

# Executive Summary

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## 1 Introduction

Our research results for the past year are divided into two major areas: 1) the quantification and prediction of reservoir heterogeneity and 2) the use of borehole measurements to quantify fluid flow related properties. As we look towards the future of instrumented reservoirs and downhole sensors, it is clear that these areas of research will begin to overlap in many ways. This overlap is evident in several of the papers presented in this report. One example is the migration of reverse VSP data (Krasovec et al, 2001), which develops a methodology with applications into reservoir imaging using downhole sensors as well as monitoring with acoustic emissions. Another example is the measurement of seismoelectric effects in boreholes (Zhu and Toksoz, 2001), which has great potential for reservoir monitoring. Other applications presented this year, such as Herrmann (2001) and Lyons et al. (2001), developed out of scaling analysis studies on well log data and now provide a promising method for extracting lithologic heterogeneity information from seismic reflection data. We are also extending our interest into new areas of measurement, such as NMR imaging (Leu et al., 2001), in order to develop a better understanding of the physics of fluid flow in porous media. We also continue our research philosophy of integrating theory, laboratory measurements, and field data analysis in all areas of reservoir science.

## 2 Quantification of Reservoir Heterogeneity

### 2.1 Imaging

We are continuing to work on subsurface imaging using borehole source/receiver configurations, specifically in a Reverse VSP (RVSP) geometry. [Krasovec et al. \(2001\)](#) has developed a migration method suited to this geometry and tested the method on RVSP data acquired in the Michigan Test Site. Her method improves image quality for limited illumination aperture situations by using additional information such as dip. Although the method results in some loss of resolution, artifacts are greatly reduced.

### 2.2 Reservoir characterization

We are approaching characterization by two means: inversion of seismic data for velocity heterogeneity using statistical methods, and also by means of scale analysis of seismic reflection signatures. Both approaches deal with second order effects in seismic data. We assume that reflectors can be identified and imaged, so we focus on the next level of information: what do the variations in shape and amplitude of a reflector tell us about the velocity field and its depositional structure? [Kane et al. \(2001a\)](#) estimate the reservoir velocity field through a combination of kriging and deconvolution, which matches seismic traces to well information and then moves progressively away from wells. In a separate paper ([Kane et al. \(2001b\)](#)), presents a wavelet-based method for deconvolution that shows great promise for seismic and well log data.

New multiscale and monoscale analysis methods applied to seismic data provide new stratigraphic attributes that are related to the nature of the interfaces in the subsurface ([Lyons et al., 2001](#)). These new attributes, which are measures of the order of the singularity of the interface, are robust, and may provide information related to facies distributions. [Herrmann \(2001\)](#) develops a new atomic decomposition method to estimating this measure and showing that the resulting attribute distribution may provide a means of quantifying seismic texture variations spatially. [Lyons et al. \(2001\)](#) applies this scale attribute to a seismic section from offshore Nova Scotia and relates the results to the stratigraphic heterogeneity of the subsurface.

The results indicate that the method is robust and may provide some insight into lithologic variations in the subsurface.

Hestholm et al. (2001) includes a method for successfully handling complex heterogeneity in finite difference forward models.

## 2.3 Sediment transport and depositional systems

Buttles et al. (2001) shows results of channel deposition in our Laboratory tank experiments. They constructed a channel geometry into which a number of sediment pulses were deposited. This deposition was imaged with an acoustic transducer system. Brenner et al. (2001) discusses initial results for theoretical modeling of depositional systems.

McLeod et al. (2001) provide a seismic study of North Sea fault patterns and relates them to the control sediment accommodation space over time, as well as fault growth over time.

## 2.4 Anisotropy

Intense interest in fractured carbonate reservoirs has encouraged us to continue our work on using dipole logs and reflection seismic data (AVOA, non-hyperbolic moveout, and other attributes) to study the effect of fractures on wave propagation, and develop methods for estimating fracture direction and fracture density. Dajani et al. (2001) applies a method for estimating in-situ fracture directions from surface measurements. Their work involves near-surface radar data, however the method can be directly applied to reflection seismic data sets. Their resulting fracture direction estimates agree very well with geological data from the area.

## 2.5 Future directions Acoustic Emissions

Any area of future interest is using production related acoustic emissions data to understand reservoir dynamics. Changes in reservoir pressure during production result in the emission of acoustic energy that can provide information about reservoir dynamics (e.g.: pressure changes, fault activation, pore collapse). To acquire and interpret such data requires downhole sensors and new location and analysis methods to handle the different geometries. The work of Krasovec et al. (2001) provides a first step towards data acquisition and imaging in the instrumented reservoirs of the future.

In order to locate emission events accurately, an estimate of the origin time of events is needed. Results from Zhu et al. (2001) indicate that seismoelectric signals may provide a means of measuring the actual origin time of acoustic emissions in a reservoir. Such data would allow for determination of much more accurate event locations and, therefore, improved interpretation of reactivated faults or zones of pore collapse.

# 3 Borehole Acoustics and Fluid Flow Properties

## 3.1 Seismoelectric Effects

Theoretical models, laboratory data, and field data suggest that frequency dependent electrical fields generated by a propagating wave may be related to the formation permeability. Our work to date suggests that these measurements show the most promise in a borehole environment, either in a logging tool or cross-well geometry. We are now working to understand the quantitative relationships between these data and formation fluid flow properties. Zhu et al. (2001) show some laboratory measurements suggest the joint measurement of the electric and magnetic field induced by a seismic signal may provide a means of separating local EM fields from propagating EM fields. Additionally, the use of magnetometers may be preferred in field applications. In closely related work, Reppert (2000) completed his thesis (which is available by request), which looked at electrokinetic effects as a function of frequency for the case of controlled materials (such as capillary tubes, etc).

## 3.2 Anisotropy and stress effects

We are actively working on methods of analyzing dipole acoustic logs to estimate in-situ stress fields. This work has significant potential for use in borehole stability applications, especially related to dynamic stress effects due to production in a reservoir. [Huang et al. \(2001\)](#) applied the acoustoelastic theory to existing laboratory data sets in order to test the applicability of the theory. Initial results indicate that the theory can be applied to rocks over stress ranges where the velocity versus stress behavior is close to linear. The theory can be applied to highly non-linear ranges if detailed stress-strain information is available for the material. The benefit of this theoretical approach is that it provides a direct link between measured velocity and stress values. Such a link is a key to using borehole measurements to estimate in-situ stress.

## 3.3 Acoustic LWD

An area of increasing interest in the industry is acoustic logging-while-drilling (LWD). Such data are becoming more common, particularly in critical, expensive holes. The new geometry and presence of a very large, rigid tool body presents complications in the propagation of modes that must be clearly understood. We are working on mode analysis (dispersion curves and excitation) for LWD acoustic logging geometry (e.g., see 1999 report), numerical modeling (Finite difference) of LWD acoustic tools, and the estimation of formation properties (especially shear velocity).

## 3.4 New approaches to imaging fluid flow

In conjunction with Prof. David Cory and his students at the MIT Nuclear Engineering Department, we are investigating new ways to use NMR imaging of fluid flow in porous media. The hope is to understand the details of microscopic flow that are related to seismic attenuation and to electrokinetic conversion. [Leu et al., 2001](#) show some initial results of a new method for obtaining flow-related information from such data.