Log analysis of Mesaverde sandstone gas reservoirs, Piceance basin, Colorado

Robert M. Cluff and **Suzanne G. Cluff**
The Discovery Group, Inc.
Denver, Colorado, USA

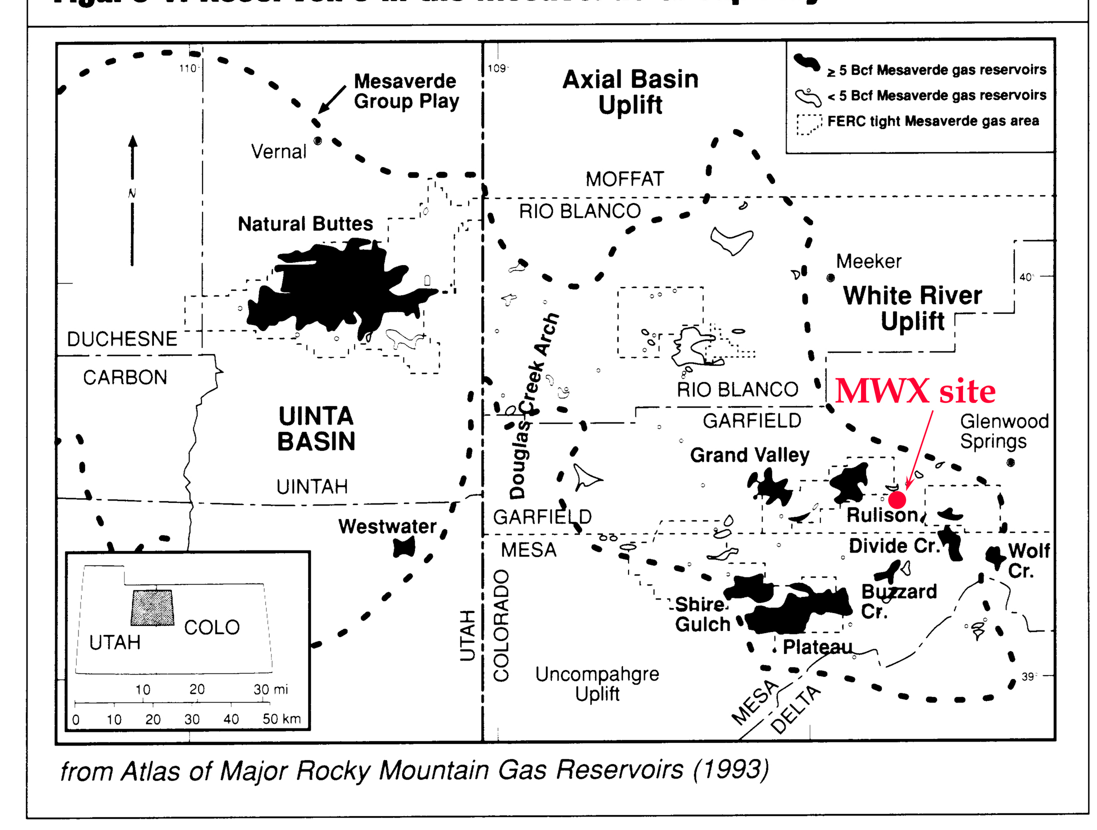
The Discovery Group, Inc.

Summary

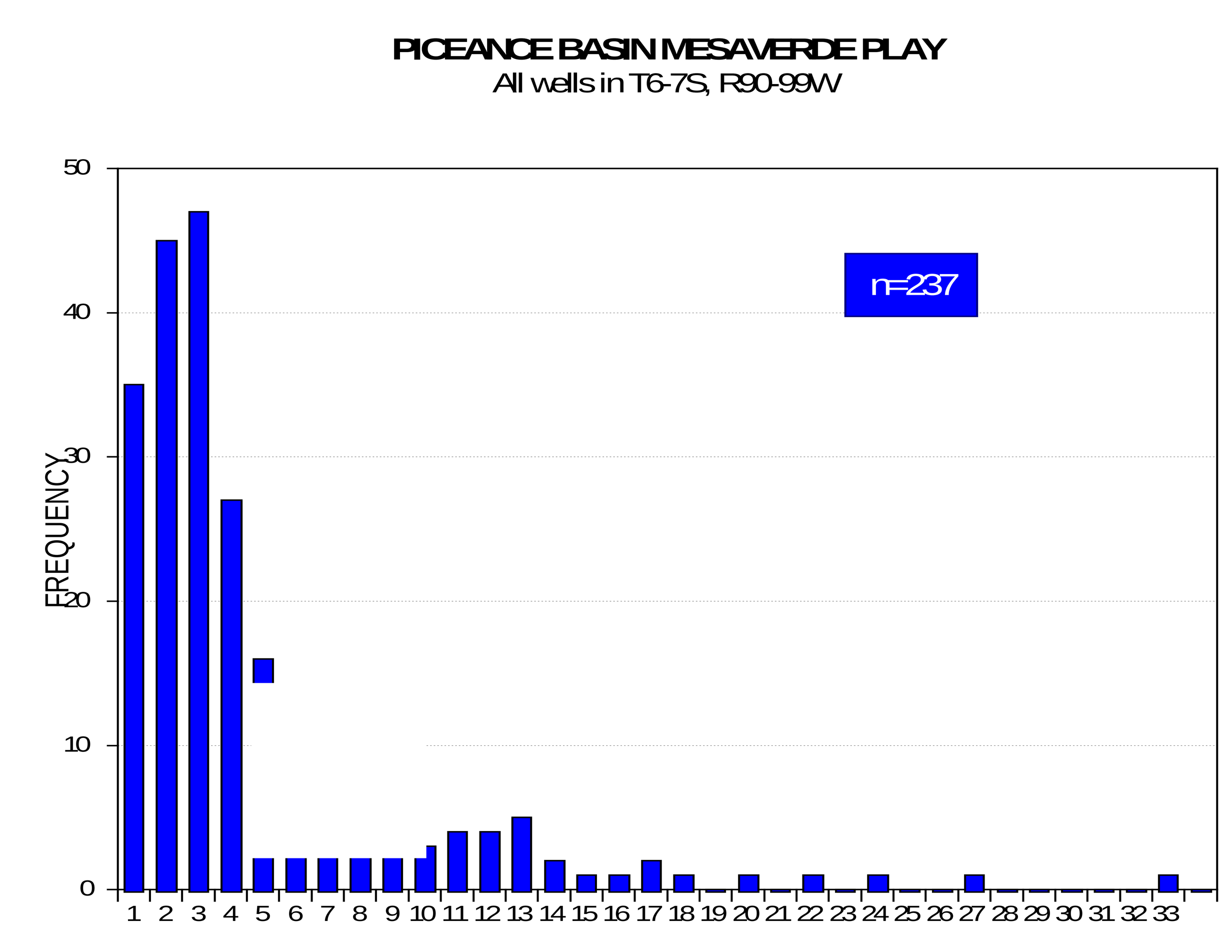
Fluvial sandstones in the Mesaverde Group produce gas in a broad east-west trend in the southern Piceance basin. Although known to contain substantial amounts of natural gas for many decades, significant development of this tight gas sand resource has only occurred in the last 15 years. Despite the best efforts of many individuals and organizations, including substantial efforts to develop tight gas sand specific models, it is generally agreed that it is not possible to predict long term well performance from wireline log data. Attempts to merge detailed petrophysical analyses with completion and stimulation results have also failed to yield equations that predict ultimate recovery with any meaningful accuracy.

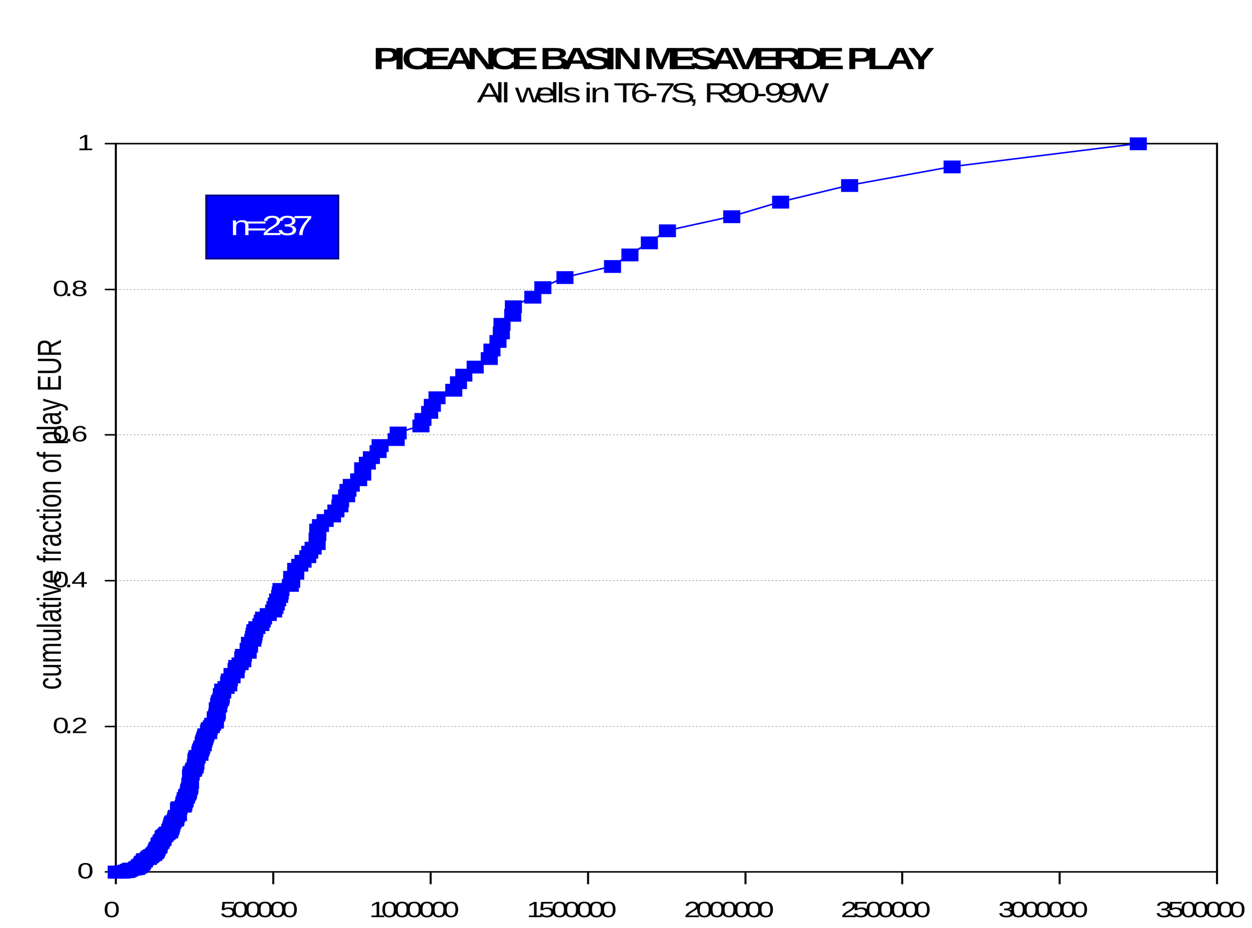
Simple and straight forward log analysis models using basic shaly sand techniques are capable of producing accurate measures of porosity and in-situ water saturations. Reasonable matrix permeability estimates can also be calculated. Predictive models fail because logs are unable to quantify, and in many cases they are unable to detect, many of the most important parameters that control productivity. These include quantitative measures of natural fracturing, reservoir compartment sizes, effectiveness of induced fractures, lateral extent of the induced fractures, connectivity to nearby compartments not contacted by the well bore, drilling and completion fluid damage, and relative permeability effects.

Figure 1: Reservoirs in the Mesaverde Group Play



from Atlas of Major Rocky Mountain Gas Reservoirs (1993)



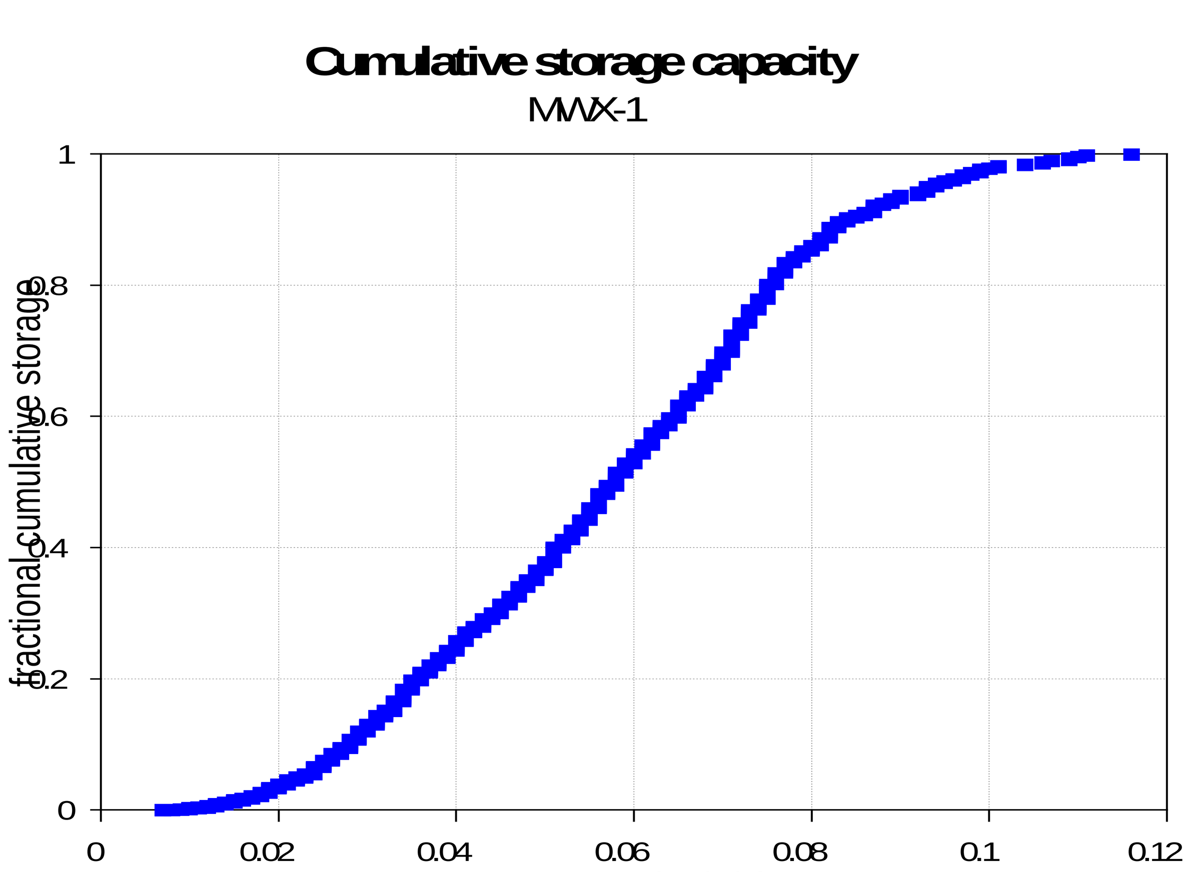


The MWX-1 example: Porosity calculations

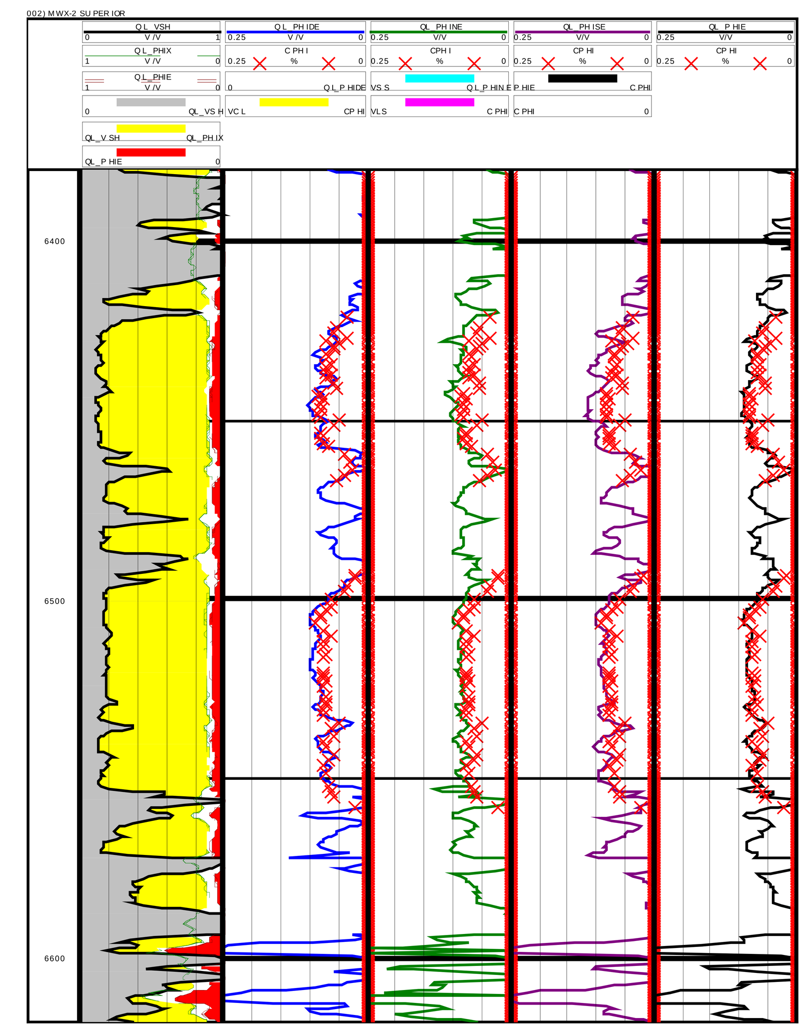
The MWX-1 well is an outstanding test site to test the veracity of log analysis models because of the large database of cores and special core analysis data collected over an exceptionally long interval of the Mesaverde. Both routine and special core analyses for this well were digitized and merged with the open hole log data, which are also exceptionally complete. Although other wells in the Piceance basin also have complete log suites and significant amounts of core data, none approach the MWX-1 in quantity or quality.

To analyze this well we used a simple shaly sand log analysis model. Volumes of shale and sand were calculated from the gamma ray log using a non-linear response model (Steiber, 1970). Total porosity was calculated from a cross-plot of the neutron-density log, which were then corrected to effective porosities using locally appropriate values for the bulk density and neutron porosity of shale.

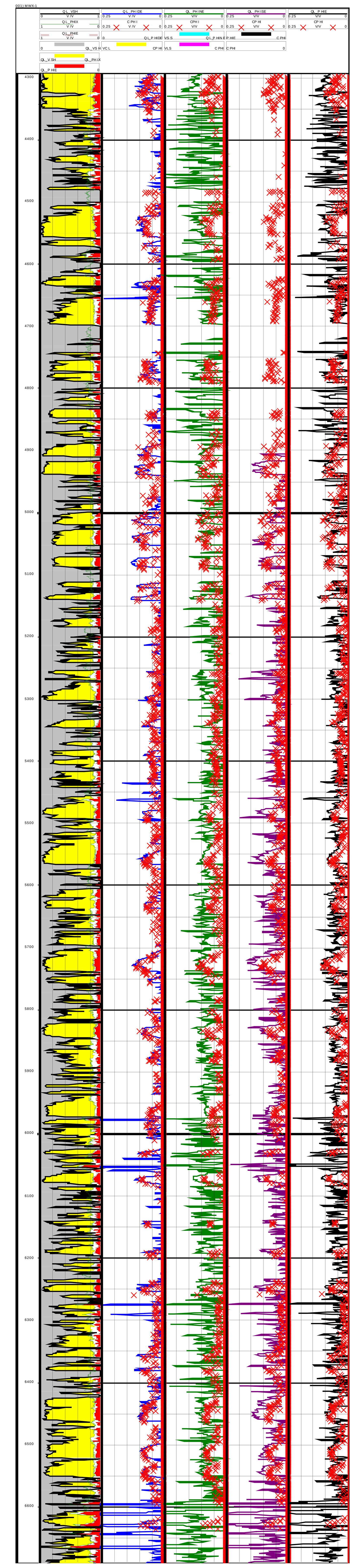
Log determined effective porosities and saturations are in excellent agreement in the thicker sandstones, e.g. 5540-5565′ and 5700-5845′. In the thinly interbedded shaly sandstone and shale intervals the logs lack the resolution to fully respond to the formation conditions, but nonetheless yield representative average values for porosity. Similarly good matches between log determined effective porc ınd core porosity are seen in cored sections of the M -2, MWX-3, and Arco-Exxon 1-36 wells.



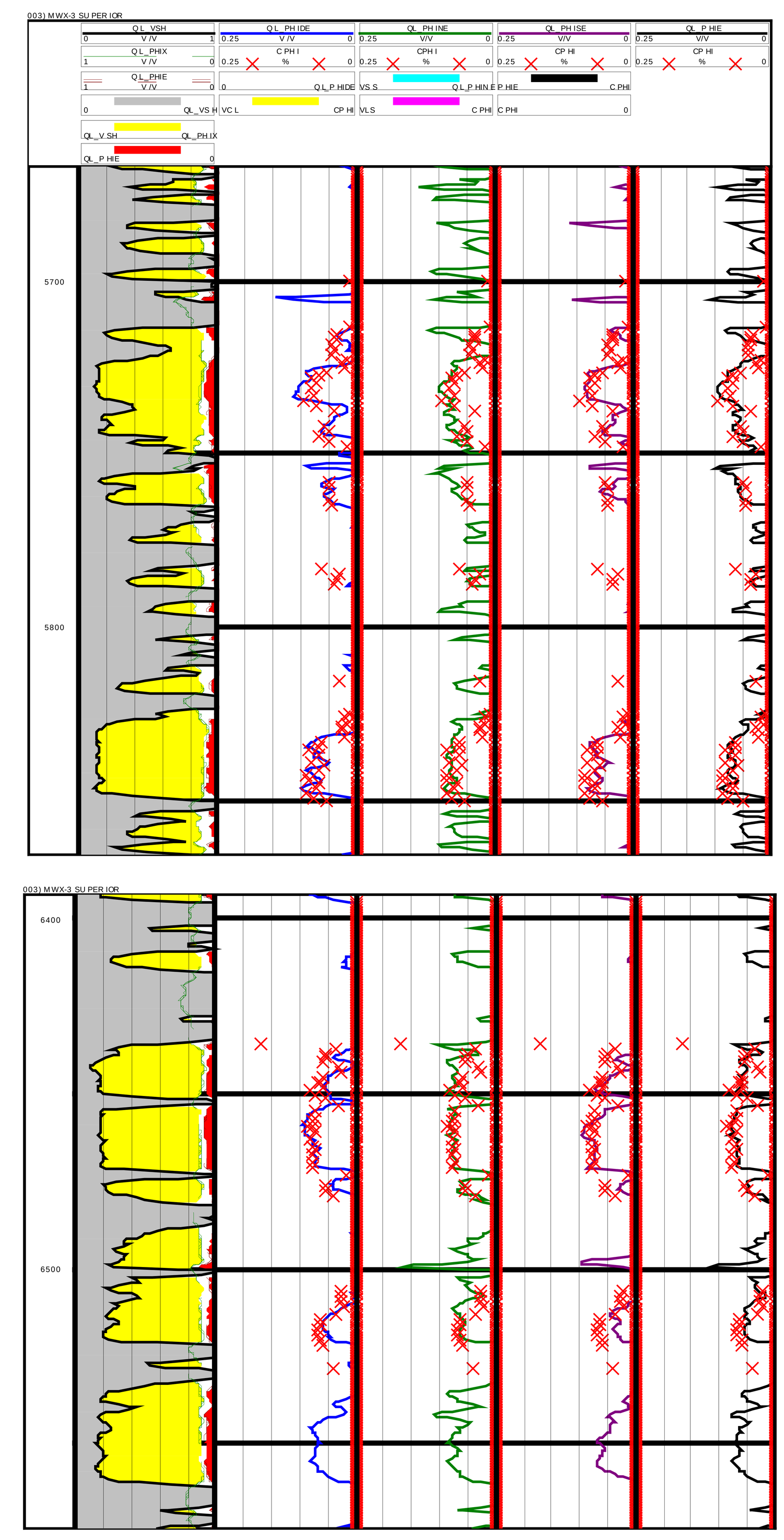
MWX-2



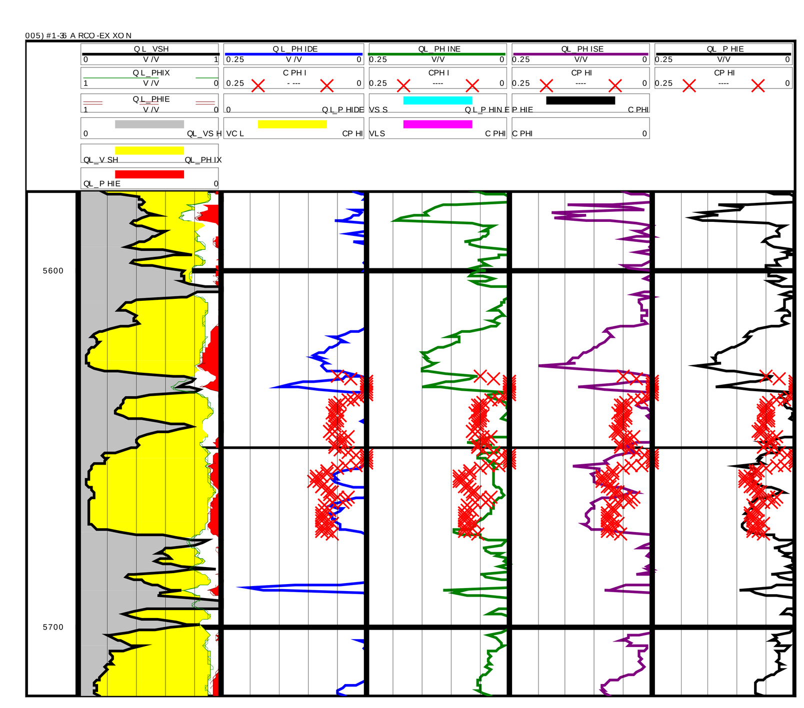
MWX-1



MWX-3



Arco-Exxon 1-36

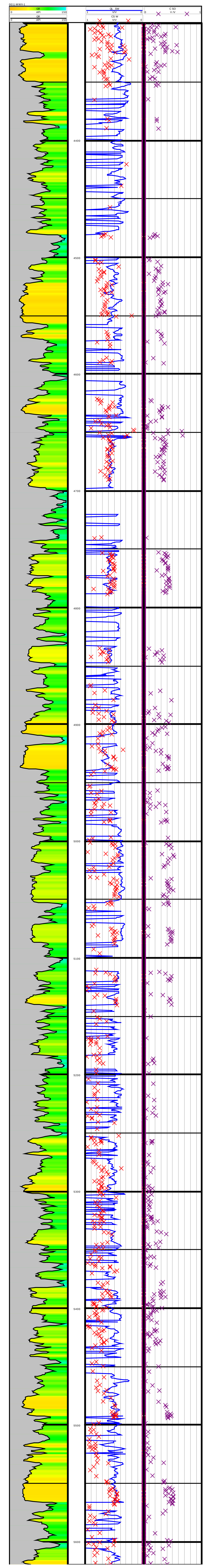


Saturation calculations

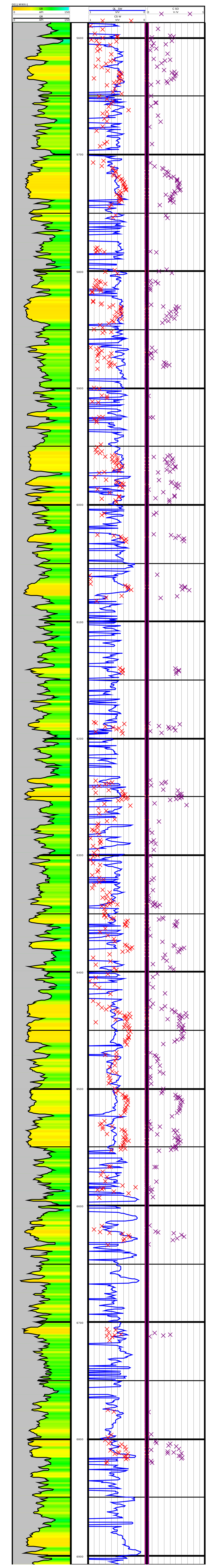
Saturations were calculated using the Dual Water model approach (Clavier et al, 1984) using a bound water resistivity calculated in shaly intervals. Comparisons to several other shaly sand saturation models indicate the model selection is not very critical. Formation water resistivity was adjusted by trial and error until a reasonable match was obtained between log calculated saturations and saturations determined by core analysis. The latter are in good agreement with capillary pressure data and from various other lines of evidence are believed to represent slightly flushed, but close to reservoir water saturations. It is necessary to zone water resistivity with depth in this well and most others we have examined in the basin.

The results in several intervals of this simple model are illustrated at right and in the previous poster. In some zones, such as MWX-1 5710-5740′, the porosity match is good but the saturation match is poor. These zones are believed to represent rock type changes and indicate the need to refine the model to account for at least two reservoir sandstone types.

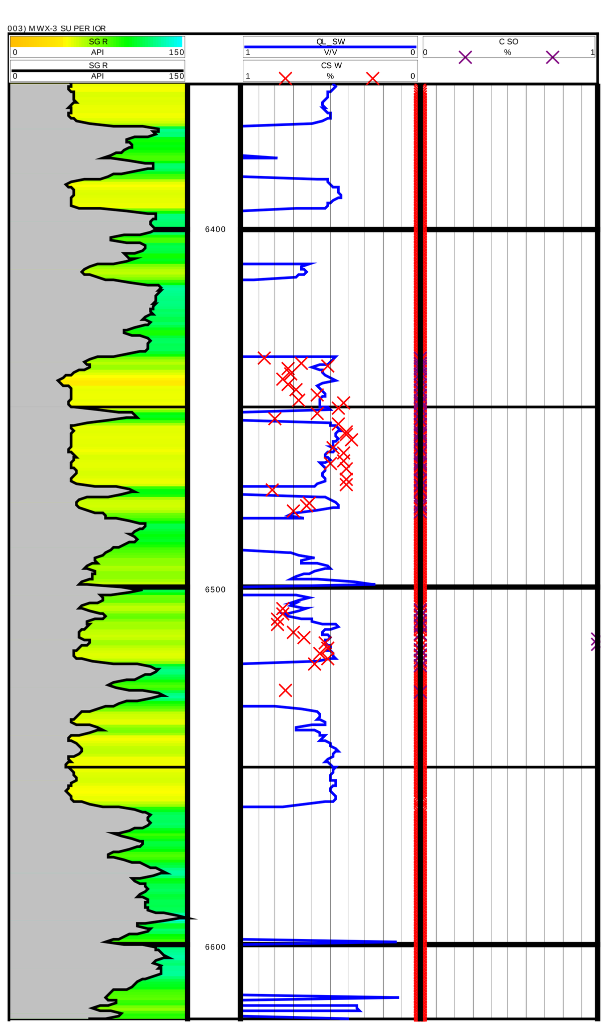
MWX-1



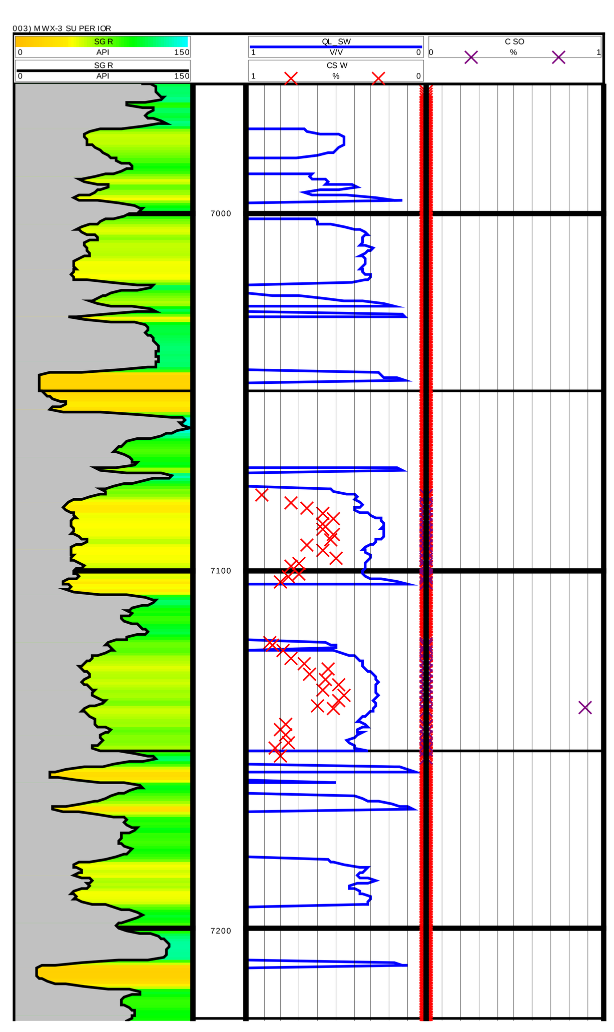
MWX-1



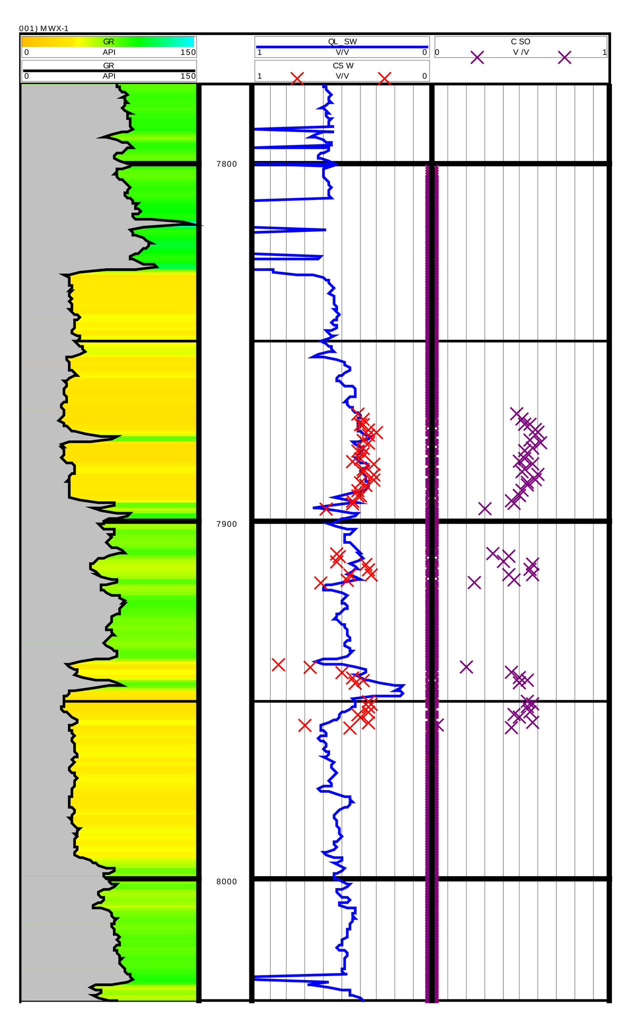
MWX-3



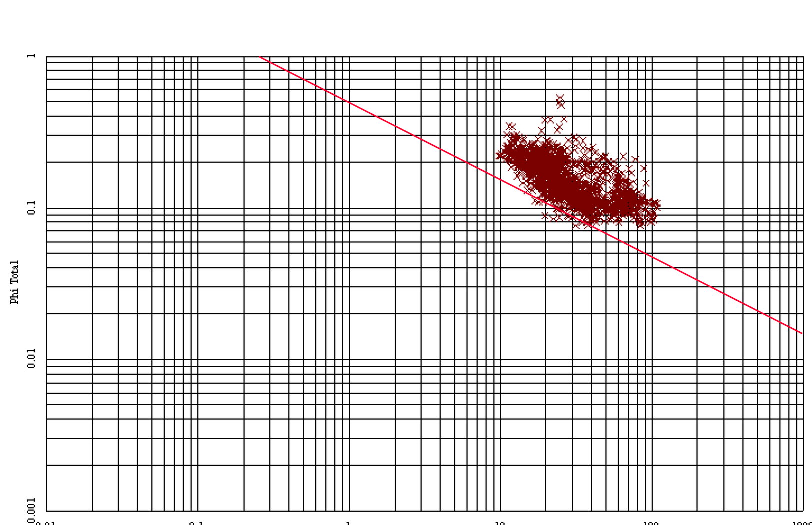
MWX-3

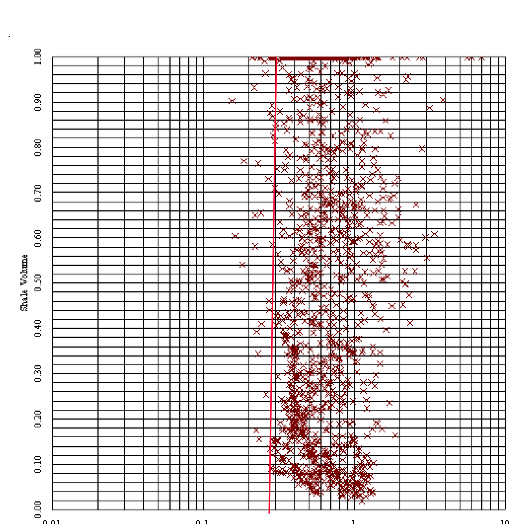


MWX-1

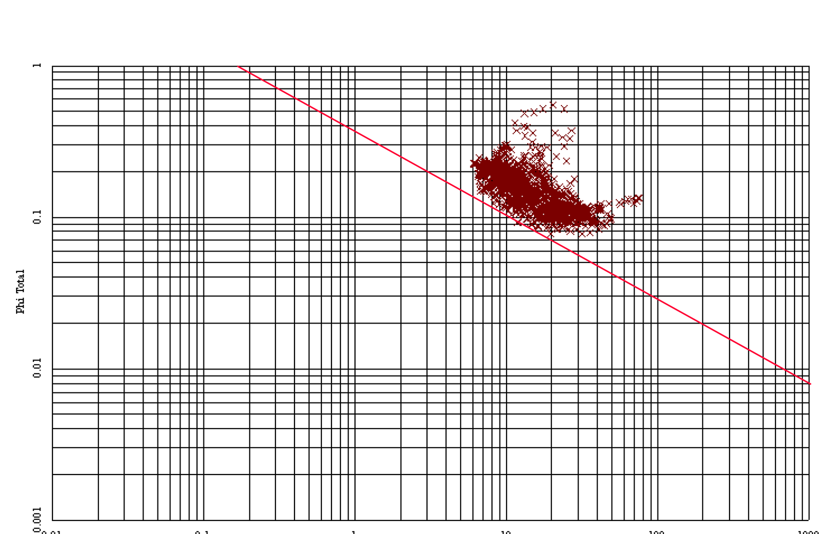


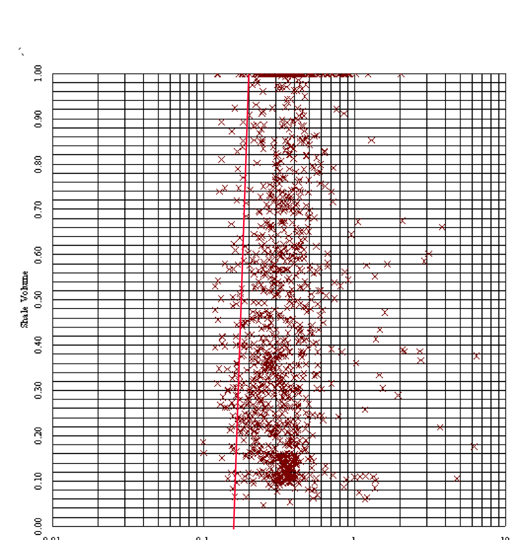
Upper Mesaverde (MWX-1)





Lower Mesaverde (MWX-1)





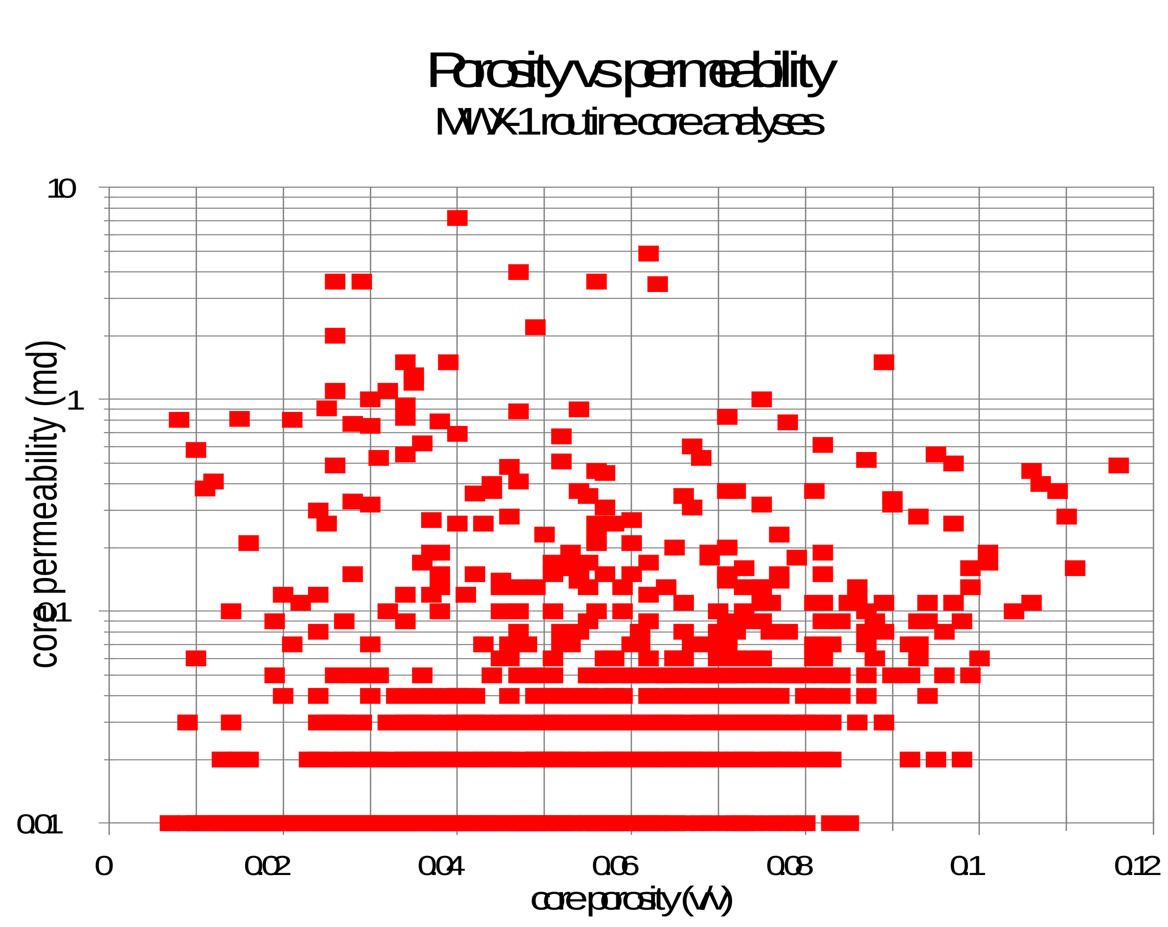
Permeability prediction

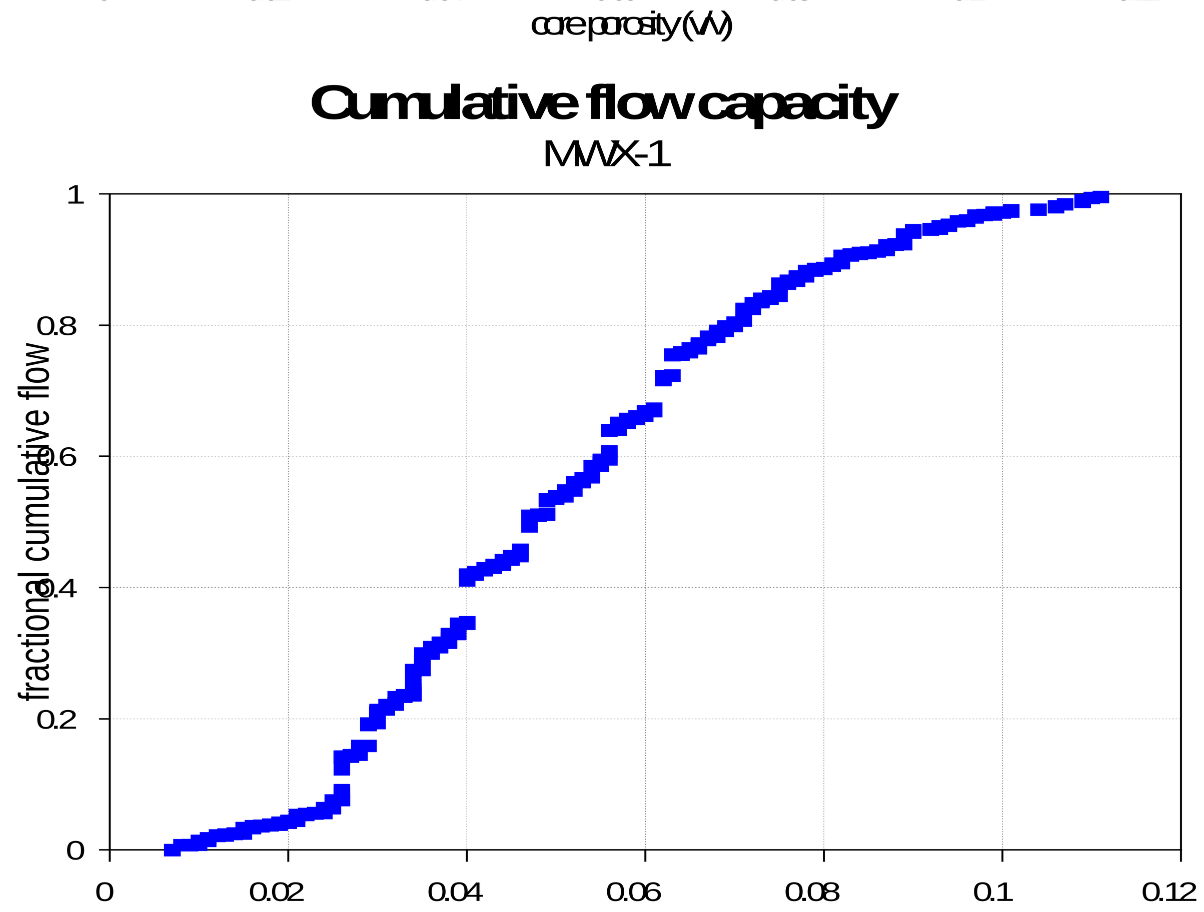
Estimating permeability of tight sandstones is one of the most important variables needed to predict productivity. We used a simple model for permeability prediction based on effective porosity and irreducible water saturation. Fundamentally the form of the equation is similar to that proposed by Timur (1968):

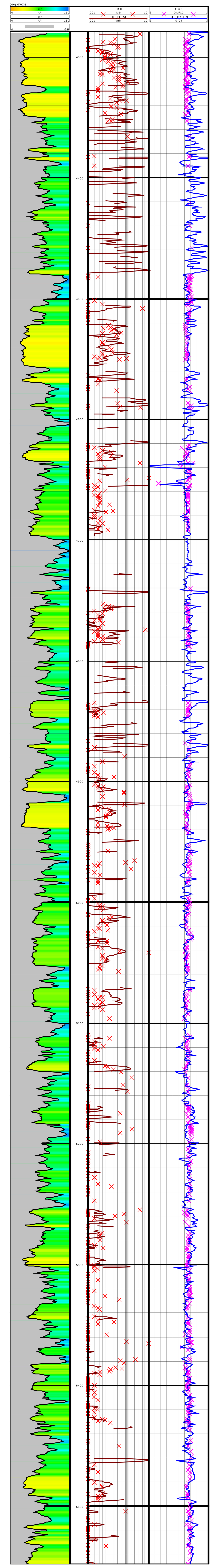
$$K = A \times \phi^B / S_{wi}^C$$

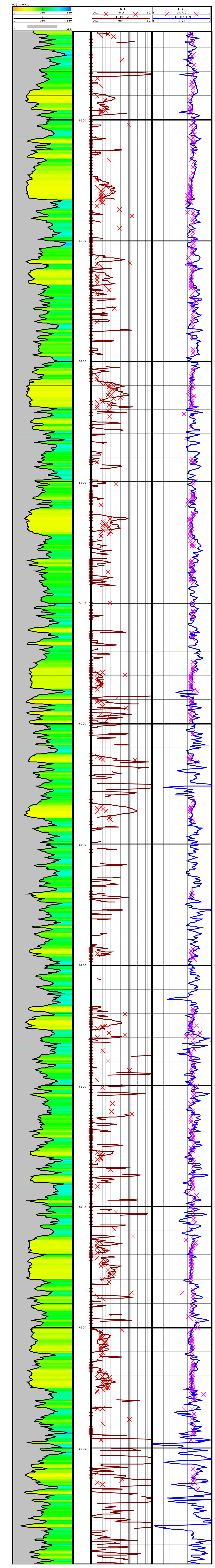
where K is permeability in millidarcies; ϕ is effective porosity as a decimal fraction; S_{wi} is irreducible water saturation as a decimal fraction; and A, B, and C are formation and area specific constants. Best results will be obtained by local calibration to core data and by detailed rock typing of the various lithofacies, where each lithotype is assigned specific constants and characteristic irreducible saturation. Even using one set of average constants and one irreducible saturation for the entire Mesaverde interval, however, yields a reasonable match between core permeability and log predicted permeability over most of the sandstones in the MWX-1 and MWX-2 wells.

It is important to emphasize that this illustrates prediction of routine matrix permeabilities at laboratory conditions. The actual permeability to gas at reservoir conditions will be considerably less due to confining stress effects and relative permeability effects at partial water saturation.





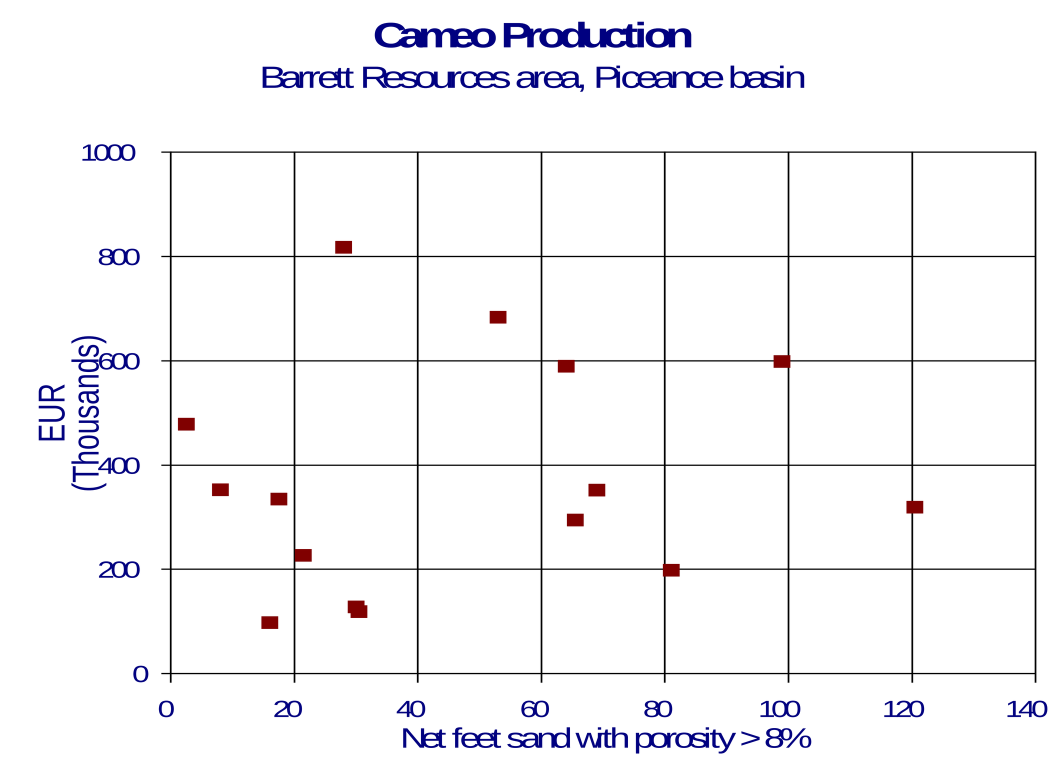


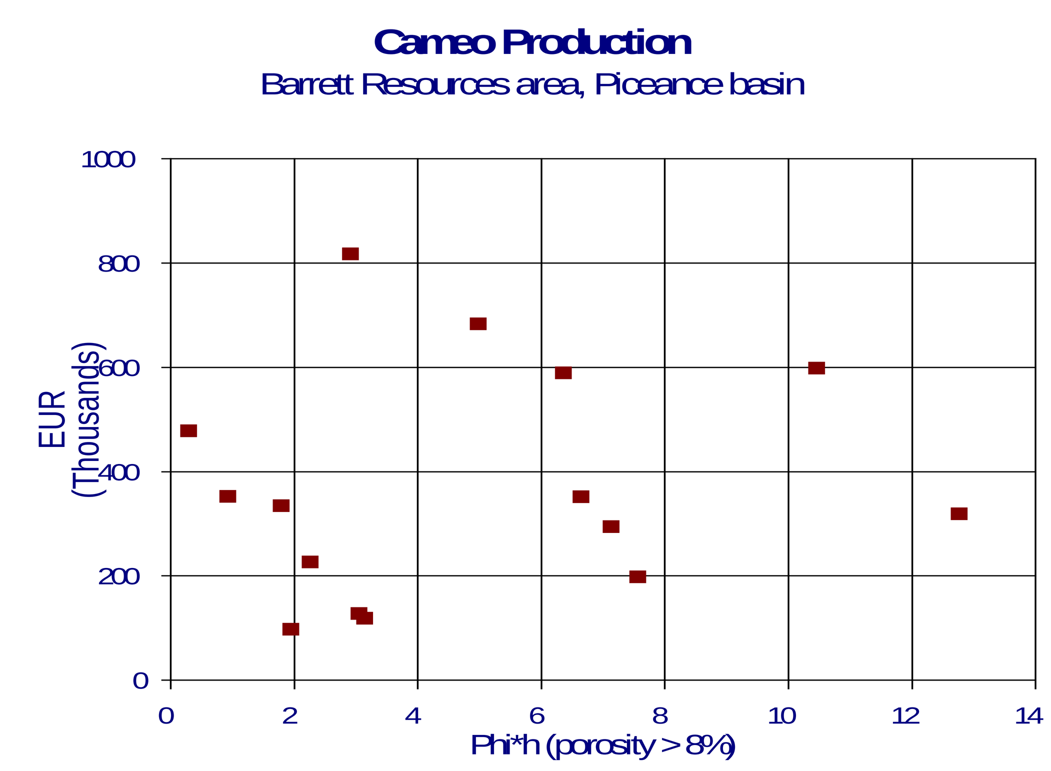


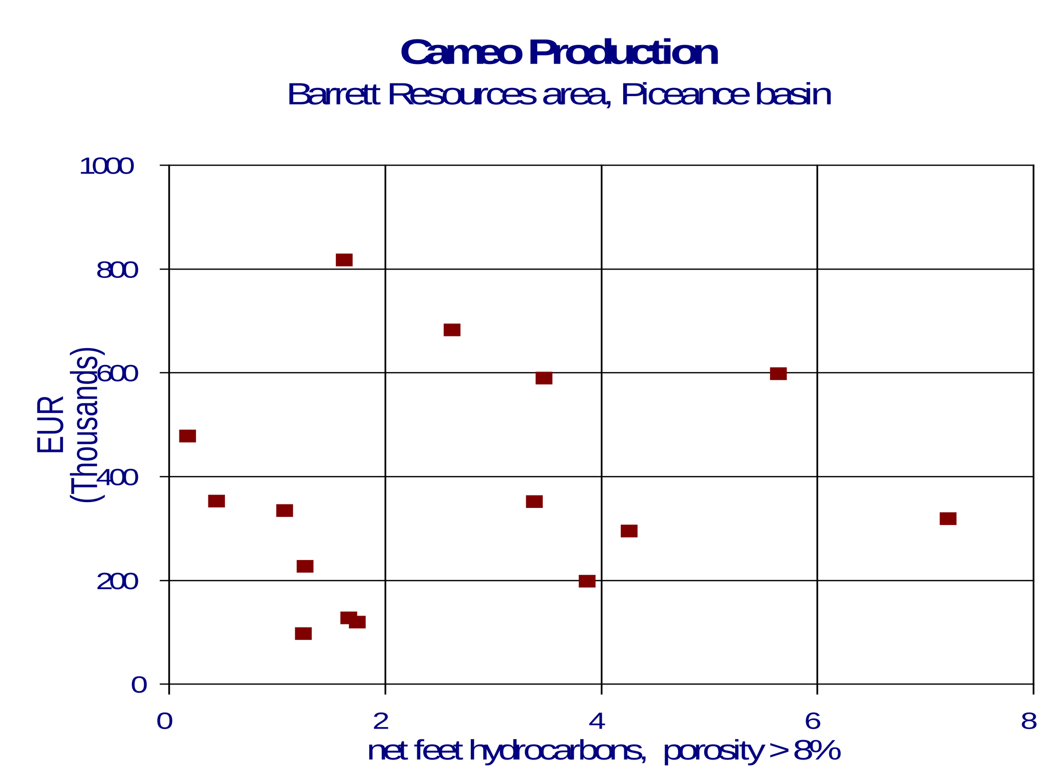
Comparison to production response

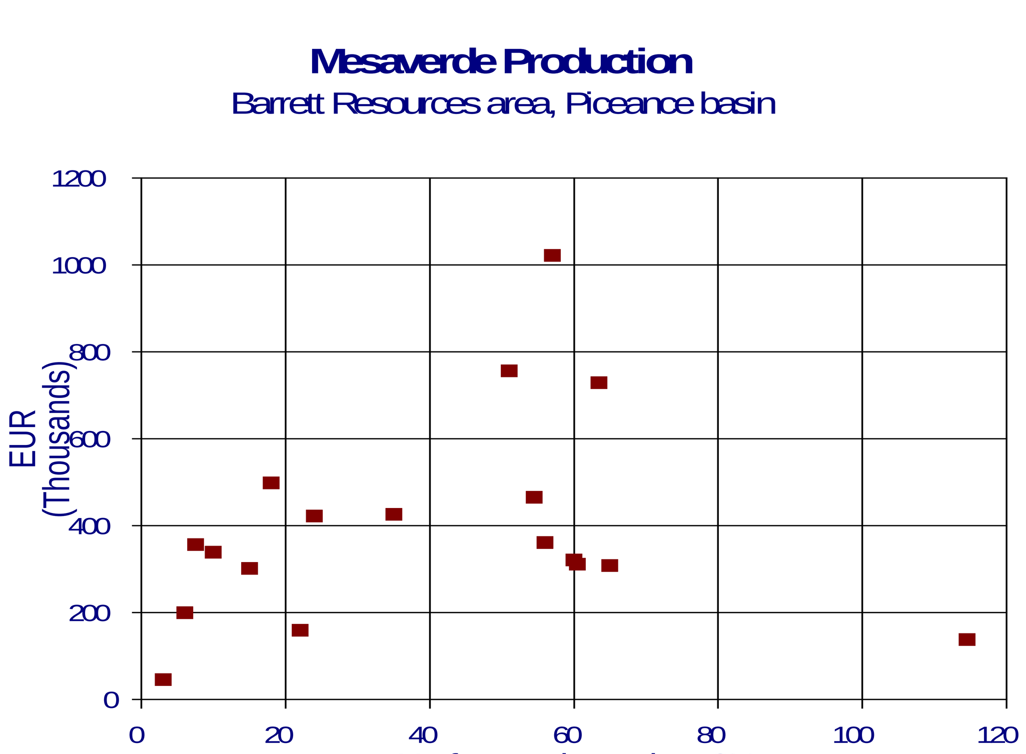
We applied this log analysis methodology consistently to a large number of Piceance basin Mesaverde producers, allowing specific analysis parameters such as Rw to vary regionally. This methodology failed to yield a simple relationship between the petrophysical measures and estimated ultimate recovery from decline curve analysis. Similarly disappointing results have been reported by various companies and individual log analysts who have attempted to deterministically estimate reserves in the Mesaverde.

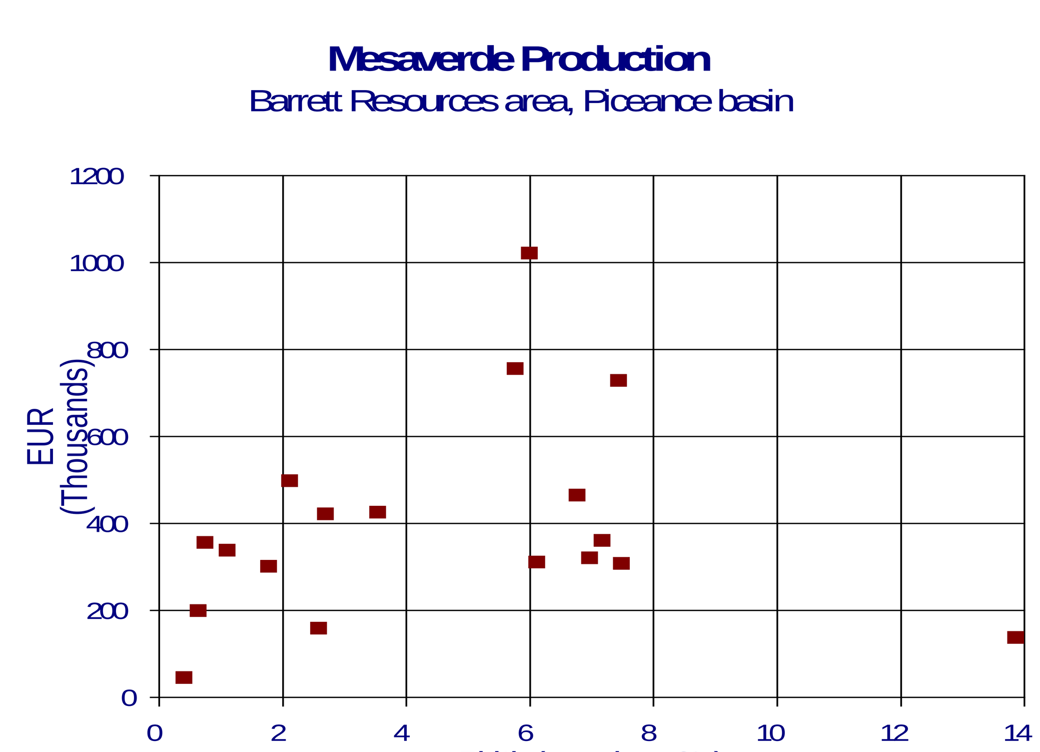
Including publicly available metrics of the completion such as pounds of proppant pumped or gallons of frac fluid in the analysis does not significantly improve the correlations. Wherever core data or other independent measures of porosity, saturation and formation permeability are available the log analysis model is in good agreement with these data. Therefore we conclude the problem is not within the log model, net pay counts, hydrocarbon pore volumes or any other deterministic measures from logs. Why then are we unable to predict ultimate recovery?

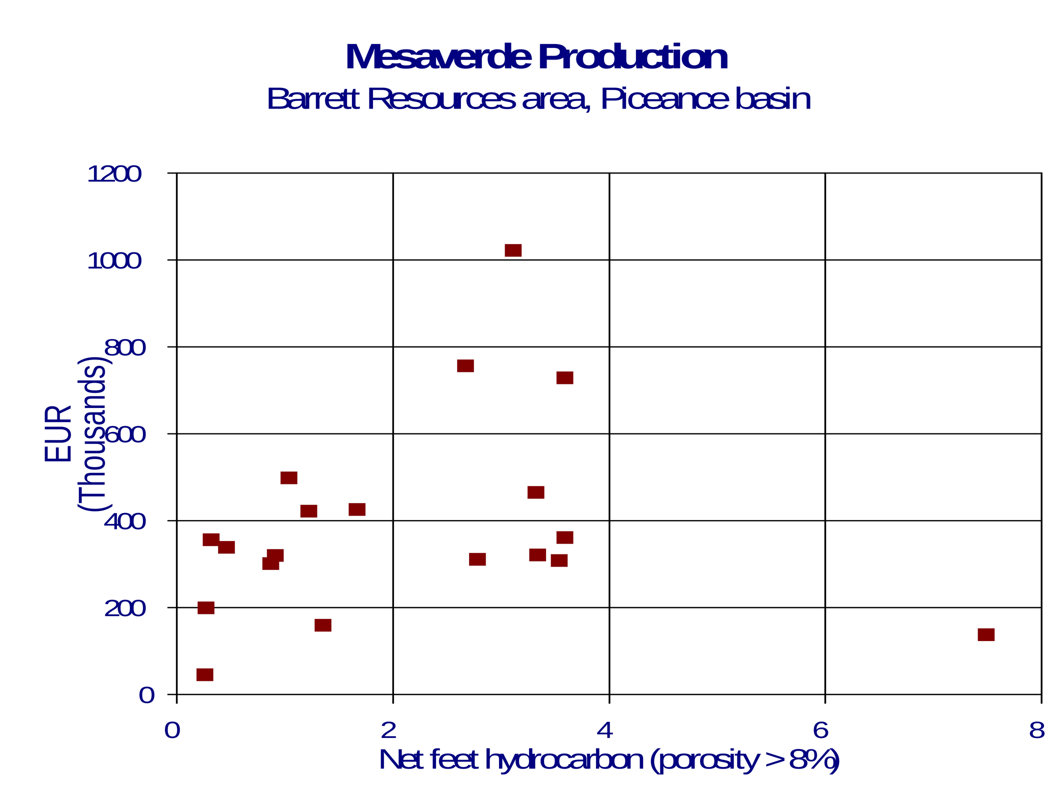


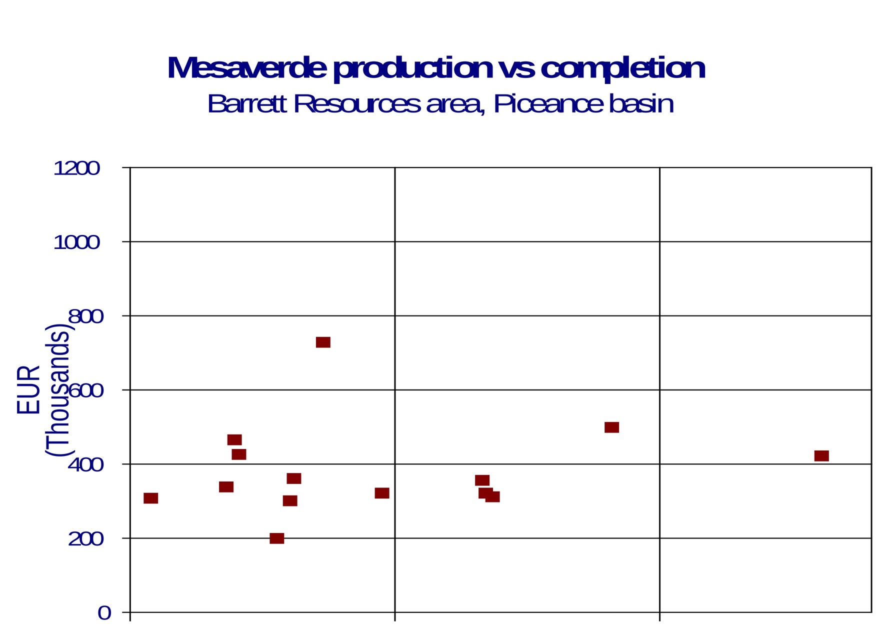


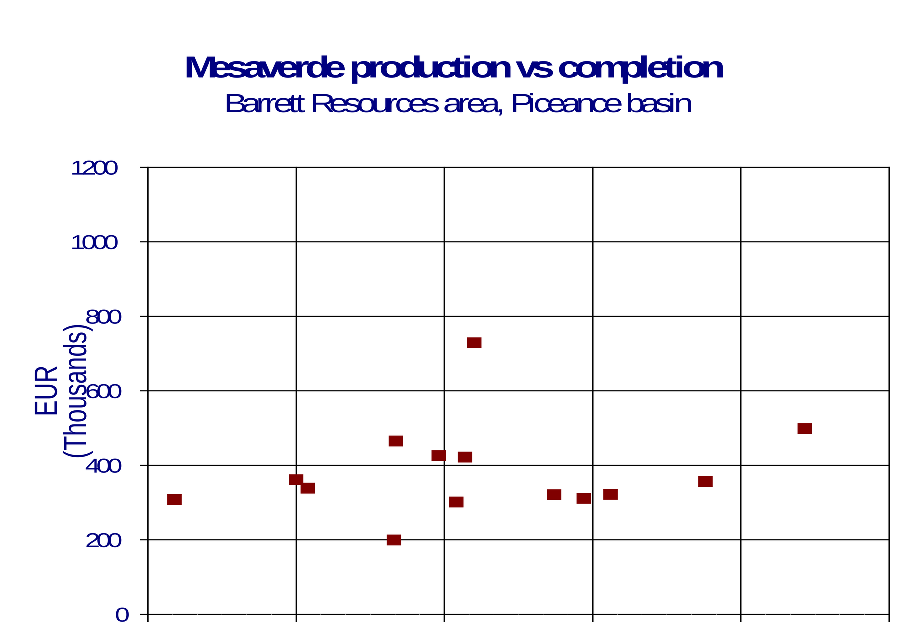










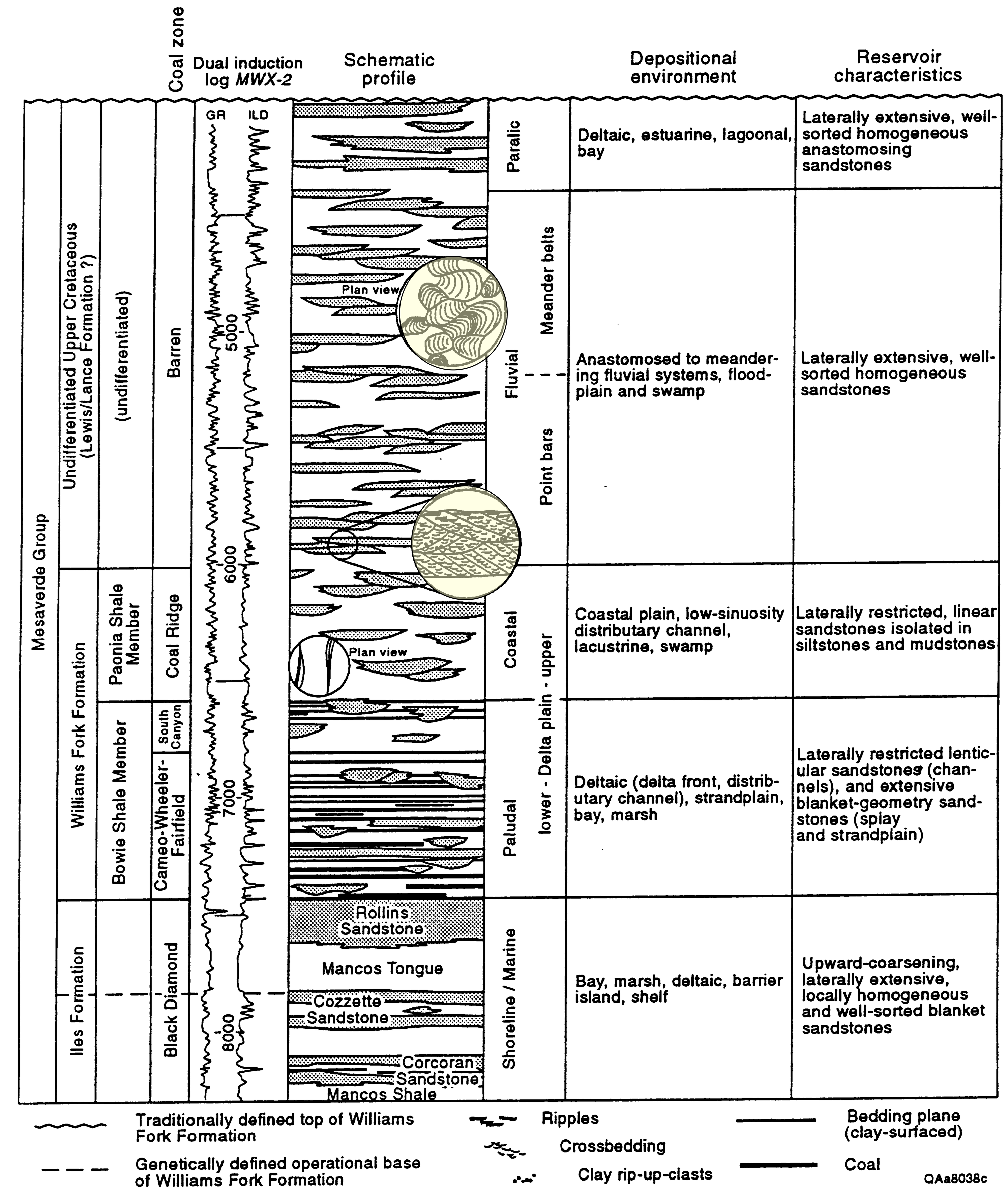


THE PROBLEM

Open hole logs are unable to quantify, and in many instances are unable to detect, some of the most important factors that control productivity. Natural fractures are widely believed to be one of the most important controls on tight gas sand production, but conventional resistivity-density-neutron-sonic logging suites give only indirect evidence for fractured intervals. Even if a conventional logging suite detects a fractured sandstone interval, there are no quantitative measures of the degree of fracturing, fracture permeability, or connectivity of the fractures away from the well bore.

Several operators working the Mesaverde play have stressed the high degree of reservoir compartmentalization, as evidenced by the lack of correlation between sandstones in very closely spaced wells. The MWX site is a prime example of this lack of lateral continuity since the three well bores are only a few hundred feet apart, yet few sands can be correlated between the wells with any confidence. Open hole logs investigate only a small volume of formation directly surrounding the well bore and are completely blind as to the lateral extent of reservoir compartments or their bulk volume. Until reliable cross-well methods are developed and deployed this situation is unlikely to change.

Completion methods obviously exert a strong influence on productivity and the completion must be considered in any attempt to predict long term performance. Generally speaking there are no logging data that directly bear on the problem of quantifying the efficiency of fracture treatments or extent of induced fractures. Simple measures of frac size that are available from state completion reports and commercial scouting services are clearly inadequate to the job of quantifying the frac jobs. Until better data become widely available, this is likely to remain a variable that cannot be adequately addressed in predictive models.



**from Tyler & others, 1995,
Texas BEG Annual report to
GRI-94/0456**

REFERENCES

Clavier , C., Coates, G., and Dumanoir, J., 1984, The theoretical and experimental bases for the Dual-Water Model for the interpretation of Shaly Sands, Society of Petroleum Engineers Journal, V. 24, no. 2, pp. 153-168 [reprinted in SPWLA Reprint Series Shaly Sand; and in AAPG Treatise of Petroleum Geology Reprint Series, no. 17, Formation Evaluation II; and in SPE Reprint Series no. 21, Open hole logging.]

Esphahanian, C., 1997, A statistical approach to pay identification in the tight, fractured, heterogeneous reservoirs of the Piceance Basin., SPE # 38366, presented at the Society of Petroleum Engineers 1997 Rocky Mountain Section meeting.

Steiber, S. J., 1970, Pulsed neutron capture log evaluation - Louisiana Gulf Coast, SPE #961, presented at 1970 Society of Petroleum Engineers 45th Annual Fall meeting.

Timur, A., 1968, An investigation of permeability, porosity, and residual water saturation relationships for sandstone reservoirs: The Log Analyst, v. 9 n. 4.

All log analysis work was performed using LESA for Windows version 1.7, by Resource Information Services Ltd., Denver, Colorado.

Log graphics plotted using LESA and LASView (PetCom Inc., Dallas, TX); cross plots from Quattro Pro for Windows version 6.0. This poster session was compiled under Microsoft PowerPoint for Windows 95/NT version 7.0 and plotted on an HP750C color inkjet plotter.

RIS