Crosswell source-receiver geometry and drilling economics BG 1.2

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Summary

Crosswell seismic methods can be used as an integrated part of the drilling decision process during development of an oil or gas field. The cost of the crosswell data acquisition and associated extra drilling can only be justified if the crosswell data is less than the risk-weighted cost of drilling additional production wells. Modelling of the crosswell objective prior to data acquisition helps to minimize both crosswell data acquisition costs as well as drilling costs.

Introduction

During field development a dry hole is sometimes drilled in close proximity to a producing well. In the absence of well completion problems, this lack of production usually means that there is a barrier to fluid flow between the dry hole and the producing well. The barrier might be in the form of a fault zone or a stratigraphic termination, as is depicted in Figure 1. Crosswell seismic surveys are sometimes conducted to determine where a fluid flow barrier is located between a producing well and a nearby dry hole. Once the barrier has been located, informed decisions about further drilling can be made.

The purpose of this paper is to discuss some important aspects in determining at what point crosswell seismic data becomes an economically justified part of the drilling decision process. An overview of the decision process is presented and a hypothetical example is presented. The example uses the model shown in Figure 1. The assumptions of the example study are that a well was drilled on the left side of the model in Figure 1 and intersected the reservoir. A second well was drilled on the right side of the model but did not intersect the reservoir. A decision must be made as to whether or not another well will be drilled and if one is to be drilled, then where it will be sited.

Lateral resolution factors of a crosswell survey

The stated purpose of a crosswell survey in this study is to locate the lateral extent of a reservoir that terminates somewhere between the producing well on the left of Figure 1 and the dry hole on the right of Figure 1. Obviously we would like to have the best possible lateral resolution in the tomogram to maximize the certainty of where the reservoir terminates. Both theory and experience show that lateral resolution in travel time tomograms is gained by having a large range of raypath angles through the target. This requirement is at odds with standard, and prudent, drilling practice of drilling production wells just deep enough to allow complete logging of the producing formation. The short boreholes below the formation generally restrict crosswell raypath angles to a narrow range and therefore the lateral resolution of the resulting tomogram is not as good as it could be. The most direct way to increase the angular raypath coverage is to extend the boreholes deep enough to accommodate the crosswell seismic sources and receivers. In production drilling, the cost of the additional drilling plus the cost of the crosswell survey would have to be justified by the information provided by the crosswell survey.

Economic factors to be evaluated

Among the considerations when contemplating a crosswell survey are:

- how much the crosswell survey will cost
- the cost of extra drilling in order to increase the raypath coverage and the crosswell lateral resolution
- the expected monetary return from additional wells
- the risk-weighted cost of drilling another well without the benefit of crosswell data to guide the drilling location
- delayed production while the crosswell survey is being recorded

The term "risk weighted" refers to the increased risk of not intersecting the reservoir with another well if geophysical data is not used.

Geophysical modelling

A key component in the drilling decision process is determining crosswell data acquisition parameters that adequately determine the lateral extent of the reservoir at a minimum cost. This determination can be made through modelling. A geophysicist can use velocity logs from the wells in addition to geological knowledge of the reservoir to construct a tentative velocity model of the area between the producing well and the dry hole. The velocity model will be used to create a synthetic crosswell seismic dataset. The synthetic dataset should have more dense coverage and have a source and receiver depth range that is greater than is likely to be recorded in the actual crosswell survey. The large nutnber of sources and receivers in the model dataset allows subsets of the travel times to be used to calculate a series of tomograms. The tomograms can be compared to show the minimum crosswell acquisition effort required to image the reservoir. The lateral extent of the reservoir can be changed and crosswell data modelled again to be certain that the acquisition parameters will image the likely range of reservoir configurations.

An example

The velocity model in Figure 1 is used as an example to walk through the decision process.

Modelling An acoustic finite difference modelling algorithm was used to model crosswell travel times through the velocity field. A 100 Hz zero-phase Ricker wavelet was used. The sample interval of the data was 1.0 ms. A total of 500 sources and 500 receivers were modelled at a depth interval of 4.0 ft (1.2 m) from a depth of 1000 ft (3050 m) to 3000 ft (915 m). This is many more source-receiver pairs than would be recorded in a real crosswell survey, however this of data gave maximum flexibility in selecting subsets of source-receiver pairs to compare crosswell geometries. The entire dataset was generated in approximately 2 hours on an IBM RS6000/580 workstation. A raytrace based modelling method would likely take less time.

Source-receiver geometries tested Three different source-receiver geometries that were tested are reported here. The source and receiver depth ranges are summarized in Table 1.

Case Number	Source Depth Range	Receiver Depth Range
Case A	1600 - 2150	1600 - 2150
Case B	1600 - 2650	1600 - 2150
Case C	1600 - 2650	1600 - 2650

Table 1. Source and receiver depths for the three cases reported. Depths are in feet.

The tomograms for cases a, b, and c are shown in Figures 2a, 2b, and 2c respectively. Each tomogram took less than 10 minutes to generate.

Comparison of tomograms Figure 2a shows the tomogram with the minimum angular coverage tested. This case shows the result of recording a crosswell survey without any additional drilling to accommodate a crosswell survey. The maximum depth of the source and receiver below the reservoir base in this case is 25 ft (7.5 m). Figure 2B is an example in which just the well on the right hand side of the model was deepened to 475 ft (145 m) below the base of the reservoir to gain additional angular coverage. Figure 2c shows the case in which both the source and the receiver well were deepened to 475 ft (145 m) below the base of the reservoir. This case gives the maximum angular raypath coverage tested.

A comparison of Figure 2a (minimum coverage) and Figure 2b (one well deepened) shows that little lateral resolution is gained by having incomplete coverage of the interwell region. The raypaths from the deeper well below the reservoir have only a narrow range of angles by which to determine the velocity field below the reservoir. The solution (output velocity field) is therefore badly underconstrained and travel time errors for rays from the deeper part of the right hand well and the well on the left can be freely taken up in velocity variations below the reservoir.

Figure 2c (maximum coverage case) clearly has the best lateral resolution of the 3 cases shown. The velocity field gives the most accurate representation of where the bulk of the low-velocity reservoir is located in the original model (Figure 1). This is not a surprising result given that this case has the maximum raypath information to work with in deriving a velocity field.

Drilling and survey cost estimates A recent well drilled in Albany County, Wyoming, USA had drilling costs of approximately $8000 per day. Drilling time from the surface to the target was about 25 days. At the depth of the target the drilling rate was about 100 ft/day (33 m/day). The total cost of drilling the well (not counting mobilization of the drilling rig) was then about $200,000. Suppose that a drilling engineer and geophysicist decided that the coverage provided by case C is the minimum effort required to give the needed confidence in imaging the reservoir. The additional drilling costs to deepen the boreholes would be about $72,000 to accommodate 'a crosswell survey (9 days times $8,000/day). A crosswell survey of the magnitude shown in Cases a, b, and c above can cost anywhere from $50,000 to $200,000 depending upon factors such as equipment and mobilization costs. Assume for this case that the cost is $120,000. The total cost of the crosswell survey, including extra drilling, would be about $198,000, or approximately that of another well. The election to drill another well with or without the guidance of a crosswell survey would depend upon the drilling team's level of confidence that a productive part of the reservoir could be intersected without the aid of the seismic data.

Discussion The model shown in Figure 1 has wells 500 ft (150 m) apart. Most well spacings in developed fields on land are on the order of several thousand feet (1000 m) though there are many exceptions of both greater and lesser well spacings. As well spacings increase, the amount of extra drilling for a crosswell survey must also increase in order to maintain a high angular coverage. Additionally, effort (cost) of the crosswell survey must also be increased if the same density of coverage is to be maintained. In short, the benefit of crosswell seismic data must be evaluated on a case-by-case basis and the costs versus the benefits weighed against one another. The purpose of them modelling is to determine the minimum effort required to image the reservoir. Fortunately, the modelling and tomogram calculation can be done in a short period of time (just a few hours) which is soon enough to decide if further drilling needs to be done while the drilling rig is still on site; thus saving the cost of moving a rig back onto the site to deepen the well to accommodate a crosswell survey. Such quick reaction time to drilling requirements implies that the geophysicist and engineer work as an integrated team with the engineer.

Conclusions

A geophysicist and drilling engineer can work together as an integrated team to optimize drilling strategies in field development. Crosswell seismic data can be used to image the lateral termination of a reservoir however, the benefit of the crosswell data must be balanced against the cost of associated extra drilling and the risk of drilling without crosswell data as a guide. Modelling of the crosswell data and calculation of tomograms can be achieved within a single day on a modern computer workstation. This enhances the ability of a geophysicist to interact with drilling engineers while the rig is still on site; thus, the incremental cost of extra drilling is minimized.

Acknowledgments

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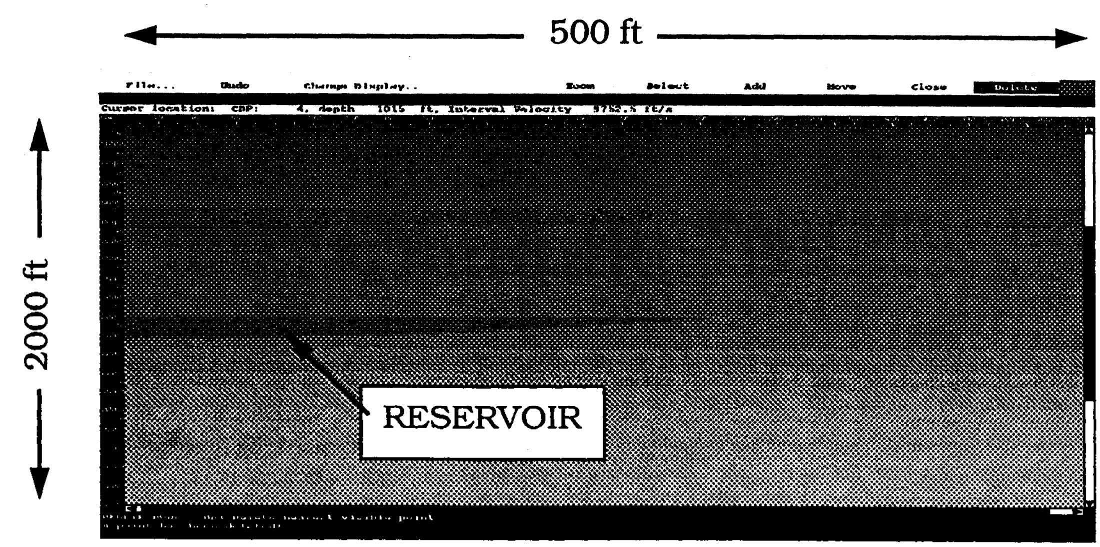

Figure 1. **The** figure is a velocity field in which a reservoir begins at the left side of the model where it has a thickness of 125 ft (38 m) and extends to the right 300 ft (92 m) where it thins to 0.0 ft The velocity field increases linearly from top to bottom at a rate of .74 ft/sec per ft (.74 m/sec per m). The reservoir has a velocity of 9995 ft/sec (3045 m/s) which is a 4.5% contrast with the surrounding rock.

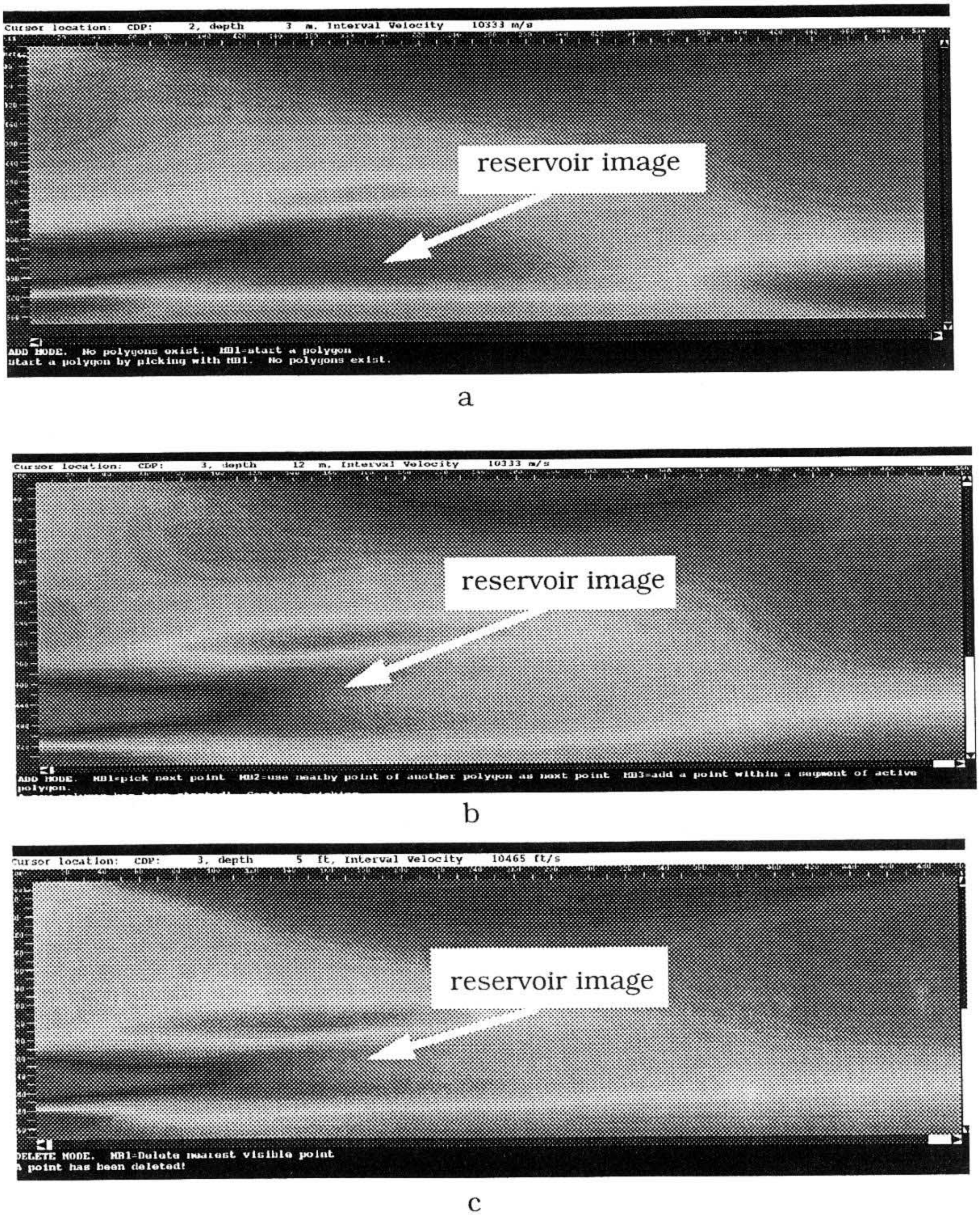

Figure 2. a) Tomogram from Case a, the minimum effort data acquisition. b) Tomogram from Case b, right hand well deeper than left well. c) Tomogram from Case c, both source and receiver well are maximum depth. The Tomogram in Figure c gives the best vertical and lateral reolution of the three cases.