INCORPORATION OF SEISMIC INTERMEDIATE-SCALE DATA FOR IMPROVING RESERVOIR MODELING

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Abstract

A description of reservoir heterogeneities at different scales is crucial for improvements in reservoir characterization. In reservoir modeling approaches based on conventional seismic and log data the gap between short and large scales is usually filled by geological and/or geostatistical inferences, which are not guided by field data.

That lack of data providing intermediate-scale information is critical in fields where the distribution and spatial patterns of heterogeineties affecting important fluid flow properties are beyond the seismic lateral resolution and cannot be statistically inferred using the well distribution. Although being too expensive or impractical to "shoot" across every interwell distance, seismic profiles such as crosswell surveys can provide that information measured over small volumes.

In this work a multi-scale approach was developed to integrate seismic intermediate-scale data and the conventional short and large scale data, represented by logs and surface seismic data respectively. Intermediate-scale data obtained by short and far-offset crosswell surveys, vertical seismic profiles and high resolution seismic lines can be geostatiscally incorporated in this approach in order to provide more complete reservoir descriptions.

The approach employs the available seismic data as reference data in order to select traces of acoustic models derived from sequential Gaussian simulation honoring log data. At the end of an iterative process, a new high-resolution acoustic model is generated. The set of traces occupying interwell positions is filtered by 2D operators designed to mimic such specific crosswell imaging and each trace is then submitted to a post-matching operation using the collocated field trace.

The post-matching is designed to accept the simulated high resolution traces whose filtered versions have higher correlation with collocated field traces. These simulated high resolution traces serve as conditioning data for the next simulation. An interwell model at the intermediate scale is the final product of this first step. Such upscaling and post-matching is then repeated to the larger-scale seismic traces, using logs and the interwell image as hard data to feed simulations. The final product is an optimal acoustic property model constrained by all logs and by seismic surveys.

This multi-scale incorporation was applied using field and synthetic data. From the synthetic study, I found that the main impact on the model is caused by the incorporation of crosswell images obtained by shooting short distance surveys. Short-offset surveys provide a tool to map and recover a very fine layered and lateral framework. Crosswells and logs can be used to stochastically draw interwell models, which are then extrapolated under the constraint of conventional seismic data.

The field study using data from McElroy Oil Field, West Texas, showed that only the short-offset crosswell survey (interwell distance of 187 feet) can provide very high-resolution interwell image containing the necessary geostatistical link between acoustic properties measured at logs and at log-collocated traces. Higher vertical resolution tools like log data and short-offset crosswell image can be used to reduce large-scale seismic uncertainties providing improvements in reservoir acoustic models.

Since some reservoir and acoustic properties are directly related, the reduction of uncertainty achieved by building these acoustic models can be transferred to models of volumetric properties such as porosity. The integration must prioritize data with higher frequency content, i.e., should follow two steps: only short-crosswell data are used in the first post-matching , and additional lower resolution seismic data during the second.

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Chapter 1

Introduction

Reservoir characterization increasingly incorporates logs and seismic data aiming for better coverage of more scales of reservoir heterogeneity scales. Stochastic modeling is considered even better due to its ability to handle the larger amount of data and properly account for the precision and scale differences. The detailed resolution in 3-D is a particularly difficult task to handle since accurate information at many scales are required to adequately provide a reliable basis for volumetric calculations and to describe the flow properties. The incorporation of intermediate-scale information is necessary in cases where the range of heterogeneity sizes affecting important fluid flow properties are beyond the lateral resolution of surface seismic and cannot be inferred from logs based on the distribution of wells in the field.

Seismic intermediate scale data such as crosswell, vertical seismic profiles, and high resolution seismic lines, can fill different parts of the resolution gap between well and surface seismic tools. The potential of a multi-scale integration is to provide a better description of heterogeneity ranges for the purpose of reducing uncertainty and improving fluid-flow simulation study.

The literature show many 2-D cases of seismic intermediate-scale and log data integration for reservoir description. The same is true for 3-D cases based on logs and 3-D conventional surface seismic data. The major concern of this thesis is the generation of a geostatistical methodology to build stochastic 3D models based on multi-scale integration.

Crosswell surveys present a higher potential among the seismic intermediate-scale data, because a very fine layered lateral framework can be mapped and recovered from high resolution interwell images. But since interwell data are available only between a small number of wells in the field, the application of such data for 3-D model building is highly dependent on how successfully we can answer the following questions:

- How and when can we extrapolate information from a small number of interwell experiments to other areas of the field?
- What is the contribution of crosswell data to improve the calibration of surface 3D seismic data for building less uncertain 3D-reservoir models?
- How can intermediate scale information from interwell surveys help to build and to select high-resolution stochastic-images?

The major contribution of this thesis is the generation of a new methodology to incorporate seismic intermediate scale data, such as crosswell, vertical seismic profile and high-resolution surface seismic data for improving stochastic reservoir modeling. Another important contribution is to show that crosswell surveys can provide reliable high resolution interwell images, i.e. containing the necessary geostatistical links between acoustic properties measured at logs and at crosswell derived log-collocated traces.

The results achieved by this research are at the top of the list of improvements required for better stochastic model building:

- incorporation of intermediate scale from measured interwell information
- better calibration of tools
- reduction of uncertainty.

The aim of this research is to improve well and surface seismic-derived 3-D stochastic modeling through an integration approach incorporating intermediate scale interwell information. Improvements are expected due to a better coverage of the range of heterogeneity scales which govern the fluid-flow connectivity through the reservoir.

Higher vertical resolution data from logs and crosswell images can be used to reduce conventional seismic uncertainty and provide better reservoir acoustic models. Since some flow and acoustic properties are related, the reduction of uncertainty achieved by building these acoustic models can be transferred to models of volumetric properties such as porosity.

The geostatistical methodology applied in this thesis is performed in two steps: Log data constrain model realizations in the vertical direction; crosswell images, mostly obtained by shooting short distance surveys, provide data to map and recover a very fine layered lateral framework. These data are used in the first step to stochastically draw interwell models. These interwell models are then extrapolated under the constraint of conventional seismic data and field geology knowledge.

In the second chapter, we review of several stochastic methodologies being applied to incorporate logs and conventional surface seismic data. The integration methodology applied in this research is a 1-D post-matching technique, based on the paper of Bortoli, et al., (1993), which was modified to accept additional data and two-dimensional geotomographic filters. The advantage of this approach is to first use only log data to feed sequential Gaussian simulation of seismic realizations with high vertical resolution. Then conventional seismic data are employed as reference data to select better realizations that match each seismic grid node.

Any kind of seismic data can be used in such way for post-matching. In the third chapter we describe the methodology to incorporate all available multi-scale data in two steps. The first step consists on drawing interwell realizations using tomograms as reference data during the first post-matching. An application of step one is presented using data from a dolomite reservoir of the McElroy Field, Texas. The second step extrapolates log and the interwell image to areas where intermediate data are not available. The second step was added in order to prioritize the two types of seismic reference data.

Since the vertical resolution of crosswell velocity tomogram is still less than I desire, Chapter 4 is devoted to using the much higher vertical resolution available from crosswell reflection images. Several process flows which combine log data with the low frequency content of tomogram and the higher frequency content provided by reflection images are described and applied to data from the same oil field.

I then repeated the application presented in Chapter 3, but with two main differences in the field data case: firstly, the reference data contain higher vertical higher frequency content than the tomogram. Secondly, log data based simulations are done for three different main zones or layers, which are stacked to better reproduce the separate statistics of each one of the layers.

In the next two chapters we present the multi-scale data integration. In Chapter 5 the integration was shown using field logs and synthetic seismic data. This chapter also presents a brief description of the geology of McElroy Field and a discussion about the problem of reservoir characterization. A synthetic study was developed to evaluate the better way to extrapolate data from crosswell site to field areas where those surveys are not available.

Based on Tucker et al paper, (1997), we then introduce a new step consisting on an indicator simulation prior to the usual sequential simulations to model the reservoir main pay zone. The categories used for the indicator approach are five different open-hole log-clusters presenting a relationship with crosswell seismic amplitudes and diagenetical imprints inside the reservoir zone. In Chapter 6 we perform an integration using data from the same oil field.

Chapter 2

Background

According to Lake and Carrol Jr, 1986, reservoir characterization is a process for quantitatively assigning reservoir properties, recognizing geological information and assessing uncertainties in spatial variability. It is crucial for reservoir evaluation, forecasting and management, because real reservoirs present from large to small scale heterogeneities, i.e. from unit boundaries due to structural or facies distribution nature, which control the connectivity pattern of the reservoir, to the internal variability, which controls the fluid-flow sensitivities (Weber, 1982).

Continuously growing applications of geostatistical techniques for reservoir characterization have been verified in the last two decades. According to Dubrule (1993), the activity has been transformed into an interdisciplinary issue impelling the development of sophisticated geostatistical approaches for data integration. Moreover, following Deutsche *et al* (1997), data integration is currently accepted to be the best recipe for obtaining improved stochastic reservoir models, constrained to the maximum amount of data, that properly account for the precision and scale differences of each data source and its volume of support.

Among many other papers, Journel and Alabert (1990), Alabert and Massenat (1990), Haldorsen and Damsleth (1990), Araktingi *et al* (1993), Deutsch (1993), present theoretical support and field applications of geostatistical approaches to integrate additional information provided by seismic data, outcrop or analog studies, geological and engineering expertise.

Current geostatistical models are built at a vertical resolution of 1 to 3 ft, and current seismic data responds to 30 to 100ft vertical resolution. As a result, maps of seismic-derived (surface seismic and vertical seismic profiles) reservoir properties represent a volume significantly larger than well based information. The gap between short and large scale data can only be filled by geological knowledge, and if available, by outcrop studies and interwell images from crosswell surveys.

Several papers, among others, Tura *et al* (1992), Lazaratos (1993), Lazaratos *et al* (1993), Tura *et al* (1994), Quan (1994), Rector *et al* (1994), Harris (1994), Bashore *et al* (1995), Tucker *et al* (1996), Harris *et al* (1996), Costa *et al* (1996), Quan *et al* (1996), Van Schaack *et al* (1996) and Wang *et al* (1996), analyzed the theoretical basis, potential, technical acquisition difficulties, image processing and field applications showing the benefits of incorporating crosswell data to reservoir characterization and monitoring .

2.1 Geostatistical Methods Constrained by Log and Seismic Data

The subject of this thesis is the combination of geostatistics and seismic methods for reservoir characterization purposes. The dense lateral sampling is the main reason for the incorporation of surface seismic data. The quality of the data controls the extent of application, varying from guiding the structural behavior in areas not covered by wells to a better understanding of the stratigraphic framework and to the estimation of reservoir properties, such as, porosity, shale content, fluid saturation, cement, lithofacies proportion maps, permeability, etc.

As mentioned by Deutsch et al (1996), there are several kinds of approaches to account for seismic data; the direct transformation approaches, the geostatistical estimation, and simulation algorithms. The transformation approaches do not respect geological variability or the scale or inherent uncertainty/imprecision of the seismic data. Estimation techniques such as kriging or cokriging are not suitable because they provide models that are too smooth. Doyen (1988), applying estimation methods, incorporated seismic data to correct the random configuration of the porosity field based on too sparse distribution of wells.

In cases where a calibration confirms that the variations of some acoustic and the petrophysical property being estimated are related and the average well spacing is smaller than the lateral correlation length, a meaningful porosity covariance model can be constructed through the incorporation of seismic data. For example, Doyen *op. cit.* used the statistical structure of two-way traveltime to model the porosity covariance function.

According to Haldorsen and Damsleth *op. cit.*, Journel (1989) and Deutsch and Journel (1992), two main reasons justify stochastic simulations rather than estimation procedures: characterization of the global uncertainty of the probability distribution of reservoir properties and the generation of equiprobable multiple realizations of the spatial distribution of a petrophysical property. By using stochastic simulations geological uncertainty is then transferred to fluid-flow reservoir simulators and the multiple results can define a probability distribution of important reservoir performances, for example to assess the uncertainty about the profitability of the reservoir development project.

Many different approaches for building seismic-derived stochastic models have been developed, with the most recent methodologies being variations of non stationary or multi-step algorithms. Besides mapping genetic units, according to Tjolsen *et al* (1996) 3D-seismic data are used to improve stochastic facies modeling. Such improvement can be done by means of statistical pattern recognition techniques, as shown in several papers, such as, Lendozionowski *et al* (1990), Fournier and Derain (1995), Fournier (1995) and Johann *et al* (1996). The process starts with the building lithotype proportions maps accounting for facies distribution, and each facies is used to constrain stochastic modeling of continuous reservoir properties, such as porosity and permeability.

According to Deutsch et al (1996), the best recipe for obtaining improved reservoir description is to properly accounting for the precision and scale differences of each data set. Stochastic reservoir modeling techniques have the ability to integrate large amount of data providing different volume of support, can provide high resolution 3-D models of genetic units, their lithotypes and/or petrophysical properties honoring reservoir heterogeneities and distributions at each particular scale.