Borehole Acoustics and Logging
and
Reservoir Delineation
Consortia

Annual Report
1997

Earth Resources Laboratory
Department of Earth, Atmospheric, and Planetary Sciences
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EXECUTIVE SUMMARY

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INTRODUCTION

Research activity in the Borehole Acoustics and Logging/Reservoir Delineation Consortia continue to focus on the development of geophysical methods to detect and characterize geological conditions which control fluid flow in a reservoir. This report presents a summary of our results from the past year. Three major areas of research are presented: subsurface fracture characterization, modeling and imaging of complex structures, and reservoir logging applications.

SUBSURFACE FRACTURE CHARACTERIZATION

Fractures are highly permeable pathways in many reservoirs, and their presence often introduces elastic anisotropy which affects both seismic reflection data as well as dipole acoustic logs. The seismic papers will be discussed here, while the dipole logging papers will be discussed as part of the reservoir logging section. Perez *et al.* show that azimuthal variations in the P-wave AVO response over a fractured reservoir in Venezuela provide a means of estimating the fracture orientation. The results of this analysis are in agreement with the orientation estimates obtained by surface shear wave reflection. Theophanis and Zhu combine physical laboratory modeling and finite difference numerical modeling of fractured reservoirs to study the effects of nonuniform fracture density distributions on the P-wave AVOA response. Shen *et al.* and Zhu *et al.* present theoretical and modeling studies of the effects of fracture density variations on the elastic properties of a reservoir unit and the seismic signatures of those variations. Their results indicate that if there is a strong velocity contrast at an interface, then the azimuthal AVO effect due to the fracture-induced anisotropy may be difficult to detect, while this effect may be more visible with smaller contrasts. The three-dimensional numerical modeling results of Zhu *et al.* indicate that heterogeneous fracture density variations in a reservoir may be detectable if the AVOA response is compared to the Shuey equation fit to the data. These results suggest that 3-D surface seismic data may be used to detect subsurface variations in fracture density in a reliable way.

Laboratory and field electroseismic measurements have also been carried out in an effort to develop methods of estimating the flow properties of fractures and other permeable pathways. Mikhailov *et al.* carried out field measurements in a borehole containing many permeable fractures. They show that a propagating Stoneley wave induces an electric field due to fluid flow in permeable fractures which they measure with electrodes in the borehole. Their results suggest that electroseismic data can provide an estimate of the interconnected porosity of the permeable zone, and may provide estimates of permeability if the measurements are taken over a range of frequencies. Zhu and Toksöz present laboratory electroseismic measurements in porous materials which also suggest that these data can be used to estimate fluid flow properties.

MODELING AND IMAGING OF COMPLEX STRUCTURES

We continue to develop faster and more efficient methods of forward modeling of elastic wave propagation, not only to understand the effects of heterogeneity on borehole and surface seismic data, but also to improve our ability to invert such data for information about complex geologic structures. De Lilla *et al.* illustrate the use of a variable grid finite difference method which can reduce the memory requirements and computational time of models by restricting fine grid sizes to areas of complex structure. Their model results show that irregular interfaces can have important effects on the AVO behavior of reflected energy. Nolte uses a triangular grid method which can more accurately handle dipping and irregular interfaces. His results show that this method eliminates unwanted scattering caused by rectangular grid representation of such interfaces. Work is also continuing on the development of the phase screen method which may provide a very fast method for pre-stack depth migration of seismic data.

Zhang *et al.* present the latest tomographic images of the Michigan reef, including a shear wave image based on the cross well data acquired with the Conoco orbital vibrator in 1995. The shear wave image shows a marked velocity decrease in the producing interval of the reservoir. Zhang and Lavely have developed a fast 3-D raytracing algorithm which can be used to design optimal seismic surveys.

Single well imaging is another area of particular interest. A number of difficult problems need to be addressed for this application. Rao *et al.* address one of these by looking at source radiation patterns in cased boreholes. Their results indicate that in unbonded casing several propagating modes exist which influence the source radiation pattern.

RESERVOIR LOGGING APPLICATIONS

We have continued to work in the area of cross dipole logging for the estimation of *in situ* anisotropy. Tao *et al.* present results comparing a number of different rotation methods to separate the fast and slow flexural waves. Their results show that each method produces reasonable results, although the computational needs are quite variable. Nolte *et al.* develop an efficient processing method to measure the dispersion characteristics of guided modes such as flexural waves. They apply their technique to data obtained from the Powder River Basin. For these data, the dispersion curves of the fast and slow flexural modes exhibit crossover which may be an indicator of stress-induced anisotropy.

Rao *et al.* show that the attenuation of early arrivals in cement bond logs can be used to quantify the cement bond quality even with variations in the tool standoff distance. Garipova *et al.* invert borehole resistivity logs for formation properties. They show that a combined inversion of lateral sounding data and lateralog measurements provides improved estimates of the fomration resistivity distribution both radially and vertically. Work is beginning on the development of a method for modeling the physics of fluid flow through a matrix of sand grains based on the dissipative particle dynamics method. This direction is promising in that it may allow us to predict the onset of sanding based on knowledge of the formation mechanical properties, grain size distributions, and fluid flow rates.