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Short Note

Some aspirations in seismic reservoir characterization

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INTRODUCTION

Having recently arrived as a Ph.D. student of the SEP as of a few days ago, I will now take the liberty of introducing myself by discussing some problems which interest me and some thoughts I have regarding their solution.

My interests reside generally in the realm of migration/inversion (m/i) of seismic reflection data, with a particular emphasis on subsurface target characterization. By m/i, I mean hybridizing separate but related concepts from migration and inversion camps, in order to produce high-resolution depth images of relative changes in a few different elastic properties, such as P and S impedance (see Lumley and Beydoun, 1991, this report). Of course, before one can attempt a respectable migration or inversion, the problem of velocity analysis needs to be addressed. I will be interested to consider the 3-D interval velocity analysis problem, and perhaps utilizing SEP's Connection Machine as the appropriate tool. After velocity analysis and m/i, quantitative appraisal of results would be highly useful. By appraisal, I mean making some quantitative measures of *confidence* in inversion results (velocity and elastic parameters), either relatively within a given image, or more absolutely from image to image. Finally, the m/i results and their corresponding confidence images may be calibrated and combined to yield comprehensive characterizations of subsurface target zones. The characterizations may lead to direct detection of interesting features, such as hydrocarbon presence (e.g., Parsons, 1986), or indirect correlations with secondary physical parameters, such as porosity or sand/shale content, through geostatistical techniques (e.g., Doyen, 1988).

Ideally, all the above could be addressed as a comprehensive project, given a suitable data set. Such a data set would probably require a small 3-D survey over a producing reservoir, coincident 2-D seismic for tying purposes, and multiple well con-

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trol with V_p, V_s, and density logs through the reservoir. Of course, it would be nice if the structure was not too complicated to begin with, and any extras such as crosshole data exhibiting reflection events across the target zone would be extraordinary. I am in contact with ARCO regarding a data set, but am open to all suggestions.

Finally, it is interesting to me to note that development of the above technology could have equally important applications and ramifications in the fields of environmental, near-surface, or crustal geophysics, in addition to the more obvious utility in hydrocarbon exploration and reservoir management.

RESERVOIR CHARACTERIZATION

3-D interval velocity analysis

Before migration, inversion, or geostatistical correlation of parameter estimates to characterize a reservoir can be done, velocity analysis is the prerequisite. In particular, it would be valuable to have a method of estimating 3-D *interval* velocities as a function of spatial coordinates. Interval velocities are required to perform depth migration, and 3-D becomes important to take advantage of the 3-D reflection seismic surveys now routinely being conducted over known, often producing, reservoirs. I recognize the magnitude of this problem and its impact on dependent processes such as migration/inversion. I am interested in perhaps using the Connection Machine at the SEP to approach this large and computer-intensive problem.

Kirchhoff elastic prestack depth migration

The first important part of the m/i is the elastic prestack depth migration. This step attempts to produce true relative amplitude estimates of elastic specular reflectivity. Presently, I have developed the theory and algorithm, in conjunction with my good friend and colleague Dr. Wafik Beydoun at ARCO Research, to estimate the $\grave{P}\acute{P}$ reflectivity, R_{pp}, as a function of the specular angle θ_{pp} (Lumley *et al.*, 1991). Other components of the full nine-component elastic reflectivity matrix $\mathbf{R}$, such as the $\grave{P}\acute{S}$ and $\grave{S}\acute{S}$ depth images, are included in the theory but not yet implemented.

The R_{pp} and θ_{pp} depth images are both estimated simultaneously in the Kirchhoff prestack depth migration algorithm, directly from the observed reflection data. Heterogeneous migration velocity models, including dipping structure, are accommodated by the use of WKBJ Green's tensors, which must be raytraced through a ray-valid medium. The migration is implemented in a constant offset manner to preserve reflectivity amplitudes as a function of specular angle. The method has been tested on synthetic and marine field data with very encouraging results (Lumley and Beydoun, 1991).

Details are in manuscript preparation for journal publication, and will appear in subsequent SEP reports. Anticipated difficulties include near surface variations in structure and elastic properties, which will likely make land data a challenging problem. Also, raytracing Green's function components in laterally variable velocity models can be very computationally intensive. Perhaps the CM can be of help here, in implementing an idea that Wafik and I have had for fast paraxial raytracing of Green's function traveltimes, WKBJ amplitudes, and various other necessary ray properties.

Elastic parameter estimation

Given depth images of $R_{pp}(\theta)$ from the migration, an inversion for relative changes in elastic parameters can be attempted. This can be achieved in a manner analogous to the AVO procedure of fitting two or three parameters to $R_{pp}(\theta)$ under the linearized Bortfeld approximation to the Zoeppritz relations. I am investigating interesting problems related to the issues of parameter choice, inversion stability, and inversion "confidence" quantification. So far, given industry standard surface acquisition geometries, it appears that P and S impedances are the most robust parameters to invert for, and that reflection data contain little or no unambiguous information on density variations for specular coverages less than about 30° ($\theta = 0°$ is defined as normal incidence).

Geostatistics

I don't know much in detail about geostatistics, but what little I do know suggests it represents a very powerful tool for correlating m/i elastic depth images with sparse sets of in situ measurements. Parameters such as porosity, permeability or sand/shale content can be measured in a few boreholes, but are not generally directly sensed by seismic reflection data. However, there is a widespread notion that in a given survey area or prospect, seismic attributes (traveltime residuals, amplitude variations, and elastic parameter values themselves) may have spatial statistical correlations with the secondary in situ parameters. If this correlation can be validated in a prospect area, then geostatistics may provide an exciting method to extrapolate/interpolate the sparse in situ measurements over the entire subsurface volume illuminated by seismic (Doyen, 1988). This could lead to interesting approaches to reservoir characterization in conjunction with the corresponding uncertainty analyses.

Applications

The deterministic elastic parameter images resulting from the m/i processing, or the stochastic correlation images resulting from geostatistical analysis, may yield exciting combinations of information extracted from seismic and other geophysical measurements over a subsurface target zone. Potential applications include determination of lithology, physical states, physical properties, and pore space constituents. Lithology determination can make an impact in stratigraphic and structural analyses from basin scales to reservoir heterogeneity scales (Parsons, 1986). Physical states, such as pressure or temperature, can be useful in monitoring EOR fronts (steam, fire), calculation of swept volumes, and predicting anomalous geopressure zones (Greaves and Fulp, 1987). Physical properties, such as porosity, permeability, sand thickness, and sand/shale content, can be valuable to extending reservoirs and in reservoir production and management, especially in the design of production and EOR strategies, and as constraints to reservoir flow simulations.

Although I have discussed applications related to the petroleum industry, with which I am most familiar, other geophysical disciplines may be conducive to this type of research. Extraction of elastic property information from high-resolution seismic reflection data, especially when calibrated and combined with in situ borehole measurements, can play a valid role in environmental, near-surface, and crustal geophysics. In those disciplines, the target becomes an acquifer, or waste repository, or interesting tectonic feature. Elastic parameter images and geostatistical correlations may offer some benefit in locating and monitoring contaminants, characterizing near-surface target sites, or interpreting physical conditions in active tectonic settings.

CONCLUSIONS

This concludes my introduction. In summary, I hope to spend my duration at the SEP advancing research in the area of reservoir characterization, including 3-D interval velocity analysis, "true amplitude" elastic prestack depth migration, elastic parameter inversion, and geostatistical analysis. Hopefully I will be able to obtain a suitable comprehensive data set to test my research results, ideally in an actively producing reservoir environment. And, all this in two years.

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