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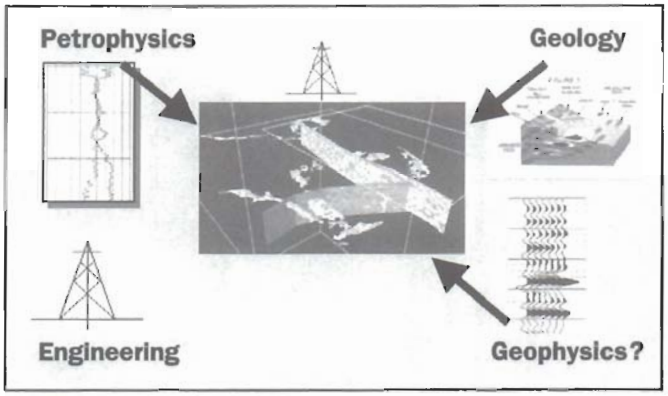

Figure 1. *Accurate reservoir description is aided by integration of data from all disciplines. How can geophysical data be quantitatively integrated in reservoir studies ?*

The Benefits of Integrating Seismic and Petrophysical Data

Introduction

One of the major problems that exists in current exploration and production projects is the successful prediction of reservoir quality (specifically permeability) in inter-well areas. This presentation focuses on the integration of pore geometry data (from direct image analysis of rock samples) with wireline logs in key wells and extrapolation to seismic data in order to improve the accuracy of field-wide and regional permeability prediction. This is of particular importance both offshore (deep Gulf of Mexico) and onshore (Wilcox, Vicksburg, etc.), geological provinces in which porosity and permeability are often not fundamentally related.

Integration for Reservoir Characterization

It is important for exploration & production companies to take full advantage of all available data when undertaking reservoir description, evaluation and characterization (Figure 1). One of the problems that still exists is how to integrate seismic data and petrophysics. The past several decades have witnessed important advances in this regard, such as seismic-based lithology determination and the gross identification of porous versus non-porous zones. The problem with such porosity-based seismic solutions is that producibility is often more a function of permeability than of porosity.

Whether we are interpreting wireline logs, thin sections, seismic data or production rates and pressures, we have one thing in common: the rocks. Even though all of our measurements are at vastly different scales and utilize many different forms of measurement techniques, they are all measurements that include some aspect of the rock. It therefore follows that if we are going to integrate disparate data sets correctly, the integration must be done in a manner that is consistent with petrophysical theory.

Pore Geometry

The methodology presented here is based on the unifying concept of pore geometry as a fundamental control on both petrophysics and geophysics. The petrophysical properties controlled by pore geometry influence compressional and shear wave velocity data that form the basis of seismology. Pore geometry influences the characteristics of both the compressional and shear waves (Davies and Young, 2001). For example, resistance to shear is a function of grain packing and the type and degree of grain cementation. Loosely packed, uncemented rocks obviously have different shear characteristics than tightly packed uncemented rocks. Clay cemented sandstones will respond differently to shear than silica cemented sandstones. Packing and cementation are aspects of rock diagenesis that obviously affect the size, shape and arrangement of the pores in the rock (pore geometry) and are fundamental controls on permeability and porosity.

Rock-based integration requires viewing the goal of each discipline (including geology, geophysics, and petrophysics) as the accurate description and characterization of the rocks. Thus thorough rock characterization is an essential precursor to the

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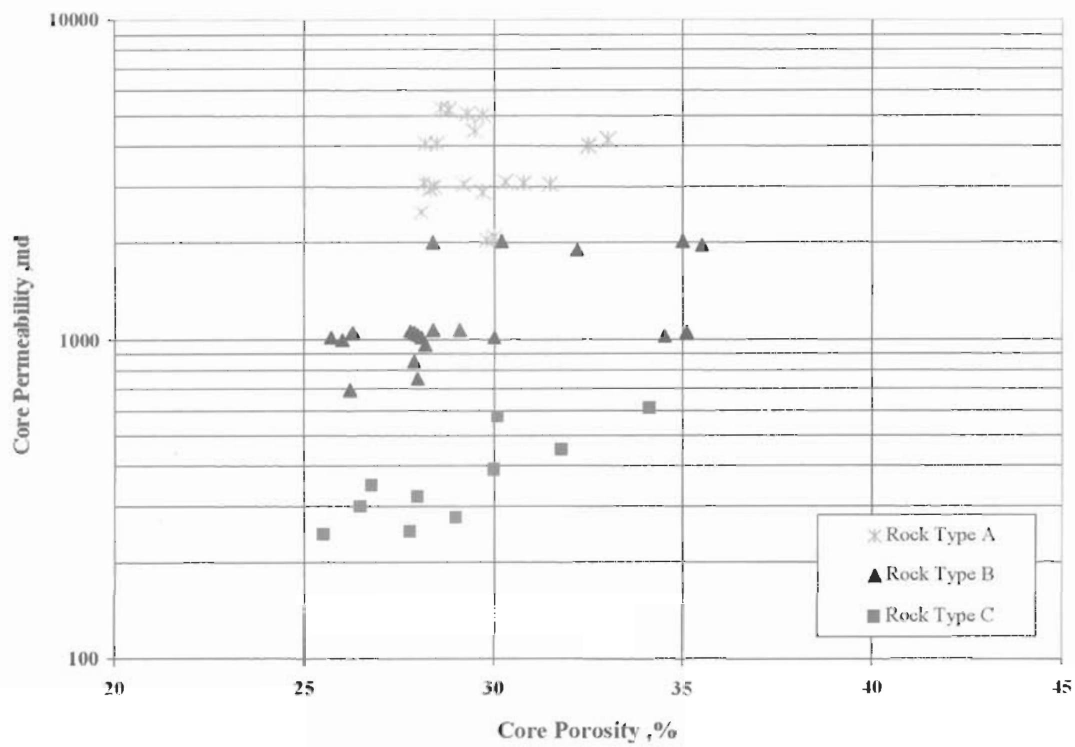

Figure 2.
Deep water, turbidite sandstone rese voirs, Offshore Gulf of Mexico, differentiated on the basis of image-derived Rock Types (based on analysis of pore geometry). Note that each Rock Type has similar values of porosity but widely different values of permeability, and that the highest porosity is not associated with the highest permeability. In this and similar reservoirs, the successful prediction of permeability requires a knowledge of the pore geometry.

data integration in our methodology. For example, minor changes in depositional environment can result in significant changes in mineralogy, lithology and texture which affect the pore geometry. Diagenesis commonly operates within a framework established at the time of deposition: thus changes in packing and cementation (pore geometry) can relate to changes in depositional environment. Thus knowledge of depositional environment and diagenesis is important to reservoir characterization. The depositional/diagenetic environment interpretation is then related to sequence stratigraphic concepts. An understanding of sequence stratigraphy provides macro-scale controls on rock distribution that can often be seen at the seismic scale.

Petrophysical Integration

In many reservoirs and geological provinces, it is not possible to predict, with any degree of accuracy, permeability from a knowledge of porosity alone (Figure 2). Thus prediction of sufficient hydrocarbon-charged porosity does not necessarily imply that the rock will produce. Although porosity and permeability are independent in a global sense, there exists a close relationship between porosity and permeability within rocks with specified pore geometry (Rock Type). Thus permeability varies as a function of both porosity and Rock Type in both sandstone and carbonate reservoirs (Calhoun, 1960: Davies et al., 1999). Because porosity and permeability are closely related within each Rock Type, permeability can be predicted from a knowledge of both porosity and Rock Type (Figure 2).

In our methodology, pore geometry is measured directly in small rock samples using a scanning electron microscope that is specially equipped for image analysis (Davies et al., 1999). This allows for the identification of Rock Types in intervals with conventional or sidewall cores (Figure 2). Neural Network Models are used to identify Rock Types and to predict porosity and permeability using only combinations of wireline log responses. This allows for field-wide extrapolation of Rock Type-derived data (specifically permeability) to all non-cored intervals and wells. Equations are developed that relate Rock Types to the sonic and shear data. These relationships are used as the basis for integration of the petrophysical and seismic data allowing for inter-well predictions of the distribution of reservoir quality for exploration and development projects.

Seismic Petrophysics

The S and P impedance data is determined using the entire pre-stack seismic data set after careful pre-processing and migration to preserve AVO effects. This results in lithology and fluid volumes for the entire seismic section. The lithology and porosity interpreted from the seismic data are then presented as a series of cross sections or block diagrams.

Because a relationship has been developed between permeability, porosity, Rock Type, Vp and Vs, the seismic data can now be used to create permeability and Rock Type volume for the seismic sections (Figure 3). Because the seismic data yields both porosity

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and Rock Type, permeability can be predicted in the interval(s) of interest using the algorithms developed earlier in the workflow. Values of permeability can be assigned to individual grid cells on the basis of inter-well seismic data.

Conclusions

Inter-well and regional predictions of reservoir quality can be based on quantitative integration of petrophysical and seismic data ("seismic petrophysics"). The methodology presented here allows seismic data to be used to predict reservoir permeability based on integration of seismic data and data regarding the detailed pore geometry of the reservoir intervals. This approach is extremely useful in difficult environments (offshore, deep water) and in field development projects.

Biographical Sketch

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DAVID K. DAVIES holds BS, PhD and DSc degrees in Geology from the University of Wales, Swansea, and an MS degree in Geology from Louisiana State University, Baton Rouge. He is President of GeoSystems LLP (formerly David K. Davies and Associates Inc), an international service and consulting company that specializes in all aspects of reservoir description, evaluation and characterization. Davies is a Levorsen Award winner of the AAPG and Distinguished Lecturer of the SPE and SPWLA.

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ROGER A. YOUNG holds a BS in physics from Clarkson College of Technology, Potsdam, New York, and an MS in reservoir engineering from the University of Houston. He is the Chief Technical Officer of eSeis Inc, a service company that specializes in seismic petrophysics using prestack seismic data. □

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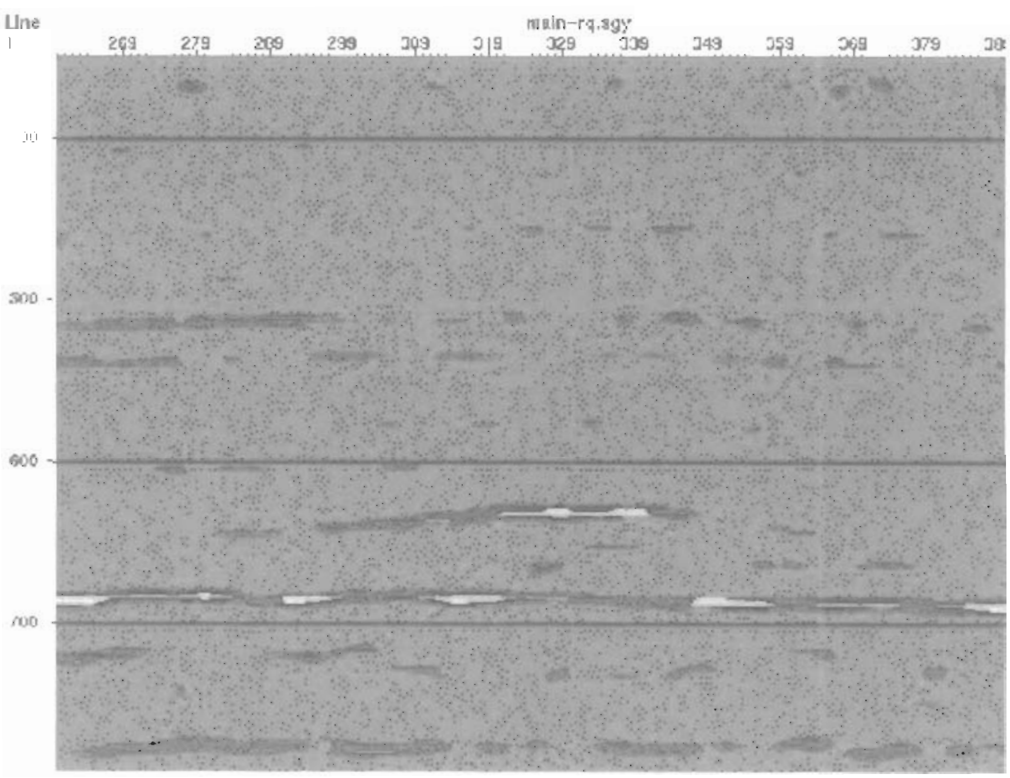

Figure 3. *Seismic cross section showing the distribution of Rock Types. Rock Type 1, sand with high permeability (>2000md) and high porosity (>25%). Rock Type 2, sand with moderate permeability (500-2000md) and high porosity (>25%). Rock Type 3, sand with low permeability (<500md) and high porosity (>25%).*