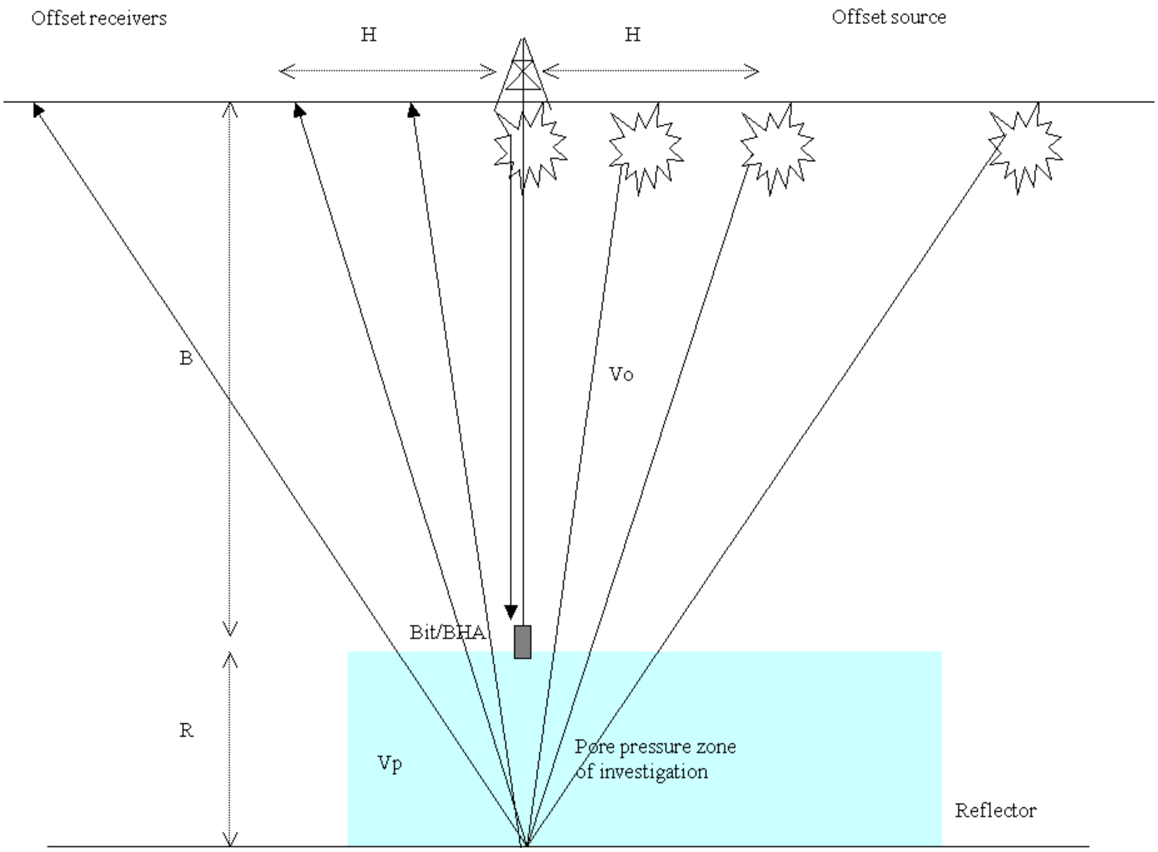

Figure 1. The basic concept.

In a more realistic representation of the subsurface the velocity model will consist of layers. The velocities of the layers down to the bit depth will be obtained from Seismic While Drilling check-shot information and optionally sonic logs. The velocity model for the region between the bit and the reflector may be modeled as one effective layer, it may be a number of layers, or it may be represented by a parameterized curve allowing for some smooth variation with depth. The reflection travel time T could be computed by using a ray-tracing algorithm, and the unknown parameters (distance to boundary R and the velocity model parameters) may be estimated by fitting the computed travel time values to the measured ones, for example, by using a least-squares technique.

Another approach, Prestack Waveform Inversion (PSWI), that we have taken in this research, is to use the full waveforms instead of just the travel times. In this case for a given subsurface velocity (and density) model the synthetic waveforms are computed. Then, the model velocities (and densities) are varied until the computed waveforms agree with the actual measurements. This technique has the advantage of utilizing both amplitude and travel-time information in the data, however, the type of subsurface models that can be inverted may be limited because of the computational costs.

Regardless of the inversion approach used, the workflow is as follows:

1. Normal Seismic While Drilling operations are followed and real-time time-depth data (and sonic, density logs if available) are obtained at the wellsite.
2. These data are then sent to a surface seismic processing workstation and the surface seismic pre-stack waveforms are re-inverted for velocities below the bit. In this inversion the inverted model is constrained such that it is consistent with the measured time-depth curve from the surface down to the bit location. It is expected that the velocities inverted this way will be more accurate than the results from inverting the surface seismic waveforms alone.
3. Again, inverted velocities are interpreted in terms of pore pressure.