Imaging Reservoir Quality Seismic Signatures of Geologic Processes

DE-FC26-04NT15506

Goal

The project goal is to develop an interpretational model for clastic reservoirs, quantifying the links among the products of sedimentary and diagenetic processes, rock properties, and seismic signatures.

Performer

Stanford University
Stanford, CA

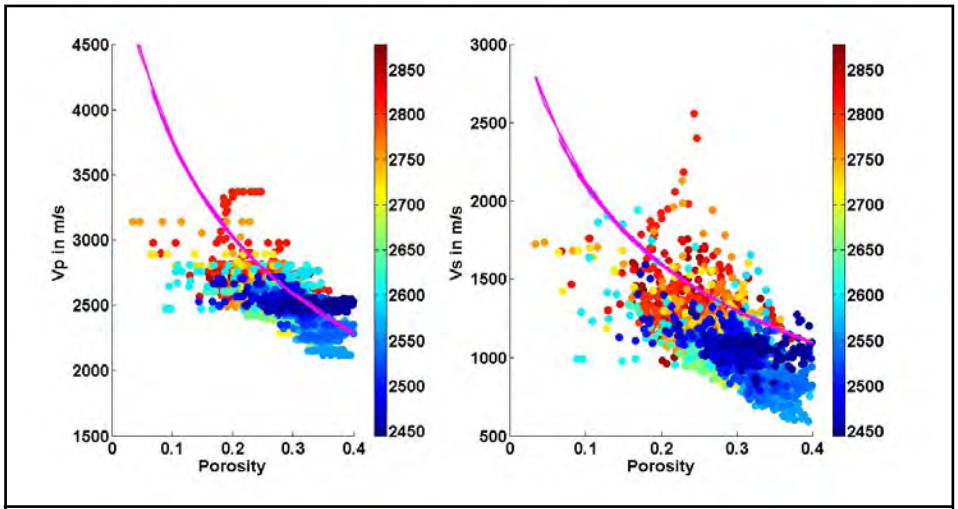
Results

Project researchers illustrated a workflow for establishing improved links between sedimentary processes, as might be inferred from a sequence stratigraphy analysis and seismic amplitudes. The strategy was to estimate plausible, though uncertain, rock properties, such as composition, grain size, sorting, and porosity from the geologic interpretation. These candidate rock properties were then used as inputs to rock physics models that predict the corresponding elastic properties that control seismic wave propagation. Comparison of the model predictions with observed seismic amplitudes allowed researchers to get improved estimates of the reservoir properties.

More complete field data sets have been received, on which the workflow will be applied with the project's continuation. In addition, researchers have completed an analysis of how packing and sorting variations impact rock elastic properties. It has previously been established that depositional variations often lead to a particular velocity-porosity relation that can be well described using a modified lower elastic bound. The current work illustrates how packing—the result of post-depositional processes—yields a similar trend. Both sorting and backing influence porosity, permeability, and their elastic signatures.

Benefits

About two-thirds of all the oil discovered in the United States remains in the ground, largely due to uncertainties and complexities in the nature of oil reservoirs. This project will help to mitigate some of these difficulties through improving reservoir characterization, reducing risk by more effectively quantifying geologic constraints and their seismic signatures, and quantifying the uncertainties associated with the interpretations for better decision making and risk analysis. The final benefit of this will be improved recovery, increased national petroleum reserves, and lower environmental risk through more-informed drilling and production planning.



Measurements of porosities and velocities from well log in prograding lobes. The magenta line is obtained using rock physics modeling for unconsolidated sand.

Background

Seismic stratigraphy, seismic sedimentology, and 3-D seismic geomorphology are the state-of-the-art techniques for interpretation and prediction of depositional lithofacies using seismic data. In classic seismic stratigraphy, geologists use qualitative analysis of reflection events (amplitude, apparent frequency, continuity, and geometry) to separate seismic facies. The connection to the actual lithofacies is established using sequence stratigraphic models and local calibration with well logs. Uncertainties in these methods arise from their inability to resolve features at scales lower than the dimensions of the seismic-facies groups, normally about 100 m, and from the assumption of oversimplified relationships between seismic impedance and general lithologies.

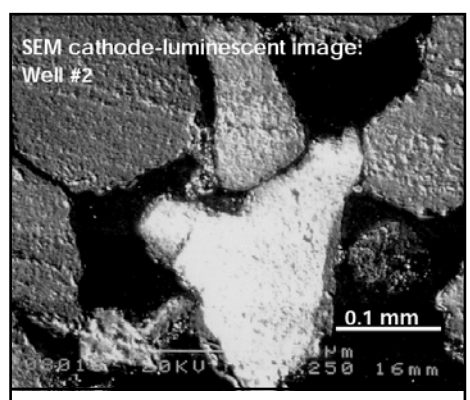
A critical factor for seismic reservoir characterization is that seismic velocities in the subsurface are related to key rock parameters such as porosity, mineralogy, microtexture, pore fluid saturation, and effective pressure. Relating sediment and rock properties to observed seismic signatures is the aim of applied rock physics in this project.

Summary

This project consists of the following four tasks:

- Geologic controls on rock microstructure. The objectives here are (1) to identify how essential rock properties, which link reservoir properties to seismic response, evolve geologically—how they vary within stratigraphic sequences associated with different depositional settings and during the various diagenetic stages; (2) to better understand the variation of composition, fabric, and elastic properties of different types of shale and mixed lithofacies, according to their depositional environments; (3) to evaluate and develop empirical and theoretical models of porosity-depth trends for sands, shale, and mixed lithofacies.

- Quantification of elastic (seismic) signatures. The objective here is to quantify the elastic signatures of lithology, multi-scale



Cathode-luminescent image of rock microstruture and pore space.

stratigraphic cycles, textural maturity, pore pressure, and the diagenetic processes of compaction and cementation.

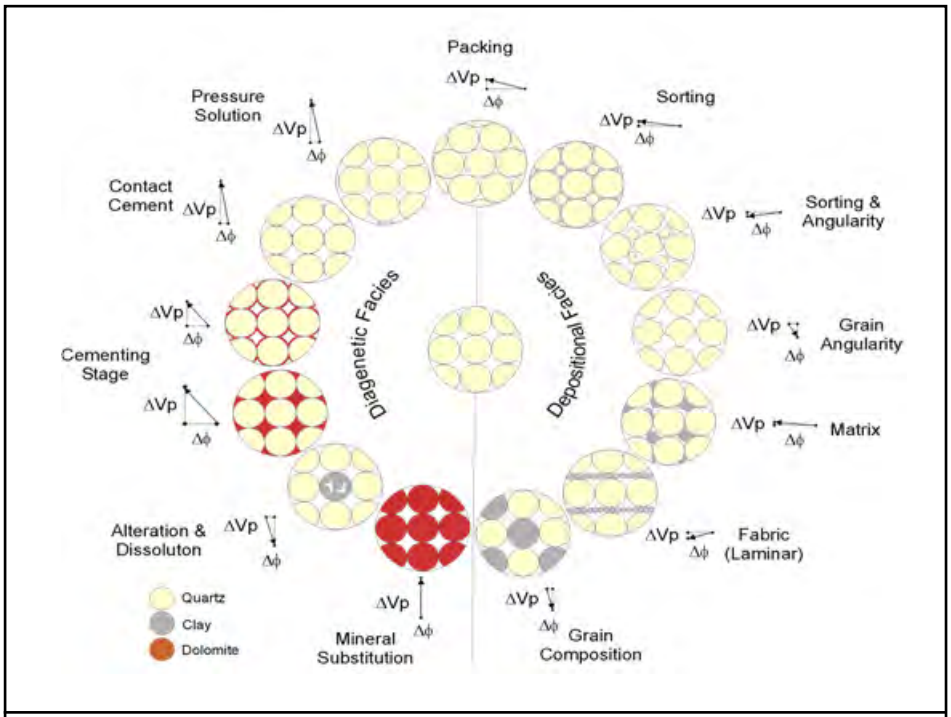
- Site selection. This task called for identifying an optimum dataset for the field study. Criteria for site selection include a geologically and economically interesting setting, relatively simple structure, and excellent core, log, and seismic data quality. The focus will be on clastic targets. Researchers will evaluate datasets already in house, as well as data sets from their industry affiliates.

- Validation, by integrating and interpreting reservoir field data. The objective here is to demonstrate, validate, and refine the methodology for quantitative reservoir characterization on a real field dataset.

Researchers completed two primary efforts of the project. The first study formulated a workflow aimed at integrating the important constraints derived from sequence stratigraphy with rock physics models to reduce the uncertainty of seismic reservoir characterization. The second study focused on understanding how parameters such as grain packing and sorting influence seismic velocity.

Sequence stratigraphy is the geologic interpretation of process/response events that can predict the likely occurrence of reservoir facies, source rocks, and seals. Traditional stratigraphic interpretation from post-stack seismic data has been predominantly qualitative, based on visual inspection of geometric patterns in the seismic reflections. However, quantitative interpretation of seismic amplitude is possible if, by using principles of sedimentology, information can be extracted about compositional maturity (mineralogy, clay content) and textural maturity (sorting, grain angularity, sphericity, and roundedness). Quantitative seismic interpretation uses rock physics to link seismic amplitude with reservoir properties such as porosity, clay-content, sorting, diagenetic cements, etc., that are estimated from the stratigraphic analysis.

Researchers have preliminarily applied this concept in a deepwater turbidite system in the Campos Basin offshore Brazil. Their interpretation was based on (a) basin history, (b) geometry and truncation patterns of reflectors, and (c) stacking patterns of well logs. They considered three parasequences within the prograding depositional lobes and used sequence stratigraphic principles to predict relative trends of sorting, an important control on porosity. Corresponding elastic properties were estimated using the soft-sediment model, which combines Hertz-Mindlin contact mechanics with the Hashin-Shtrikman lower bound. AVO (amplitude versus offset) signatures at the sequence boundaries were predicted, showing, for example, distinct landward-basinward trends of intercept and gradient.



Conceptual model illustrating depositional parameters such as sorting, packing, grain angularity, fabric, and diagenesis have predictable relations with porosity and elastic properties.

The soft sediment model trend is considered to be solely the effect of sorting. However, the project's mathematical models demonstrated that packing also has an influence. The velocity-porosity trend observed in subsurface data agrees with the flat trend predicted from the researchers' theoretical analysis. A least-squares regression between sorting and porosity from the core data indicates a small negative correlation between porosity and the grain size, which indicates a minor influence of packing, probably associated with grain angularity (fine grains tend to be more angular than coarser sands). However, the effect of sorting on porosity in these sands is stronger than the effect of packing. The high-porosity sands have better sorting than the low-porosity clean sands. These two different types of sands create the flat trend observed in the velocity-porosity plane.

Current Status (February 2007)

At the end of 24 months, the project is on schedule. Field data have been obtained, and analysis is underway. Initial rock physics models have been proposed and tested in four different depositional environments. Researchers illustrated an interpretational workflow and have completed theoretical analysis of the effects of packing and sorting on porosity. Year 3 of the project is on hold, waiting for funding to be approved.

Funding

This project was selected in response to DOE's Oil Exploration and Production solicitation DE-PS26-04NT15450, program ID 2A: Subsurface imaging.

Publications

Dutta, T., Mukerji, T., and Mavko, G, "Modeling Elastic Properties of Unconsolidated Sands," American Geophysical Union, 2005 Proceedings, Session No. MR33A-0144.

Project Start: January 1, 2005
Project End: December 31, 2007

Anticipated DOE Contribution: $631,918
Performer Contribution: $156,500 (20 percent of total)

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