Calibration of Seismic Attributes for Reservoir Characterization

Semi-Annual Report

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Abstract

The project, “Calibration of Seismic Attributes for Reservoir Calibration,” is on schedule and making unplanned discoveries in addition to those intended when the project commenced. The discoveries, planned and unplanned, can be grouped into four classes: pitfalls to avoid in interpretation of seismic attributes; suggested workflows to follow in working with seismic attributes; new methods of calculating certain new attributes which we feel to be useful; and new theoretical approaches to certain petrophysical properties.

We are using data from Wyoming, North Texas, South Texas, and the Gulf of Mexico offshore of Louisiana. These environments provide a diverse array of physical conditions and rock types, and a variety of interpretation methods to be applied to them. The Wyoming field is a very difficult one, including alternating layers of thin beds of coals, shales, and hard sandstones, and there may be an observable effect due to hydrocarbon production; we are using this field as the ‘test’ of those techniques and methods we have developed or that we prefer based on our work on the other fields. Work on this field is still underway, although progressing nicely. The work on the public domain data sets in Texas, Boonsville and Stratton, is complete except for some minor additonal processing steps, and final write-ups are underway. The work on the Gulf of Mexico field has been completed to the extent originally planned, but it has led us to such important new observations and discoveries that we have expanded our original scope to include time-lapse studies and petrophysical aspects of pressure changes; work on this expanded scope is continuing. Presentations have been made at professional-society meetings, company offices, consortium workshops, and university settings. Papers, including one review paper on “Reservoir Geophysics” have been published. Several Master’s theses, which will spin off one or more published papers each, are in their final stages of preparation. One patent application is being considered by our university officials, based on a technique developed under this project.

We have found that the data sets we have used (particularly the public-domain ones), and the observations we have made and the results we have obtained lend themselves very well to a set of tutorials and interactive guides to the use of seismic attributes. We have therefore requested a one-year extension (at no cost) to the project, to allow the careful development of a set of tutorials on the subject, which will probably be published on CDs.

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Executive Summary

This project is intended to enhance our ability to use seismic data for the determination of rock and fluid properties through an improved understanding of the physics underlying the relationships between seismic attributes and formation. We have expanded our study to include four data sets, covering a variety of rock types and depositional environments; all of which are host to significant reserves in the domestic United States.

Our project has reached differing significant conclusions based on the different data sets.

- The Wamsutter data from Wyoming has been very carefully interpreted, tied to well logs, and inverted. This data set is being used to test the techniques which have resulted from analyses of the other data sets.
- The Stratton data from South Texas has been reinterpreted along several horizons, and has been used in stratigraphic facies studies. We have found several pitfalls using this data set, and we suspect that these pitfalls are commonly encountered in other similar sequences. In addition, we have developed preferred interpretation processes based on these data.
- The Boonsville data from North Texas has been reinterpreted along several horizons, and firm conclusions have been drawn, providing a very robust workflow for use in other data sets which include multiple rock types along one horizon. A technique to quantify the distribution of these rock types has been developed, and a patent application may be placed.
- The Teal South data set from the Gulf of Mexico has been inverted for acoustic impedance, and fully interpreted for hydrocarbon indicators. We have discovered several very intriguing aspects of the field, and suspect that they will be relevant elsewhere. First, we think that neighboring fields, even ones that are not under production, are undergoing pressure declines from production in one field. These declines in pressure result in the creation of a free gas phase, which in turn results in the expulsion of oil from the spill point. The oil lost from these un-tapped reservoirs is likely to be gone forever.

Some of our most significant general conclusions include:

- Reflections are not layer properties (inversion for layer properties is important)
- Point measurements should not be made away from seismic peaks or troughs
- Frequency-domain and time-domain studies simply describe the waveshape
- The convolutional model is rarely appropriate
- The synthetic must tie (if it doesn't, there is something wrong in the model)
- Multiple attributes can help, or they can hinder (too many attributes can be misleading)

Introduction

The objectives of this project are three-fold: To determine the physical relationships between seismic attributes and reservoir properties in specific field studies; to improve the usefulness of seismic data by strengthening the physical basis of the use of attributes; and, in the third year of the project, to test the approaches suggested or developed during the first two years on at least one new data set. In association with these studies, collaboration with corporate partners and technology transfer as ideas are developed and tested are ongoing integral components.

This project is divided into four main tasks, and these are further subdivided into subtasks. The following sections refer to those tasks; when appropriate, the application of each task to each data set is described. The breakdown in the 'Results and Discussion' section of this report will be based not on tasks, but on the data sets and on the concepts derived from those data sets. In this report, it consists of a sort of narrative that details the most-interesting results as we see them, and is not intended to be a complete review; we save that for the annual report.

Task 1: Project Management

Project management encompasses reporting and project support. Both are fully on schedule. We continue to obtain additional high-end software suites (most recently adding pre-release time-lapse software from Hampson-Russell and PC-based interpretation software from Seismic Micro-Technology), and incorporate them into our studies. System administration is running very smoothly; we have had to add new hardware to handle the massive volumes of data and these large software suites, but the cost of hardware has declined such that we remain in budget.

Task 2: Borehole Data

Borehole data for this project consists of three types: existing data (of all sorts), new core and outcrop data (to determine fine-scale heterogeneities), and new log data acquired for this project. We have made use of data provided by our corporate partners, including production data, have sought out additional data relating to the data sets, and have obtained new data in some instances. This task is now complete; no new borehole data is anticipated for this project.

Task 3: Processing

Processing of the seismic data has proceeded on schedule; we have expanded the scope of the project to include some pre-stack processing of the Teal South data, using ProMax software from Landmark Graphics. We have received multiple licenses of Jason Workbench inversion software to enable expanded inversion efforts on each data set simultaneously.

Task 4: Visualization

Our visualization of reservoir properties has become extremely efficient. We use visualization for improved reservoir characterization, for enhancing communication with our corporate partners, and for technology transfer.

Technology Transfer

Our web site is complete, and being updated regularly (http://www.geo.mtu.edu/spot). A significant invited review paper on "Reservoir Geophysics" was published in GEOPHYSICS (Jan-Feb 2001 issue). Abstracts have been approved for presentations to the EAGE/SEG "Workshop on Reservoir Rocks" and (three presentations) to the Annual AAPG convention in June. A presentation to members of the US Congress and to congressional staffers was made in mid-July, 2000, including members of then-Senator (from Michigan) Spencer Abraham's staff.

Results and Discussion

Reflections are not layer properties:

We all know that reflections can, at their simplest, be considered to result from the convolution of a source wavelet with a reflection coefficient, but we often forget that if the overlying layer changes property, the character of the reflection will change. Inversion of seismic traces for acoustic impedance (or elastic impedance for offset volumes) is intended to remove this ambiguity, and can work extremely successfully. In fact, we have made use of trace inversion to deduce appropriate input parameters for Gassmann-based fluid substitution and forward modeling for time-lapse monitoring. Inversion, of course, is model-driven, in that the user must define which well-log data to honor, determine the limits to put on the possible range of results, and decide how to interpolate between well control. But, in the hands of a highly-trained and careful practitioner, we feel that inversion is one of the most important tools available to the geophysicist/interpreter.

Point measurements should not be made off of seismic peaks or troughs:

In areas of thin beds, the use of point-based attributes (such as amplitude) can be extremely misleading without careful calibration. For example, some data sets have been interpreted in terms of seismic amplitude measured at some time above or below a continuous reflector. The amplitude so measured may result from the vagaries of wavelet interference, or even just a thickening of an intervening bed, and can lead to measurements made at different points on the 'flank' of the reflected wavelet. The resulting attribute map may resemble a geologic feature, but that resemblance may be fortuitous, or caused by a geologic feature other than the one we think we are mapping.

Frequency-domain and time-domain studies simply describe the waveshape:

In some cases, it is easiest to look at frequency-based results (such as spectral decomposition or instantaneous frequency), and in some cases, it is easiest to look at time-domain results (such as amplitude, arc-length, or isochron differences). But we should always keep in mind that these are simply ways of analyzing one aspect or another of what is really a complicated (and complex) waveshape. We should use whatever tool or technique is most appropriate for the occasion, but it is really the waveshape that we are studying. Recently, techniques for classifying the waveshape, within temporal windows in the data volume, have become available. These are based on neural network approaches, and tend to lose physical significance unless used with care; modeling and model-driven classification systems are becoming more-widely available, helping the interpreter to maintain the link with physical properties of the reservoir.

The convolutional model is not correct:

We all know that the convolutional model is an approximation: it assumes that the seismic volume is constructed of zero-offset traces, with or without multiples and migration artifacts. But we also all know that amplitude-versus-offset is an important tool in pre-stack analysis of data. We often forget, unless reminded, that the final stacked seismic volume or section is a result of stacking data from various offsets, with their various amplitudes. The final stacked trace is not equivalent to a zero-offset trace. And yet, we tend to use it as such much more often than we should.

The synthetic must tie:

We should place a great emphasis on obtaining a synthetic seismogram that fits the recorded data extremely well, or we cannot place much confidence in our interpretation. This is not often easy; all the problems described above conspire to reduce the value of the synthetic seismogram. But if the synthetic does not tie the data, there must be a reason, and it is the task of the prudent geophysicist/interpreter to find the reason; it may be due to offset effects, to ignoring the effective theory model in upscaling of thin layers, or any number of other effects. The inversion process, by its nature and as implemented in most software packages, forces the user to extract from the data a wavelet that is representative of the wavelet that is (likely) present in the data (assuming the convolutional model, of course). This emphasis on wavelet extraction is probably one of the reasons that inversion is often so successful in aiding interpretation.

Multiple attributes can help, or they can hinder:

Much has been written recently on the likelihood of obtaining spurious correlations if, as is often the case, one can combine many dozens of attributes from a few wells in the search for a significant relationship. We expect to find, for example, one apparently significant correlation at the 95% confidence level from among 20 possibilities – from a RANDOM data set! In general, one should try not to use more than about three ‘independent’ attributes in combination.

How constrained must we be? How detailed should our relationships be?

The scientist in each of us wants to prove the calibration of each attribute beyond a doubt. The pragmatist in each of us wants to find a correlation and use it. We should all strive for an engineering efficiency, where we find the correlation, explain its origin to our satisfaction, and then use it to the advantage of our asset team. But we should always be looking for a possible pitfall. For example, we may find a relationship between a specific attribute and pay in an environment where a facies (say, a reef) is either present or absent. But the use of that relationship within a reef facies to determine the actual net pay would be unwise; in fact, the relationship may be exactly the opposite within the one facies, and our interpretation would be grossly in error. Occasionally, the quick answer is also the correct answer; but often, and perhaps most often, the quick answer is a poor answer.

General Conclusions:

The processing/interpreting geophysicist should approach the problem of extracting petrophysical information from seismic data (performing ‘seismic petrophysical’ analysis) from two directions, each with parallel processes. One is the processing of seismic data – this should be performed to bring the data as close as possible to true amplitudes, true capture of offset effects (often through creation of two volumes: the acoustic, or zero-offset volume; and the elastic, or far-offset volume), and, ultimately, as close as possible to true LAYER properties, through careful inversion. Remember, it is the layer property that interests us; it is a quirk of nature that provides us with reflections at interfaces instead. The second direction is the understanding of the rock physics involved, and the effect that various physical parameters (saturation, thickness, porosity, etc) can have on the seismic waveshape. We generally accomplish this through modeling, and the creation of synthetic seismograms for various scenarios, but often the attention is lacking at the detail required to truly understand the effects. In any given data set, there will typically be impediments to performing the calibration of seismic attributes in a thorough manner, and challenges to overcoming limitations in data availibility or quality require a knowledge of the geologic model, of rock physics, of logging, of seismic processing and acquisition, and of interpretation techniques.

Special Study: Teal South Time-Lapse

The Teal South reservoir, a small unsaturated oil reservoir in the Gulf of Mexico that was quickly brought below bubble point, and that forms the basis of a time-lapse study undertaken by Texaco and a consortium under the auspices of the Energy Research Clearing House, has provided a wealth of interesting new concepts. In an earlier report and in a presentation to SEG in August of 2000, we reported on the apparent significance of the dry-frame stiffening effect during production of this conventional bright-spot class III AVO reservoir. In short, the near-offset seismic data may show a dimming of reflection intensity (the opposite of conventional wisdom) while the far offsets may show a brightening with production. The net effect on the stacked section depends on the vagaries of the stacking details. We have since obtained prestack data from the time-lapse volumes, and find that our model appears to be supported (but we are not yet finished, and this may change). We also found a remarkable feature: the smaller, apparently isolated, non-produced oil reservoirs within a mile of the producing reservoir seem to be developing a free gas phase, and are almost certainly losing oil from their spill points, never to be recovered from any known production scenario. This model, and the details to explain it, will be presented to the ERCH consortium, and put to further tests in the immediate future.

Specific New Technology

We have developed a new processing technique, and are currently investigating the possibility of obtaining a patent on it. In brief, it consists of using seismograms in areas of known geology to develop a map of regions of similar geologic nature; it is not limited to any number of geologic scenarios, and contains a measure, immediately visible on the maps that are produced, of the confidence of the prediction or the degree of similarity.

Conclusions

The project, "Calibration of Seismic Attributes for Reservoir Characterization," is on schedule as planned. We have reached a number of firm conclusions, and made some unexpected discoveries, most of which have been reasonably confirmed by testing. We will complete the original scope of work within the time frame of the original contract, but have requested a no-cost time extension of one year in order to expand the technology transfer component to include preparation and distribution of a set of tutorials, perhaps on CD, demonstrating the concepts emphasized in this project.