FOSSIL ENERGY

DOE/BC/15105-3
(OSTI ID: 780437)

INTEGRATED OUTCROP AND SUBSURFACE STUDIES OF THE INTERWELL ENVIRONMENT OF CARBONATE RESERVOIRS: CLEAR FORK (LEONARADIAN AGE) RESERVOIRS, WEST TEXAS AND NEW MEXICO

Semi-Annual Report
March 31, 2000-October 1, 2000

By:
F. Jerry Lucia
James W. Jennings, Jr.

Date Published: May 2001

Work Performed Under Contract No. DE-AC26-98BC15105

The University of Texas at Austin
Austin, Texas

National Energy Technology Laboratory
National Petroleum Technology Office
U.S. DEPARTMENT OF ENERGY
Tulsa, Oklahoma

DOE/BC/15105-3
Distribution Category UC-122

Integrated Outcrop and Subsurface Studies of the Interwell Environment of Carbonate Reservoirs: Clear Fork (Leonaradian Age) Reservoirs, West Texas and New Mexico

By
F. Jerry Lucia
James W. Jennings, Jr.

May 2001

Work Performed Under Contract DE-AC26-98BC15105

Prepared for
U.S. Department of Energy
Assistant Secretary for Fossil Energy

Robert E. Lemmon, Project Manager
National Petroleum Technology Office
P.O. Box 3628
Tulsa, OK 74101

Prepared by
Bureau of Economic Geology
The University of Texas at Austin
P.O. Box 7726
University Station
Austin, TX 78713

TABLE OF CONTENTS

SEMI-ANNUAL TECHNICAL PROGRESS REPORT

for

INTEGRATED OUTCROP AND SUBSURFACE STUDIES OF THE INTERWELL ENVIRONMENT OF CARBONATE RESERVOIRS: CLEAR FORK (LEONARDIAN AGE) RESERVOIRS, WEST TEXAS AND NEW MEXICO

Contract No. DE-AC26-98BC15105

Abstract

A preliminary reservoir model has been constructed for the Lower Clear Fork of the South Wasson Clear Fork reservoir. The model was constructed by calibrating high-frequency cycles observed in cores to the porosity log. The rock fabrics mostly fall in petrophysical class 1, and cross plots of porosity and water saturation could not be used to identify rock fabrics. Data from two limestone fields and one dolostone field are presented to support the contention that grain-dominated fabrics have higher porosity than mud-dominated fabrics do and that this difference is retained when the limestone is dolomitized. Therefore, vertical profiles from low- to high-porosity dolostones typically reflect a vertical succession of mud-dominated to grain-dominated fabrics, and this succession is the basis for mapping high-frequency cycles. The rock-fabric layers resulting from mapping high-frequency cycles are compared with proportional layers derived from a method used by Altura (now Oxy Permian). The proportional layering method tends to average high and low permeability values and smooth out important differences. The rock-fabric layers retain the high and low permeability values better because of the interpretation that high permeability is concentrated in the upper layers of high-frequency cycles. An ideal high-frequency cycle has been used to construct a detailed stochastic model using petrophysical data from the subsurface and outcrop. The model illustrates the lateral heterogeneity that can be expected within one high-frequency cycle.

Results and Discussion

We have completed 24 months of this project and are reporting progress we have made in the area of reservoir modeling. The South Wasson Clear Fork (SWCF) field is composed of two reservoirs, the Middle Clear Fork (MCF) and the Lower Clear Fork (LCF), as can be seen by inspection of the water-saturation profile (fig. 1). The Tubb and the top of the MCF are seals. The Upper Clear Fork and Glorieta are at residual oil probably because the hydrocarbons have remigrated. This project is focused on constructing a reservoir model for a one 1-mi^2 volume within the reservoir (fig. 1). We have constructed a reservoir model based on well logs of the MCF reservoir (Lucia and Ruppel, 1999). In this report we describe (1) the reservoir model based on well logs for the LCF, (2) a comparison between our rock-fabric model and a proportional layered model developed by Altura (now Oxy Permian), and (3) our initial efforts to model the permeability distribution in the interwell volume.

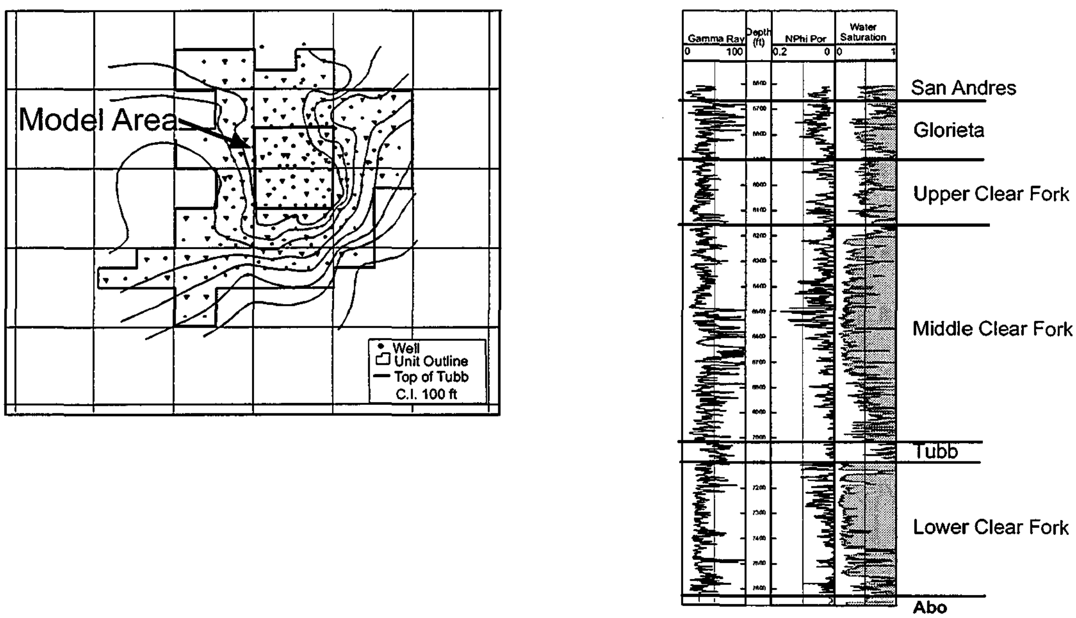


Figure 1. Location map showing structure on top of the Tubb Formation, the location of the 1-mi^2 study area, and a type log for the South Wasson Clear Fork field.

Lower Clear Fork Reservoir Model

The cross plot of porosity and permeability for the LCF is similar to the MCF cross plot in that the samples plot in the class 1 field, with the exception of four moldic grain-dominated dolopackstones (fig. 2). The only class 1 fabric is large crystalline dolostone. Large-grained grain-dominated packstones, however, also commonly plot in the class 1 field (Lucia, 1999). Medium crystalline grain-dominated dolopackstones and mud-dominated fabrics, however, should plot in the class 2 field if the samples are reasonably uniform. As suggested by the study of the MCF fabrics (Lucia and Ruppel, 1999), the reason these samples plot in the class 1 field is that the presence of large volumes of poikilotopic anhydrite creates a nonuniform pattern of dense and porous volumes within the samples. This nonuniform pattern results in anomalously large pore size for a given porosity.

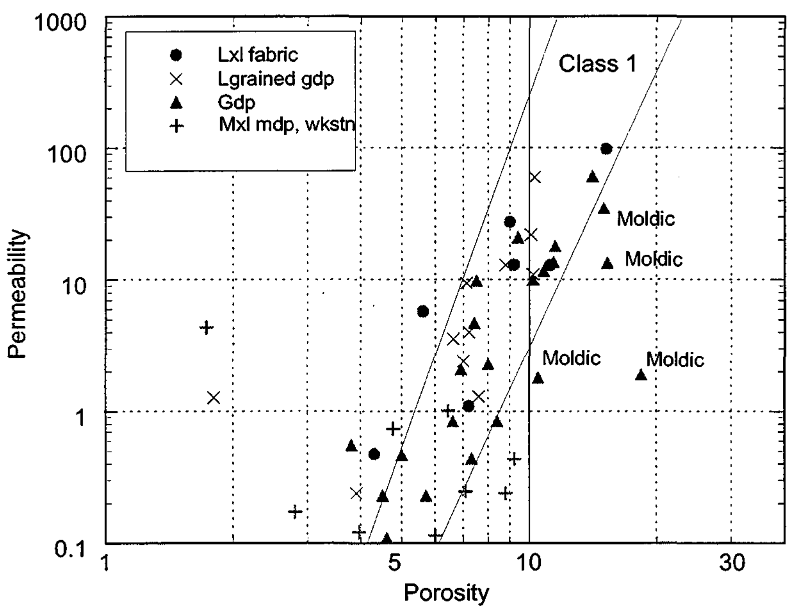


Figure 2. Cross plot of porosity and permeability for the Lower Clear Fork using samples with thin sections only. Similar to the Middle Clear Fork, the samples plot in the class 1 field with the exception of four moldic grain-dominated dolopackstones.

The presence of a single petrophysical class has the advantage of a direct relationship between porosity and permeability, except in the presence of the few moldic grain-dominated fabrics present in this reservoir. A porosity model can be directly converted to a permeability model using a single porosity-permeability transform. A single petrophysical class has the disadvantage in that rock fabrics cannot be easily determined from cross plots of water saturation and porosity. In the MCF model, porosity was correlated with rock fabric in that grain-dominated dolopackstones tend to have higher porosity than mud-dominated dolostones. Porous intervals are interpreted to be grain-dominated packstones capping upward-shallowing high-frequency cycles. A similar correlation has been made for the LCF (fig. 3).

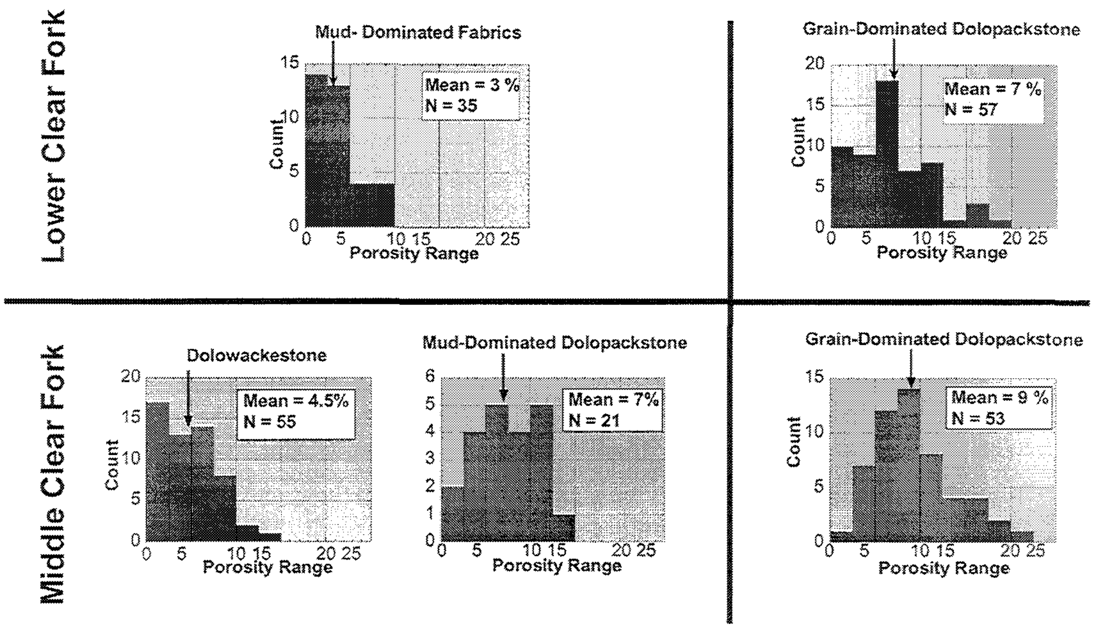


Figure 3. Porosity histograms for the Middle and Lower Clear Fork reservoirs showing that the mud-dominated dolostones have lower mean porosity values than the grain-dominated dolostones.

Using porosity to map rock-fabric cycles is based on the premise that porosity in simple limestones decreases with increasing mud content and that the porosity found in early dolostones is inherited from the precursor limestone. To examine this premise, data from two simple limestone reservoirs are examined, Cretaceous limestone from the Tubarao field in offshore Brazil and Jurassic limestone from the Haradh area, Ghawar field, Saudi Arabia. There is a clear distinction between the average porosity of the grain-dominated fabrics and the mud-dominated fabrics in the Tubarao field (fig. 4). In the

Ghawar data the average porosity decreases with increasing mud content, but there is considerable overlap of porosity values (fig. 4).

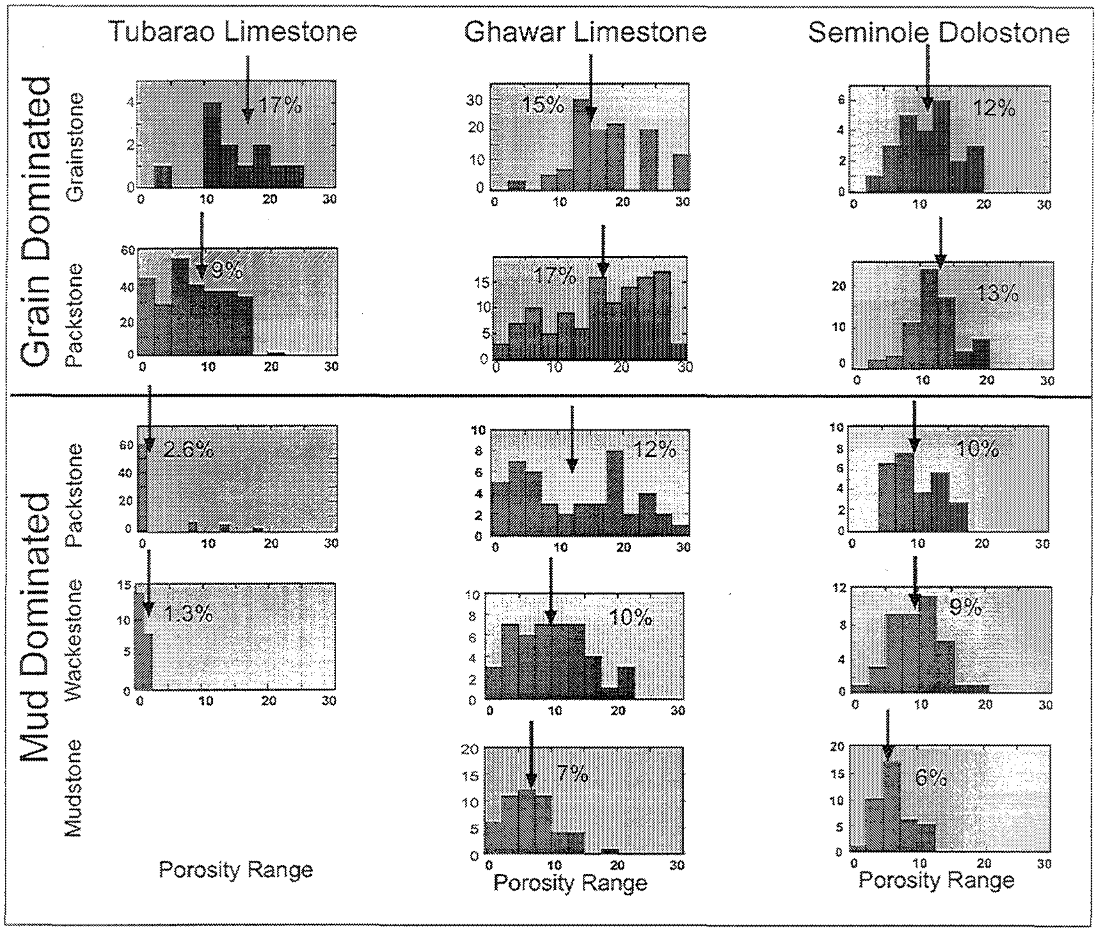


Figure 4. Porosity histograms from two simple limestone fields and one early dolostone field illustrating the similarity between average porosity and rock fabric in the limestone and dolostone fields.

Data from the Permian San Andres reservoir in the Seminole field, West Texas, show a decrease in porosity with increasing mud content of the precursor limestone, similar to the Ghawar limestone data (fig. 4). Whereas it is not suggested that the precursor Seminole limestone had porosity values equal to the Ghawar limestone, it is suggested that the porosity of the precursor Seminole limestone decreased with increasing mud and that this porosity profile was inherited by the Seminole dolostones. By this process, the mud-dominated dolostones have less porosity than the grain-dominated dolostones.

Although the porosity distinction between the three basic rock fabrics may be retained through the dolomitization process, the permeability and petrophysical class may not because they are a function of pore-size distribution, which is directly related to dolomite crystal size (fig. 5). If the dolomite crystal size is fine (less than 20μm) the three basic rock fabrics will be represented by three basic petrophysical classes. A medium dolomite crystal size (20 to 100 μm) will result in combining mud-dominated fabrics with grain-dominated packstone in class 2, whereas grainstones will remain as class 1. A large dolomite crystal size (greater than 100 μm) results in all three fabrics being class 1. Thus, as dolomite crystal size increases, the distinction between rock fabrics diminishes, but the porosity distinction remains.

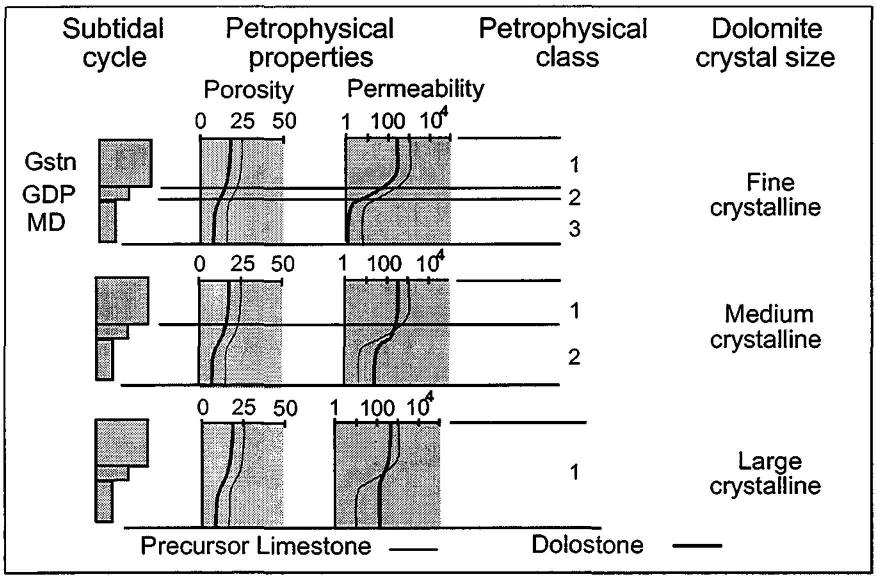


Figure 5. A cartoon to describe the inherited porosity profile of dolostone and the effect of dolomite crystal size on resulting petrophysical class and permeability (modified from Lucia, 1999).

Detailed core descriptions must first be simplified into a rock-fabric description before they can be calibrated with porosity logs (fig. 6). High frequency cycles (HFC) are

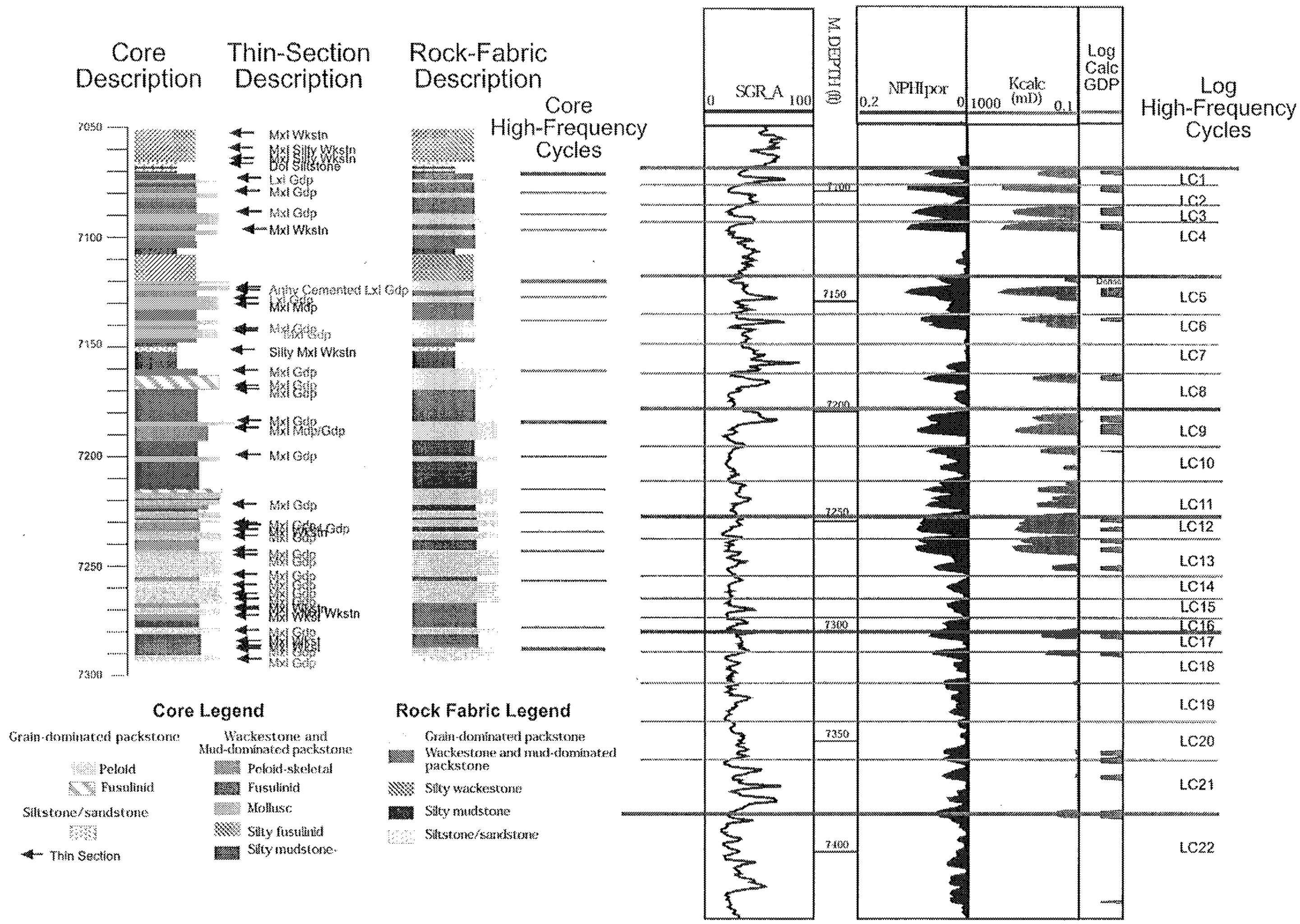


Figure 6. Detailed core description is simplified into a rock-fabric description for calibration with the porosity log.

identified from core data and calibrated to the porosity log. The premise is that high-frequency cycles are capped by grain-dominated packstones or grainstones and that these fabrics can be identified by high porosity. Comparing the porosity log with core HFC's shows that most of the core HFC's are capped by high porosity intervals (fig. 6).

HFC's based on descriptions of cores from well 7531 and well 7509 were correlated to 38 wells in the study area using porosity as an indicator of rock fabric. The resulting model for the LCF contains 21 cycles with an average thickness of about 13 ft (fig. 7). Each cycle is divided into two flow layers. With a few exceptions, the upper layer is more porous than the lower layer (fig. 8). An exception can been seen in well 8542, cycle 5, where the lower flow layer is more porous than the upper flow layer suggesting that here the dolowackestone has more porosity than the grain-dominated dolopackstone (fig. 8a). In wells where the cycles have little porosity the flow layers are forced through maintaining a degree of parallelism because the position of the flow layer makes very little difference to the flow model in these tight intervals. Examples illustrated in figure 8b are cycle 9 in well 7538, cycle 10 in well 8542, cycle 11 in well 7538, cycle 14 in well 7531, cycle 15 in well 7531, and cycle 16 in wells 7531 and 7538.

Rock Fabric Compared with Proportional Layers

Altura (now Oxy Permian) layered the South Wasson Clear Fork reservoir using layers of proportional thickness between six established markers, Upper Clear Fork, E marker, Middle Clear Fork, Tubb, Lower Clear Fork, and Wichita (Abo) (fig. 9). Below the E marker the thickness of the layers was a nominal 10 ft based on vertical variograms of porosity. The average thickness of the rock-fabric layers in the MCF is 14 ft and 6 ft in the LCF. Although the layer thickness in the two models is similar, they conform differently to the vertical distribution of porosity and permeability.

The conformance to petrophysical properties in the two layering schemes is illustrated for cycles 2–7 in the Middle Clear Fork (fig. 10). Cycles 2–7 have 12 rock-fabric flow layers with an average thickness of about 12 ft and 14 proportional layers nominally 10 ft thick. The rock-fabric flow layers use porosity as a tool for correlating the HFC's and therefore partition porosity reasonably well. Some of the proportional layers

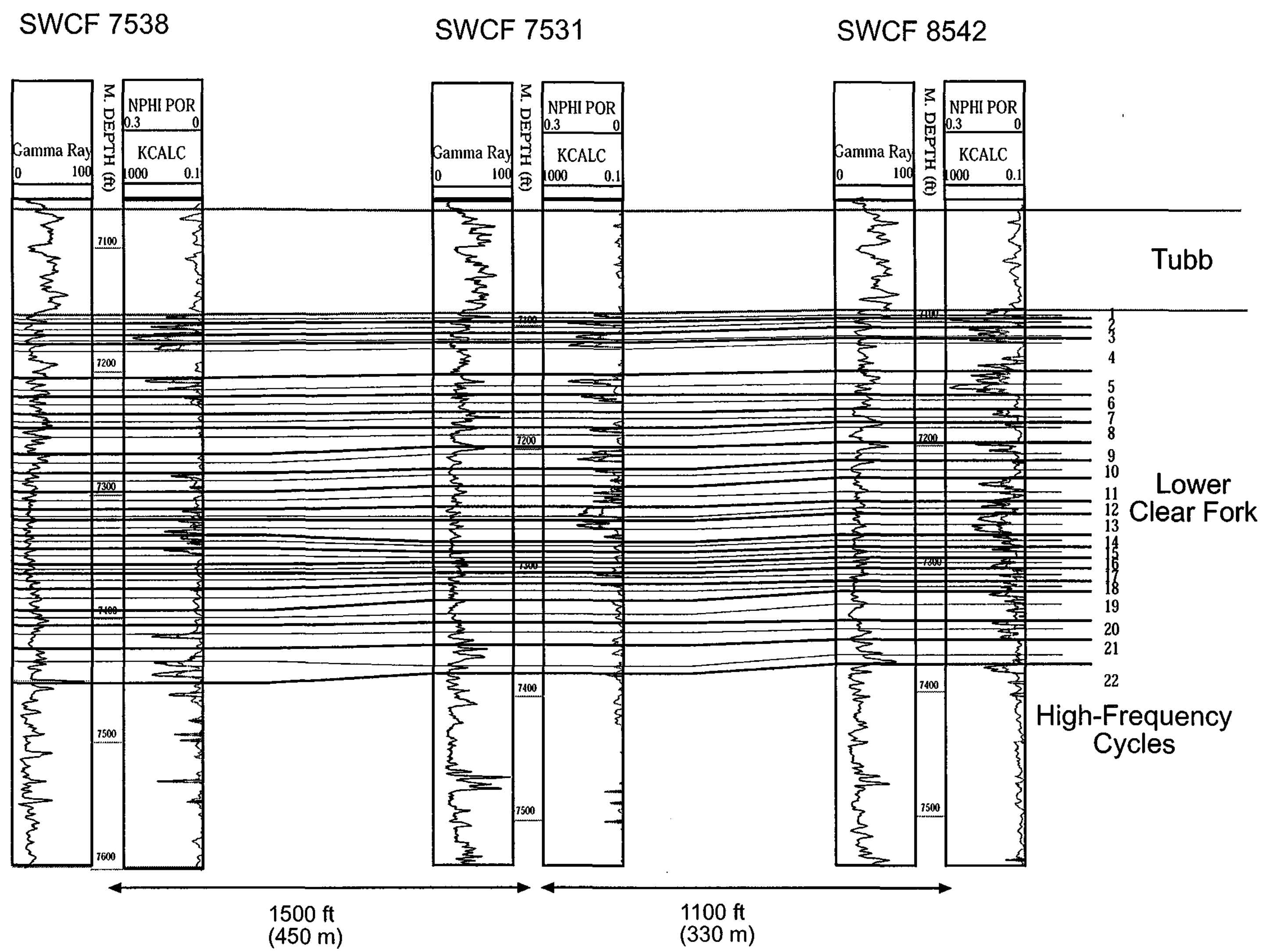


Figure 7. The correlation of 37 wells results in 21 cycles with an average thickness of about 13 ft. Each cycle is divided into two flow layers on basis of the porosity profile. The layers are not parallel.

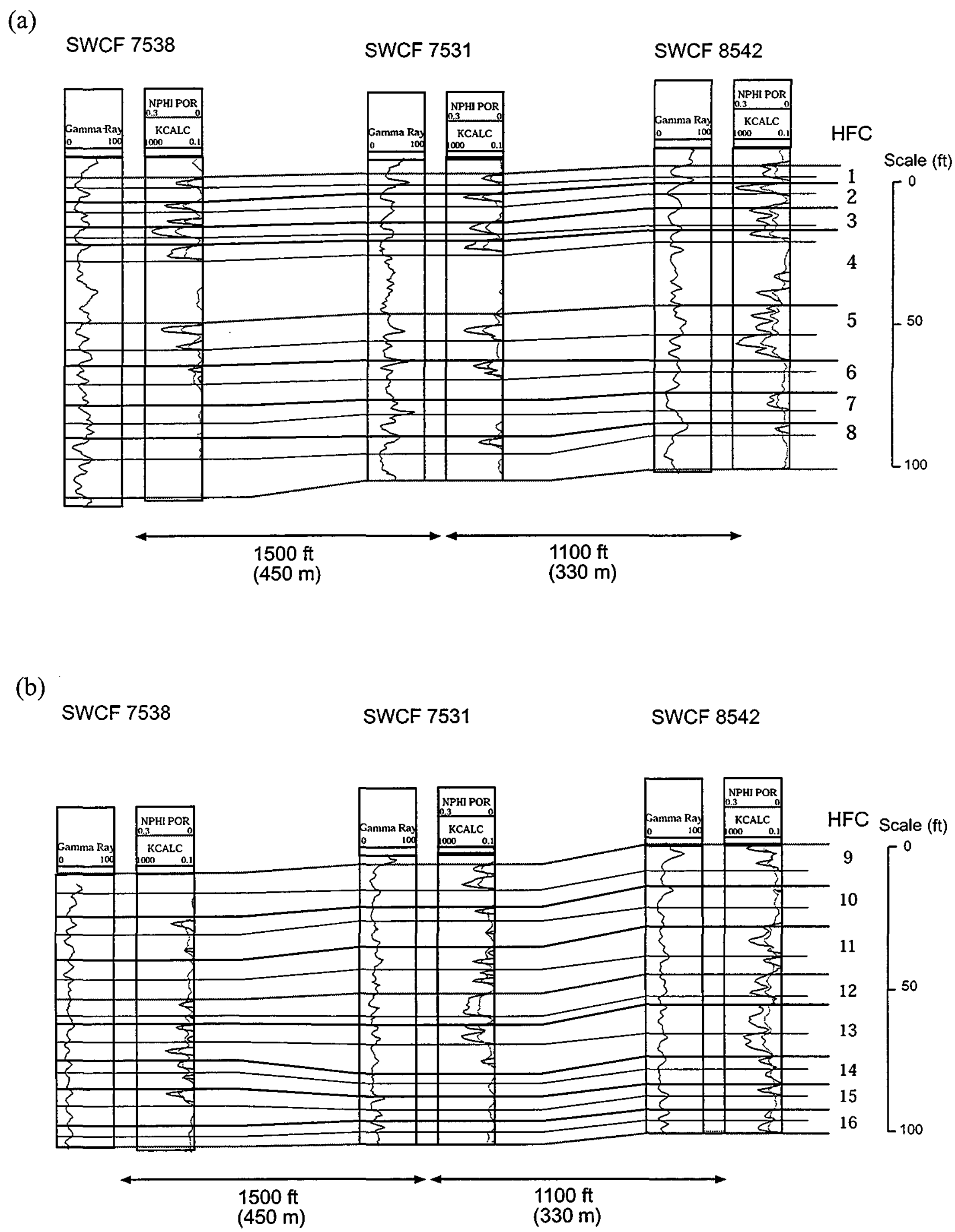


Figure 8. Detail of cycles (a) 1–8 and (b) 9–16 showing high-frequency cycles and flow layers.

also partition high and low porosity, such as layers 21 and 22 in well 753 (fig. 10). Mostly, however, the layers bisect porosity intervals, such as layers 23, 28, and 14 in well 8542 and layers 22, 21, and 19 in well 7538. In addition, layer 21 correlates a high-porosity interval in well 7531 with a low-porosity interval in well 8542. Therefore, the proportional layering approach does not conform to the cycle stratigraphy and does not maintain high and low porosity and permeability values. This effect can also be demonstrated for the Lower Clear Fork.

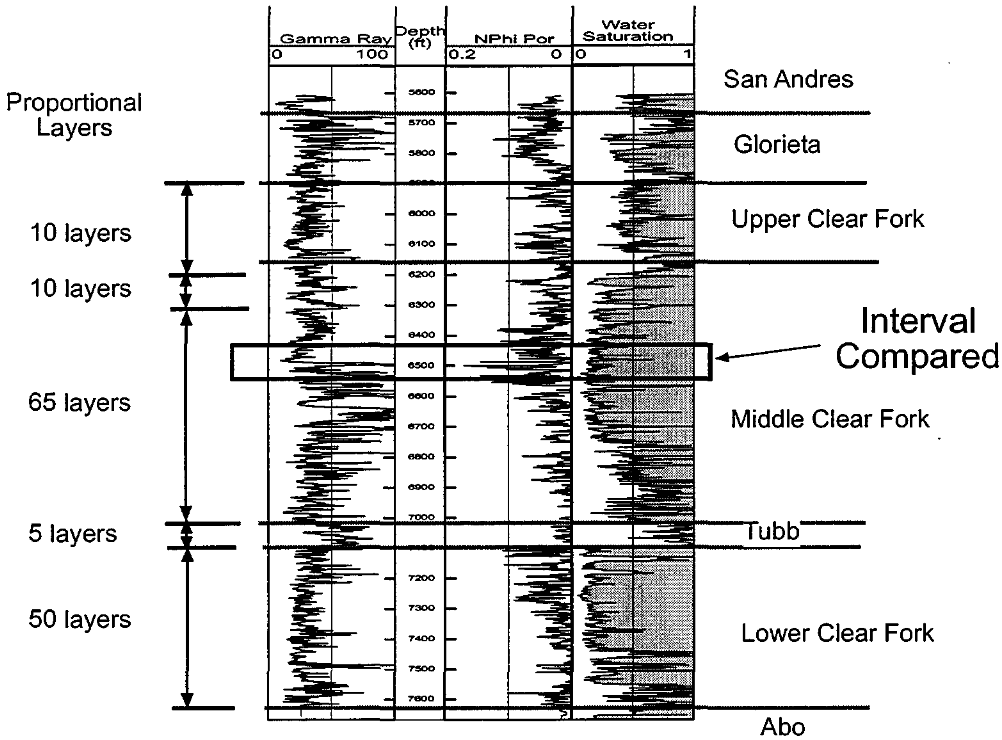
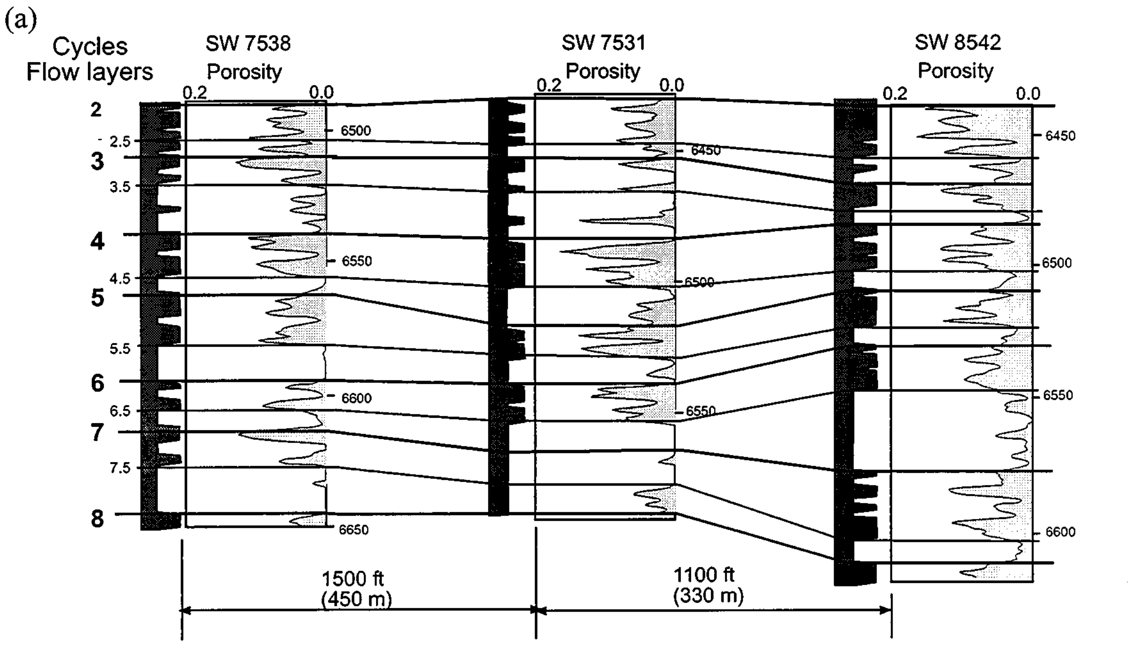


Figure 9. Type log showing porosity on proportional layers used by Altura (now Oxy Permian) and the interval where rock-fabric and proportional layers are compared.

The effect of layer nonconformance on porosity and permeability distribution can be seen in figure 11. The thickness of the MCF has been normalized for the 38 wells. Porosity values for each well are binned into the layers and plotted against depth. A smoothing curve has been applied to help show the difference between the proportional and rock-fabric layering methods. A simple porosity-permeability transform was used to calculate permeability for the rock-fabric layers. The results (fig. 11) illustrate that the



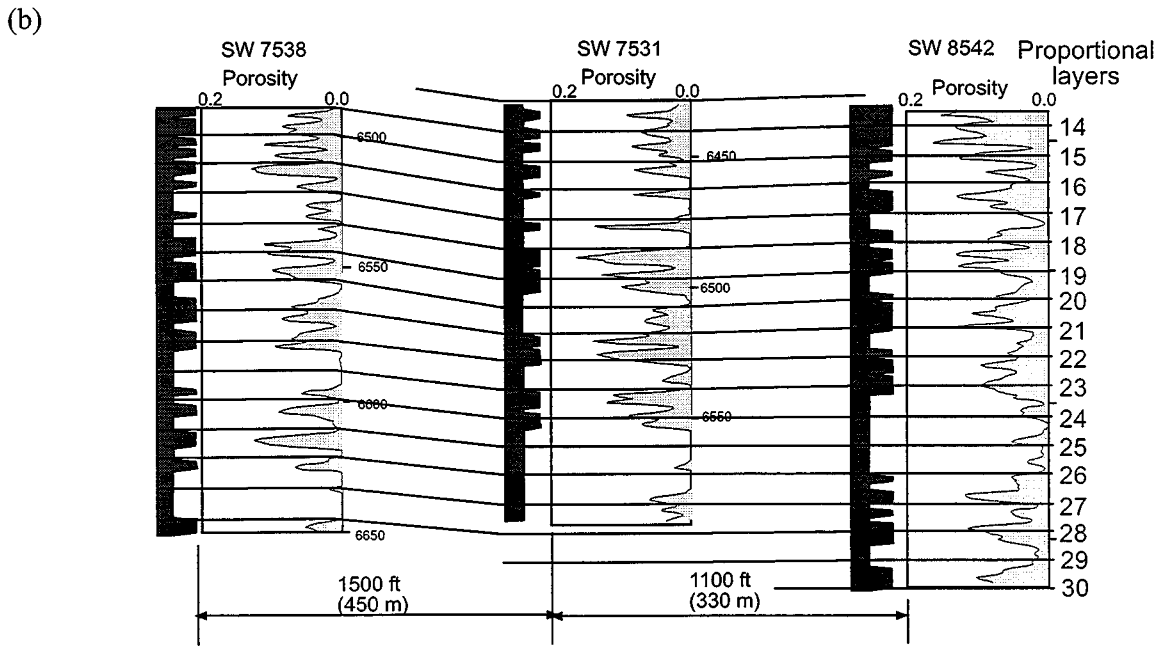


Figure 10. The rock-fabric layers (a) for cycles 2–7 in the Middle Clear Fork are compared with the proportional layers (b).

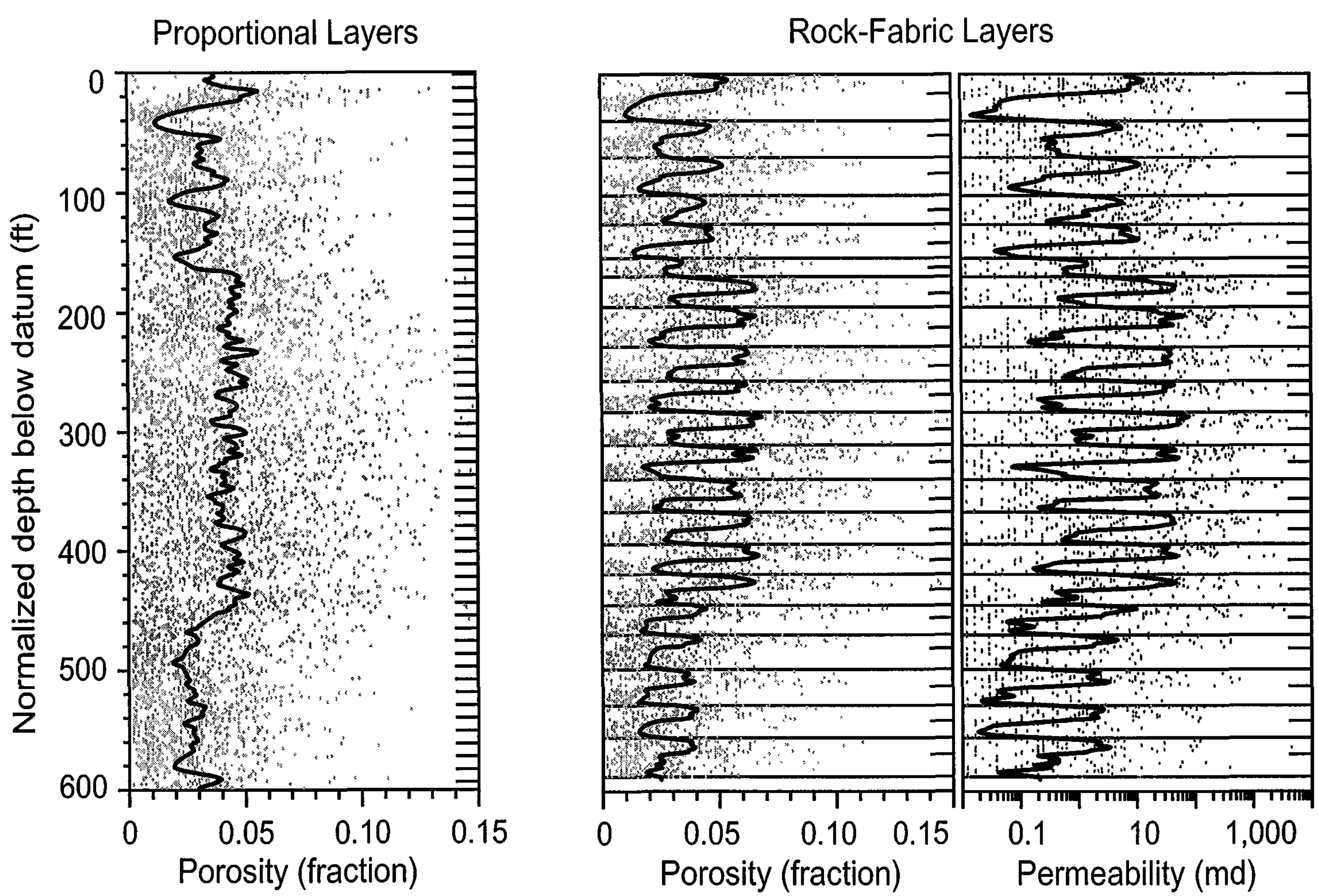


Figure 11. Porosity values from 38 wells are combined to illustrate the different effects proportional and rock-fabric layers have on porosity and permeability distribution.

rock-fabric layers maintain the high and low porosity and permeability values, whereas the proportional layers tend to smooth out the highs and lows. This difference will most likely have a large effect on the outcome of performance modeling that is currently in progress.

Stochastic Modeling

A detailed petrophysical model of a single MCF cycle has been constructed using the partitioning of porosity into cycle bottom and cycle top. Using core data from well 7531 and the rock-fabric flow unit tops, a comparison was made between the porosity distribution in cycle tops and bottoms (fig. 12). The mean porosity was higher in the cycle tops than in the cycle bottoms. There was considerable overlap with 38 percent of the cycle tops having porosity less than the mean porosity of the cycle bottoms and 20 percent of the cycle bottoms having porosity higher than the mean porosity of the cycle tops. The porosity spread is greater for the cycle tops than the bottoms. This is consistent with using porosity to identify rock fabrics (fig. 3) and to map HFC's.

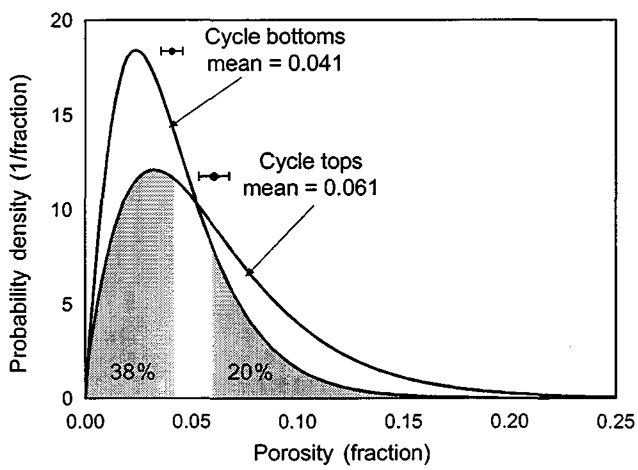


Figure 12. Porosity histograms of cycle types and bottoms using core data from well 7531.

A detailed stochastic porosity model of a single cycle 26 ft high and 50 ft long was constructed using the porosity histograms, a vertical variogram from core data, and a horizontal variogram based on data taken from the Clear Fork outcrop in Apache Canyon, Sierra Diablo Mountains (fig. 13). The model illustrates the lateral variability that can occur on the scale of 10's of feet in this reservoir (fig 14).

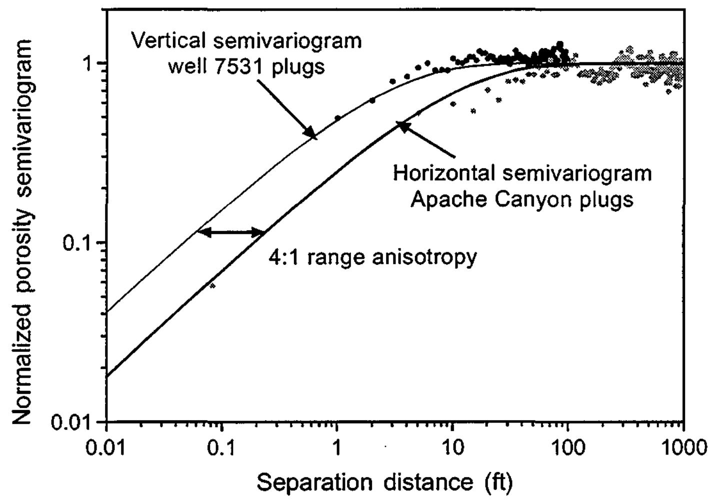


Figure 13. Vertical and horizontal variograms used in the construction of the detailed stochastic porosity model.

References

Lucia, F. J, 1999, Carbonate Reservoir Characterization: Berlin Heidelberg, Springer-Verlag, 226 p.

Lucia, F. J., and Ruppel, S. C., 1999, Semi-Annual report, DOE Contract No. DE-AC26-98BC15105, March 30, 1999, to October 1, 1999.

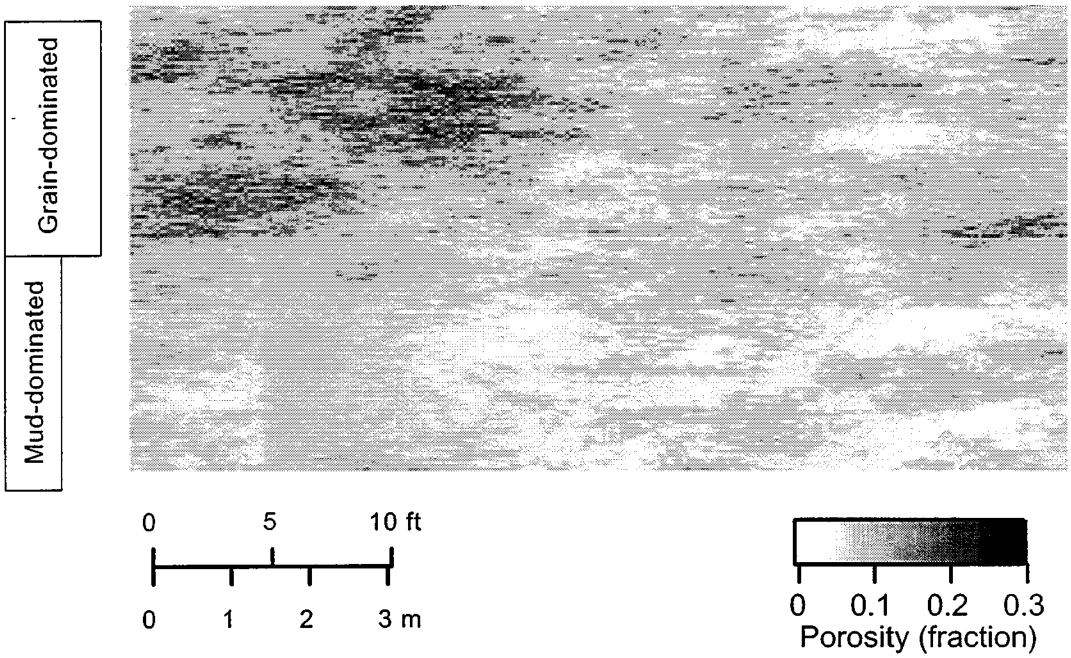


Figure 14. Detailed stochastic porosity model of an ideal Middle Clear Fork high-frequency cycle.