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**PREFERRED WATERFLOOD MANAGEMENT PRACTICES FOR THE
SPRABERRY TREND AREA**

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Harold Vance Department of Petroleum Engineering
Texas A& M University
3116 TAMU
College Station, TX 77843-3116
(979) 845-2241

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Program Manager: C. M. Sizemore
Pioneer Natural Resources

Principal Investigator: David S. Schechter
Harold Vance Department of Petroleum
Engineering

Contracting Officer's Representative: Dan Ferguson
National Petroleum Technology Office

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ABSTRACT

This report describes the work performed during the second year of the project, “Preferred Waterflood Management Practices for the Spraberry Trend Area.”

The objective of this project is to significantly increase field-wide production in the Spraberry Trend in a short time frame through the application of preferred practices for managing and optimizing water injection. Our goal is to dispel negative attitudes and lack of confidence in water injection and to document the methodology and results for public dissemination to motivate waterflood expansion in the Spraberry Trend. To achieve this objective, in this period we concentrated our effort on characterization of Germania Unit using an analog field ET O’Daniel unit and old cased hole neutron.

Petrophysical Characterization of the Germania Spraberry units requires a unique approach for a number of reasons – limited core data, lack of modern log data and absence of directed studies within the unit. The need for characterization of the Germania unit has emerged as a first step in the review, understanding and enhancement of the production practices applicable within the unit and the trend area in general.

In the absence or lack of the afore mentioned resources, an approach that will rely heavily on previous petrophysical work carried out in the neighboring ET O’Daniel unit (6.2 miles away), and normalization of the old log data prior to conventional interpretation techniques will be used.

A log-based rock model has been able to guide successfully the prediction of pay and non-pay intervals within the ET O’Daniel unit, and will be useful if found applicable within the Germania unit. A novel multiple regression technique utilizing non-parametric transformations to achieve better correlations in predicting a dependent variable (permeability) from multiple independent variables (rock type, shale volume and porosity) will also be investigated in this study.

A log data base includes digitized formats of Gamma Ray, Cased Hole Neutron, limited Resistivity and Neutron/Density/Sonic porosity logs over a considerable wide area.

In addition, a progress report on GSU waterflood pilot is reported for this period. We have seen positive response of water injection on new wells.

We believe by proper data acquisition and precise reservoir engineering techniques, any lack of confidence in waterflooding can be overcome. Therefore, we develop field management software to control a vast data from the pilot and to perform precise reservoir engineering techniques such as decline curve analysis, gas and oil material balances, bubble map plot and PVT analysis. The manual for this software is listed in the Appendix-A.

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EXECUTIVE SUMMARY

This report describes the work performed during the second year of the project, "Preferred Waterflood Management Practices for the Spraberry Trend Area." The objective of this project is to significantly increase field-wide production in the Spraberry Trend in a short time frame through the application of preferred practices for managing and optimizing water injection. Our goal is to dispel negative attitudes and lack of confidence in water injection and to document the methodology and results for public dissemination to motivate waterflood expansion in the Spraberry Trend.

This report provides results of the fourth semi-annual technical progress report that consists of petrophysical characterization of the Germania Spraberry units (GSU); an update on GSU waterflood pilot and development field management software along with the software manual. Within the project objective, the specific goals for this period are to (1) characterize the germania unit using an analog field ET O'Daniel unit and old cased hole neutron, (2) update a waterflood pilot progress and (3) provide a field management software to control and analyze a vast data from the pilot. In this report we present the following work that has been performed to achieve the aforementioned goals. The following headings and subsequent findings outline the work that appears in this report.

Germania Unit Characterization using an Analog Field and Old Cased Hole Neutron. Extensive reservoir characterization work has been carried out in the ET O'Daniel based on recent core and log data acquisition, production and injection data, welltesting results, tracer analysis and simulation studies. The GSU on the other hand lacks core and modern log data, and has not been characterized for predicting rock type and pay zones. In this study, we focus on the petrophysical evaluation of the upper Spraberry unit derived from a database of 85 log suites, primarily consisting of Gamma ray and Old Cased Hole Neutron logs. Core based relationships developed in the ET O'Daniel unit are borrowed upon to aid the characterization of this field, and will generally suffice due to the similar depositional environment and proximity of the units from one another.

Germania Spraberry Field Demonstration Status. In our previous results, we forecasted the incremental oil recovery due to waterflood in other pilot area, which was applied to the Germania Spraberry Unit (GSU,) and requested management approval of this project. The project was approved and we proposed the new location of injectors based on the existing injectors' location and response of previous injectors to producers. We also identified the wells that have casing leaks using OFM based on the plot of water-oil ratio. In this period, we observed the response of water injection through each of production wells and the group of the wells in each track. We analyzed the production and injection data through production database management using Oil Field Manager (OFM) and Field Management Database Software (FMDS), which was developed for better managing, predicting and tracking the production responses. The water injection began on Feb 3, 2003 with a constant rate of 270 BWPD. We maintained the Voidage Replacement Ratio (VRR) is equal to one. The total amount of water that has been injected up to September 30, 2003 was about 370, 000 BBLs. We observed the water injection response in the

tracks 2, 3 and 4 daily bases. Several wells have responded to waterflood even though not a dramatic increase in oil production as shown in ET O'Daniel Waterflood pilot. High jump in oil rate can be observed from the GSU tracts due to new production wells that have high initial production rate (20 to 150 bbls/day).

Development of Reservoir Management Database Software. In previous report we have shown the early stage of our software development. The software was developed for specific Spraberry field only and further more we used excel visual basic as our software platform. We found a Graphic User Interface (GUI) is limited in this platform thus we changed our platform to visual basic-object oriented programming language. In the current version, the software can be used for general purposes, so it can be used to manage and analyze production and injection data in other field. The software has the capability to perform similar tasks as the OFM database system such as decline curve analysis, material balance, and bubble map plot. In addition it has more unique features in grouping the wells, performing decline curve analysis for well by well and a group of wells, displaying the graph in x-y plot, 2D and 3D map and much more. There are many other features of this software that can be found in the manual/tutorial presented in Appendix A.

Project Fact Sheet

Progress work efforts at Project Fact Sheet are listed in Appendix B.

I. GERMANIA UNIT CHARACTERIZATION USING AN ANALOG FIELD AND OLD CASED HOLE NEUTRON

1.1 Introduction

The Spraberry Trend area is a unitized hydrocarbon production basin in the heart of West Texas. The major production comes from fine grained, low permeability siltstones and sandstones, enhanced by an intricate network of natural fractures. Carbonate and Siliclastic (submarine fans) depositional episodes during the Permian era make up the lithofacies of the Spraberry unit.

Up to date production from the basin is estimated at about 800 million barrels of oil and 3 trillion cubic ft of gas from over 8000 active wells¹, this figure could range between 8 – 12% of the projected OHIP.

Of particular interest is the ET O’Daniel and Germania Spraberry units, two of eleven units operated by Pioneer Natural resources. Extensive reservoir characterization work has been carried out in the ET O’Daniel based on recent core and log data acquisition, production data and simulation studies.¹⁻⁴ The Germania Spraberry unit, on the other hand, lacks core and modern log data, and has not been characterized beyond pulse and tracer analysis to analyze fracture trends and performance.

A preliminary step in the implementation of an enhanced recovery process within the unit is the characterization of the reservoir (petrophysics and fracture properties and fracture network.)

This study is concerned with the log-based characterization of the Germania unit and will focus on the petrophysical evaluation of the upper Spraberry unit, particularly the productive 1U and 5U intervals.

A database of 85 log suites, primarily consisting of Gamma Ray and Old Cased Hole Neutron logs, is available for this study. Core based relationships developed in the ET O’Daniel unit are utilized to aid the characterization of this field, and will generally suffice, due to the similar depositional environment and proximity of the units to one another (6.2 miles).

Established criteria for predicting rock type and pay zones in the ET O’Daniel will be applied, if found to be an acceptable correlation to Germania and will guide subsequent characterization efforts in the unit.

1.2 Area of Interest

The Spraberry Trend area spreads over an area of approximately half-a-million acres and is trapped by complex updip pinchouts and facies changes within the thick upper Spraberry producing interval. A few fields are simple anticlinal structures like Benedum and Pegasus. The regional fracture patterns are enhanced by anti-clinal folds producing a locally commercial reservoir at Pegasus^{5,6}.

The E.T. O'Daniel unit and the Germania unit are adjacent units at the north end of the Spraberry trend area. These fields are 2 of 11 fields operated by the Pioneer Natural Resources (PNR) and are located in the Midland county area of West Texas.

The distance between the two fields is estimated to be about 6.2 miles based on inter-well distance measured from boundary wells (see Fig. 1.1.)

While the ET O'Daniel has been the subject of major studies regarding fracture patterns^{7,8,9}, log - core analysis¹⁰⁻¹⁴ and waterflood, as well as CO2 injection pilot projects¹⁶⁻¹⁹, no major investigation of the lithofacies or fracture characteristics of the Germania unit has been performed. Fracture trends on a gross scale by way of pulse and tracer tests is the basis of predicting flow behavior within the Germania unit.

Due to the proximity of the ET O'Daniel unit to the Germania unit, as well as the depositional environment within the four county area^{15,16} (Midland, Glasscock, Upton and Reagan) it's logical to superimpose the conclusions drawn from the petrophysical evaluation of the ET O'Daniel unit upon the Germania unit.

Bearing this in mind, further discussions on the characterization work regarding this area will be focused on the ET O'Daniel unit.

1.3 Rock-Log model

Gamma Ray and old Cased Hole Neutron logs form the bulk of the electric logging data available within the ET O'Daniel, although more recent Array Induction, Density and Neutron porosity data have been acquired in pilot areas within the unit. This acquisition is localized and hence the older Neutron logs are an indispensable source for wide scale characterization of the field.

A log based rock model^{13,14} was developed for the trend area using shale content (gamma ray) and porosity as discriminatory criteria for rock type. In this model, classification is made for 3 rock types – A, B and C.

Table 1.1 summarizes the identifiers for the rock model within the Upper Spraberry operational units¹⁷.

1.3.1 Lithology

The Bulk Density - Neutron cross plots have many uses, and are invaluable as indicators for lithology and rock types. Fig. 1.3a – d, show the results of cross plots of Bulk Density - Neutron in the wells in which they are available.

The gas correction if applied will tend to shift the data down and right i.e. reduce bulk density and increase neutron porosity. Shale correction will depend on the type of shale (structural, laminated or dispersed.)

1.4 Log Conversions and Normalization

26 logs are available within the ET O'Daniel unit, including log data for the cored wells. The wells are a variety of observation wells, injectors and producers with a few outliers included.

59 well logs are available within the Germania Spraberry unit. Most of the logs are Neutron logs taken as far back as 1950's, with a few recent porosity and resistivity logs.

1.4.1 Gamma Ray

Gamma ray curves for all the logs within the ET O’Daniel and Germania database were analyzed, and it was discovered that no two logs gave the same values at any chosen marker. Though this is expected, the wide variance in the response across these markers indicate the necessity for normalization of the gamma ray logs. More so, due to the fact that for a multi-well analysis, the shale volume calculations will need to be revised for every well log, if this process is not carried out.

1.4.2 Gamma Ray and Neutron normalization

It can be inferred that the field standard based on the limited database is the range with the highest number of occurrence. Wells 37, 38, 39, 40, 47, 48, C1 and 26 are spread across the 20 – 140 API range and are the group with the highest consistency.

A histogram for a type well representing the field standard is used to adjust all other wells deemed to require normalization. Fig. 1.5 shows the histogram and cumulative density functions for wells #46, 45, 36 and 35 before and after normalization using well C1 as the standard.

A single equation for applying linear adjustments to log data is given by Shier (1991)¹⁸.

$$X_{norm} = R_{low} + \frac{(R_{high} - R_{low})(X_{raw} - W_{low})}{(W_{high} - W_{low})} \quad (1.1)$$

A different method used to adjust well log data involves the adjustment of each data point by a constant value, such that the mean of the sample data equals the mean of the type log data. Thereafter, an ‘Affine’ correction is then applied to the sample data such that the variance of the sample equals the variance of the type log data. This is an iterative process, unless a computer program is used to solve for the appropriate shift and correction factor required to match the mean and variance of the type log data.

$$X_{norm} = \sqrt{s.f.}(X_{raw} - \mu) + \mu \quad (1.2)$$

X_{norm}	-	Normalized well value
X_{raw}	-	Actual well value
R_{low}	-	Regional low normalization value
R_{high}	-	Regional high normalization value
W_{low}	-	Wells lithological low value
W_{high}	-	Wells lithological high value
s.f.	-	Correction factor
μ	-	Population mean

1.4.3 Standardization of Neutron Log units

The most common measure of porosity within the GSU log database is counts per second (cps) and is a measure of the number of neutrons detected after bombarding the formation with energetic neutrons at the rate of several million per second.

The neutron density decreases almost logarithmically with hydrogen richness, which is why porosity is a logarithmic function of neutron deflection.

The API RP33 recommends a system of neutron unit calibration in the standardization-well-logging pit of the University of Houston.

One API neutron unit is defined as 1/1000 of the difference between instrument zero (tool response to zero radiation) and log deflection opposite a 6 ft. zone of Indiana limestone of 19% porosity.

1.4.4 Conversion from neutron units to Linear porosity units.

A useful equation for converting a linear scale with respect to counts per second (logarithmic w.r.t porosity), to a linear scale w.r.t porosity is given by Shier (1991)¹⁸.

This method is also known as the Two – point method.

$$X_{norm} = 10^{\frac{y}{(W_{high_cps} - W_{low_cps})}} \quad (1.3)$$

$$y = X_{raw} (\log R_{high\phi} - \log R_{low\phi}) + (W_{high_cps})(\log R_{low\phi}) - (W_{low_cps})(\log R_{high\phi})$$

X_{norm}	-	Normalized well value (porosity, v/v)
X_{raw}	-	Actual well value (cps, API, EU)
$R_{high\phi}$	-	Value for high porosity location from core or reliable log data (known for a particular region, unit – v/v).
$R_{low\phi}$	-	Known value for low porosity location from core or reliable log data (known for a particular region, unit – v/v).
W_{high_cps}	-	Well value at $R_{high\phi}$ location (cps, API, EU)
W_{low_cps}	-	Well value at $R_{low\phi}$ location (cps, API, EU)

This equation is valid for all neutron curves measuring neutron counts, regardless of the units.

The normalization equation requires the input of two lithologies from both a “type” well and the well being normalized. One lithology input is from a log interval that produces a high log reading and the other is from an interval that produces a low log reading. These lithology intervals that bound the normalization process are known as normalization zones. Normalization zones should have a well log response that is consistent from well to well (as is the case of lithology intervals consisting purely of salt and anhydrite.) If such zones are unavailable, the analyst chooses zones whose behavioral changes are understood from location to location. This implies that for any one field, many normalization zones may have to be selected in order to properly limit the high and low readings of the different curve types being adjusted.

After identifying lithology intervals that will be used for normalization, the characteristic values of R_{low} and R_{high} in these zones must be determined. This is accomplished by picking a “type” well (or wells) containing normalization zones considered by the analysts to have the correct well log response. This “type” well (or wells) is then defined as the standard to which all other curves will be adjusted.

1.5 Calibrating core with logs in ET O’Daniel

1.5.1 Log Porosity – Core Porosity X-plots

The core and log porosity cross plots indicate the level of agreement between core data and log data. If there is sufficient agreement between both porosities or a relationship between both data sets can be consistently established, further analysis can be confidently carried out on the basis of log porosity.

A depth match is performed prior to a cross plot of both porosity values (core and log.) The depth match may be improved by analyzing the degree of correlation obtained for the crossplots based on depth shifting the core data. This is done if a ‘clear’ relationship cannot be established just by visual analysis.

From regression analysis a best fit equation for the x-plot in 1U was found to be:

$$Y = 0.050342 + 0.539983X \text{ and } R^2 = 0.677$$

And for 5U:

$$Y = 0.05810 + 0.560472X \text{ and } R^2 = 0.620651$$

The ET O’Daniel 39 well gave the most consistent core to log relationship of all the cored wells analyzed, even more so within the 1U interval. Table 3.2 shows the summary of the cross plots for all the cored wells in the ET O’Daniel field.

1.6 Porosity – Permeability cross plots

1.6.1 Regression Analysis

The porosity values from log data (PHIE) previously verified using the core data, can be used to establish a porosity–permeability relationship. While the conventional method uses regression techniques to identify the trend, an alternative and more effective method ‘Alternating Conditional Expectation’ (Xue *et al*, 1996)¹⁹ can and will be used to identify and model the independent variables that affect effective permeability.

Use of this method is necessary as no clear relationship can be identified from any of the six (6) ET O’Daniel cored wells. This method is capable of using multiple independent variables in estimating the expected value of permeability.

The figures above and below show the results of the regression analysis on the six cored well from the crossplots of Neutron and or Density porosity vs. core porosity.

Only well #39 gives a relatively ‘high’ degree of correlation, both visually as well as the R-squared value. This correlation is not sufficient to go ahead with ($R^2 < 0.5$) a transformation based on regression.

A cross validation of a proposed transform based on the regression analysis shows that none of the equations sufficiently match the calculated permeability with the core permeability. Ideally, the points should cluster about the 45 degree line, the more dispersed the points, the poorer the correlation between the paired data sets.

The cross validation shown below are the best results obtained by conventional regression using density porosity and neutron porosity log data.

1.6.2 Data Conditioning (‘ACE’)

Besides porosity, rock type (lithology) and initial water saturation have an influence on effective permeability. The limitation of any log derived permeability is in the fact that porosity and water saturations are static volumetric terms, whereas permeability is a measure of the movement of fluid through rock²⁰. Any permeability correlation between porosity and or water saturation is unlikely to have a wide geographic or geologic application. The only way to obtain a robust permeability distribution is by acquiring field-wide core and well test data.

Correlating permeability in the Germania unit is hampered due to an absence of core data. Production data is available, but is beyond the scope of this project. Therefore we are limited to methods which use static properties to correlate the permeability, specifically the ‘Alternating Conditional Expectation’ (ACE) method.

From the established rock model (Table 2.1), the Upper Spraberry has been classified into 3 rock types based on shale content and porosity, this classification will be included as a variable in the estimation of the permeability transform. Therefore, 3 independent variables will be used: rock type, shale volume and porosity in calculating the dependent variable, permeability.

Input data using ACE algorithm for well # 47 is given in Table 3.3.

1 = ($V_{shl} < 0.15$, $\phi > 0.07$), 2 = ($V_{shl} < 0.15$, $\phi < 0.07$), 3 = ($V_{shl} > 0.15$). Porosity cutoffs for the rock types are made using both Density (DPHI) and Neutron (NPHI), indicated by RTYP_D and RTYP_N respectively.

1.6.3 The ‘ACE’ transformations

The optimized multivariate regression was performed to determine the optimal transformation for both porosity type data (Density or Neutron porosity.) Table 1.3 and 1.4 show a data set for both porosity data and rock type distinctions based on shale volume and porosity.

The processing of the transformations for the independent (predictor) variables is shown in the proceeding figures.

Transformations for the shale volume, inverse permeability are the same as in Figs 1.20 and 1.21 for density porosity.

ET O’Daniel 39 log porosity - permeability as well as the cross-validation of the transformed permeability show that for the region of interest, this well gives consistently

good results. The equation used to generate a permeability profile for wells with porosity (NPHI) and GR curves will be based on the well #39.

$$\phi_{transform} = -6.187\phi^2 - 0.15763\phi + 0.16734 \quad (3.10)$$

$$RTYP_{transform} = 0.53421rtyp - 1.0234 \quad (3.11)$$

$$Vshl_{transform} = 14.204Vshl^2 - 13.373Vshl + 1.6487 \quad (3.12)$$

$$k \max_{calc} = 0.18767Sum_{transform}^2 + 0.2864Sum_{transform} + 0.16508 \quad (3.13)$$

1.7 Water Saturation

An iterative approach will be used to estimate the R_w values to be used in the Archie equation. The simple Archie equation is chosen for its simplicity given the lack of adequate data to utilize the more appropriate dual water model.

The 1st annual technical progress report⁵, recommends values of a, m and n for use in the Archie equation based on the match of the saturation profile in the Shackelford I-38 well.

When these exponents (a = 1 , m = 1.66 , n = 1.46) are used in the ET O’Daniel field, the resulting profiles are not well matched and the adjustment factor of the R_w value is altered to match observed core saturations.

Figs. 1.31 – 1.33 show the saturation profiles in track 4 from core analysis against saturation profiles obtained from Archie’s equation.

$$R_o = aR_w/\phi^m \quad (3.14)$$

$$SwA = (R_o/R_t)^{1/n} \quad (3.15)$$

Different saturation profiles were compared to the core profiles by varying the R_w value in Eq. 3.14, the best match was obtained for an R_w value of 0.080 ohm.

1.8 Estimating OIP from Net pay map

The OIP is estimated using the porosity and pay maps to obtain the pore volume estimate and applying the saturations obtained from Table 1.5.

The maximum and minimum values in the table will be used to estimate the range of possible OIP values.

The ϕh (porosity-Net pay) maps Figs. 1.34 and 1.35 are integrated over the area to calculate the OIP using the Geographix software.

Acreage of ET O’Daniel Unit = 1540 acres

The integrated 1U volume (Pore volume) = 11,704,800.33 reservoir bbls (RB)

Applying the minimum saturation observed in well ETO38 of 31.3%, the OIP is given by:

$$\text{Pore Volume} * (1-S_w) = 11,704,800.33 \text{ RB} * 0.687 = \mathbf{8,036,516 \text{ RB}}$$

Applying the maximum saturation observed in well ETO39 of 50.3%, the OIP is given by:

$$11,704,800.33 \text{ RB} * 0.497 = \mathbf{5,820,797 \text{ RB}}$$

The integrated 5U volume (Pore volume) = 11,446,836.96 reservoir bbls (RB)

Applying the minimum saturation observed in well ETO40 of 34.8%, the OIP is given by:

$$\text{Pore Volume} * (1-S_w) = 11,446,836.96 \text{ RB} * 0.652 = \mathbf{7,461,048 \text{ RB}}$$

Applying the maximum saturation observed in well ETO39 of 49.1%, the OIP is given by:

$$11,446,836.96 \text{ RB} * 0.509 = \mathbf{5,829,874 \text{ RB}}$$

1.9 The Germania Spraberry Unit

The Germania unit shows, through the gamma ray logs, the characteristic response observed in the ET O'Daniel unit within the five reservoir units (1U thru 5U.) The formation markers were generally distinguishable and continuous over the lateral space between both units. Application of the log based rock model to distinguish reservoir and non-reservoir quality rock through porosity and shale indicators will form the basis of the reservoir description process and the generation of structure and isopach maps that describe this unit.

1.9.1 Verification of Log Based Rock model

The log based rock model developed from log analysis and petrographic studies in the ET O'Daniel unit was applied with partial success in the Germania Spraberry unit. From observation within the GSU log playback, the rock model consistently underestimated the pay interval compared with the average ET O'Daniel interval.

The more recent logs with pre-processed neutron porosity curves give better results than the old neutron logs in predicting the pay zones within the GSU.

1.9.2 Maps

Based on the normalized log data, formation markers for the upper Spraberry unit were identified and used to generate structure maps (Figs. 44 and 45), isopach maps (Figs. 46 and 47), net sand thickness map (Figs. 48 and 49), porosity distribution maps (Figs. 50 and 51), and permeability distribution maps for the 1U and 5U flow units.

1.10 Estimating OIP from Net pay map

The OIP is estimated for the Germania unit using the porosity and pay maps to obtain the pore volume as done for the ET O'Daniel unit.

There are 2 wells (GSU214 and 407) within the database that have useful resistivity curves (Figs 1.40 and 1.42).

Acreage of Germania Unit = 4811 acres

The integrated 1U volume (Pore volume) = 19,720,344.22 reservoir bbls (RB)

The integrated 5U volume (Pore volume) = 19,308,937.4 reservoir bbls (RB)

A summary of the saturations observed in the two wells is given in Table 5.1, along with the OIP estimates for the derived water saturations.

Table 1.1 - Based on effective porosity and shale content, a log based rock model for the upper Spraberry establishes the criteria for pay identification.

Formation	Rock Type	Shale Volume	PHIE	Facies	Fluorescence	Pay	Unit
Upper Spraberry	A	< 15%	> 7%	SS	Strong	yes	1U, 5U
	B		< 7%	DS+SS	Weak	no	2U, 3U, 4U
	C	> 15%		SH+DS+SS	None		muddy zones

SS - Siltstone

SH - Shale

DS - Dolomite

Table 1.2 – Regression obtained from crossplots of core – log permeability for cored ET O'Daniel wells. Best results are obtained in ETO#39 well.

1U			5U	
Well	Least Sq. Regression	R2	Least Sq. Regression	R2
37	$y = -0.018494 + 1.12948x$	0.542	$y = -0.024442 + 0.949273x$	0.106
38	$y = -0.024815 + 1.049007x$	0.230		
39	$y = 0.050342 + 0.539983x$	0.677	$y = 0.050810 + 0.560472x$	0.621
40	$y = 0.050857 + 0.520833x$	0.509	$y = 0.028280 + 0.662358x$	0.396
47	$y = 0.017356 + 0.560368x$	0.073	$y = -0.021898 + 1.243577x$	0.073
48	$y = 0.014259 + 1.042477x$	0.519	$y = 0.034999 + 0.748994x$	0.776
y = core porosity, x = log porosity				

Table 1.3 – Data for rock type, shale volume and porosity used in multivariate regression model ‘ACE’ for well ETO47

Depth	kmax	DPHI	NPHI	Vshl	RTYP_D	RTYP_N
7084	0.002	0.123	0.218	30.8%	3	3
7085	0.001	0.118	0.109	9.5%	1	1
7086	0.002	0.211	0.118	7.6%	1	1
7087	0.006	0.189	0.131	17.2%	3	3
7089	0.009	0.113	0.161	39.8%	3	3
7090	0.088	0.102	0.192	42.0%	3	3
7091	0.006	0.150	0.193	24.0%	3	3
7092	0.001	0.166	0.127	7.0%	1	1
7093	0.062	0.186	0.120	2.1%	1	1
7094	0.051	0.181	0.134	2.9%	1	1
7095	0.002	0.203	0.160	5.7%	1	1
7096	0.014	0.213	0.150	12.0%	1	1
7097	0.008	0.211	0.154	12.2%	1	1
7098	0.004	0.186	0.163	5.4%	1	1
7099	0.186	0.158	0.140	3.0%	1	1
7100	0.187	0.243	0.153	6.3%	1	1
7101	0.194	0.237	0.157	9.0%	1	1
7102	0.480	0.237	0.159	23.0%	3	3
7103	0.831	0.300	0.173	39.2%	3	3
7104	0.002	0.254	0.162	31.1%	3	3
7105	0.426	0.172	0.164	29.9%	3	3
7106	0.513	0.152	0.170	23.1%	3	3
7240	0.005	0.087	0.190	25.2%	3	3
7241	0.013	0.069	0.131	13.7%	2	1
7242	0.002	0.028	0.092	2.5%	2	1
7243	0.017	0.056	0.119	7.5%	2	1
7244	0.002	0.121	0.121	9.7%	1	1
7246	0.001	0.107	0.180	29.1%	3	3
7247	0.001	0.066	0.231	45.2%	3	3
7248	0.001	0.044	0.175	24.3%	3	3
7249	0.001	0.107	0.125	8.0%	1	1
7250	0.012	0.169	0.142	3.6%	1	1
7251	0.117	0.181	0.145	4.6%	1	1
7252	0.001	0.185	0.149	7.4%	1	1
7253	0.001	0.172	0.157	7.7%	1	1
7254	0.001	0.149	0.149	10.4%	1	1
7255	0.468	0.155	0.133	11.0%	1	1
7256	0.906	0.147	0.147	11.3%	1	1
7257	1.240	0.135	0.135	9.9%	1	1
7258	0.030	0.104	0.124	9.0%	1	1
7259	0.310	0.108	0.153	16.6%	3	3
7260	0.610	0.110	0.169	21.4%	3	3
7261	0.416	0.105	0.214	28.5%	3	3
7262	0.504	0.091	0.195	38.4%	3	3
7263	0.395	0.100	0.191	45.5%	3	3
7264	0.001	0.092	0.218	52.2%	3	3
7265	0.071	0.097	0.187	49.9%	3	3
7266	0.001	0.107	0.184	34.7%	3	3
7267	0.001	0.126	0.161	23.4%	3	3

Table 1.4 – Data for rock type, Shale volume and porosity used in multivariate regression model ‘ACE’ for well ETO39

Depth	Kmax	DPHI	NPHI	Vsh	RTYP_D	RTYP_N
7064	0.030	0.148	0.190	65.3%	3	3
7064.5	0.028	0.149	0.226	67.5%	3	3
7065	0.030	0.171	0.253	59.1%	3	3
7065.5	0.041	0.163	0.220	46.3%	3	3
7066	0.060	0.124	0.170	33.8%	3	3
7066.5	0.162	0.094	0.117	10.6%	1	1
7067	0.360	0.091	0.084	4.8%	1	1
7067.5	1.127	0.088	0.074	4.6%	1	1
7068	1.820	0.082	0.086	5.2%	1	1
7068.5	1.583	0.073	0.096	8.6%	1	1
7069	0.981	0.067	0.117	15.9%	3	3
7069.5	0.361	0.063	0.152	27.0%	3	3
7070	0.070	0.059	0.170	37.7%	3	3
7070.5	0.060	0.058	0.160	51.8%	3	3
7071	0.060	0.066	0.150	52.2%	3	3
7071.5	0.067	0.072	0.146	49.2%	3	3
7072	0.080	0.075	0.146	43.5%	3	3
7072.5	0.114	0.074	0.158	29.7%	3	3
7073	0.160	0.078	0.125	13.8%	1	1
7073.5	0.205	0.088	0.082	6.3%	1	1
7074	0.290	0.097	0.079	3.5%	1	1
7074.5	0.444	0.11	0.078	3.4%	1	1
7075	0.620	0.116	0.079	3.7%	1	1
7075.5	0.799	0.121	0.090	3.7%	1	1
7076	0.980	0.142	0.097	4.0%	1	1
7076.5	1.067	0.158	0.149	5.3%	1	1
7077	1.030	0.166	0.154	7.6%	1	1
7077.5	0.706	0.177	0.159	10.0%	1	1
7078	0.400	0.184	0.153	13.3%	1	1
7078.5	0.471	0.201	0.143	18.1%	3	3
7079	0.540	0.208	0.166	18.8%	3	3
7079.5	0.478	0.226	0.175	17.0%	3	3
7080	0.420	0.235	0.159	12.8%	1	1
7080.5	0.424	0.281	0.151	8.8%	1	1
7081	0.420	0.313	0.151	7.0%	1	1
7081.5	0.253	0.361	0.160	6.4%	1	1
7082	0.090	0.393	0.159	7.1%	1	1
7082.5	0.057	0.449	0.162	8.6%	1	1
7083	0.040	0.477	0.166	11.8%	1	1
7083.5	0.034	0.505	0.178	17.5%	3	3
7084	0.030	0.481	0.189	24.0%	3	3
7084.5	0.032	0.38	0.201	29.1%	3	3
7085	0.040	0.312	0.185	31.0%	3	3
7085.5	0.089	0.233	0.158	30.0%	3	3
7086	0.160	0.2	0.157	28.7%	3	3
7086.5	0.122	0.226	0.150	26.9%	3	3
7087	0.060	0.262	0.151	24.0%	3	3
7087.5	0.927	0.291	0.183	20.9%	3	3

Depth	Kmax	DPHI	NPHI	Vsh	RTYP_D	RTYP_N
7088	1.780	0.295	0.193	19.2%	3	3
7088.5	0.919	0.283	0.180	19.3%	3	3
7089	0.070	0.361	0.183	19.8%	3	3
7222.5	0.014	0.06	0.110	6.4%	2	1
7223	0.023	0.057	0.121	5.0%	2	1
7223.5	0.035	0.098	0.134	6.2%	1	1
7224	0.049	0.087	0.143	8.0%	1	1
7224.5	0.061	0.129	0.133	8.7%	1	1
7225	0.070	0.147	0.129	10.0%	1	1
7225.5	0.066	0.15	0.118	13.3%	1	1
7226	0.060	0.15	0.116	19.2%	3	3
7226.5	0.086	0.136	0.131	32.7%	3	3
7227	0.120	0.103	0.170	48.0%	3	3
7227.5	0.065	0.106	0.241	54.6%	3	3
7228	0.030	0.066	0.267	40.0%	3	3
7228.5	0.129	0.055	0.204	23.4%	3	3
7229	0.270	0.048	0.158	10.6%	2	1
7229.5	0.448	0.048	0.132	4.8%	2	1
7230	0.600	0.084	0.133	2.0%	1	1
7230.5	0.634	0.12	0.134	0.9%	1	1
7231	0.600	0.142	0.136	1.0%	1	1
7231.5	0.541	0.158	0.132	1.9%	1	1
7232	0.490	0.162	0.134	2.4%	1	1
7232.5	0.466	0.16	0.139	2.6%	1	1
7233	0.450	0.159	0.143	3.4%	1	1
7233.5	0.449	0.157	0.150	4.4%	1	1
7234	0.450	0.153	0.149	5.8%	1	1
7234.5	0.406	0.152	0.148	6.4%	1	1
7235	0.330	0.154	0.142	6.8%	1	1
7235.5	0.174	0.158	0.129	9.2%	1	1
7236	0.010	0.158	0.127	15.0%	1	1
7236.5	0.194	0.151	0.132	28.9%	3	3
7237	0.430	0.129	0.154	44.6%	3	3
7237.5	0.328	0.105	0.168	49.3%	3	3
7238	0.010	0.085	0.152	40.1%	3	3

Table 1.5 – Interval averaged water saturations for wells with resistivity curves.

Well	Interval	Avg. Sw	Date logged	Status
ET O'Daniel 38	1U	31.3%	8/14/98	Oil
ET O'Daniel 39	1U	50.3%	7/5/98	Oil
	5U	49.1%	7/5/98	Oil
ET O'Daniel 40	1U	33.9%	9/4/98	Oil
	5U	34.8%	9/4/98	Oil
ET O'Daniel 47	1U	37.4%	7/22/98	Inj
ET O'Daniel 48	1U	32.2%	9/24/98	Inj
	5U	41.1%	9/24/98	Inj

Table 1.6 – Updated Table 3.5 with OIP estimate based on observed well saturations. Maximum OIP estimates are shown for ETO38 and ETO40 for the 1U and 5U respectively

Well	Interval	Avg. S _w	Date logged	Status	OIP Estimate, rbbls
ET O'Daniel 38	1U	31.3%	8/14/98	Oil	8,036,515.91
ET O'Daniel 39	1U	50.3%	7/5/98	Oil	5,820,797.20
	5U	49.1%	7/5/98	Oil	5,829,874.06
ET O'Daniel 40	1U	33.9%	9/4/98	Oil	7,742,725.42
	5U	34.8%	9/4/98	Oil	7,461,048.33
ET O'Daniel 47	1U	37.4%	7/22/98	Inj	7,323,693.57
ET O'Daniel 48	1U	32.2%	9/24/98	Inj	7,941,707.02
	5U	41.1%	9/24/98	Inj	6,747,910.39

Table 1.7 – OIP estimates based on saturations in 2 wells

Well	Interval	Avg S _w	Date Logged	Status	OIP estimate, rbbls
214	1U	0.3681	12/17/2002	na	12,461,285.51
	5U	0.4241	12/17/2002	na	11,120,017.05
407	1U	0.3118	7/4/1992	Oil	13,571,540.89
	5U	0.3605	7/4/1992	Oil	12,348,065.47

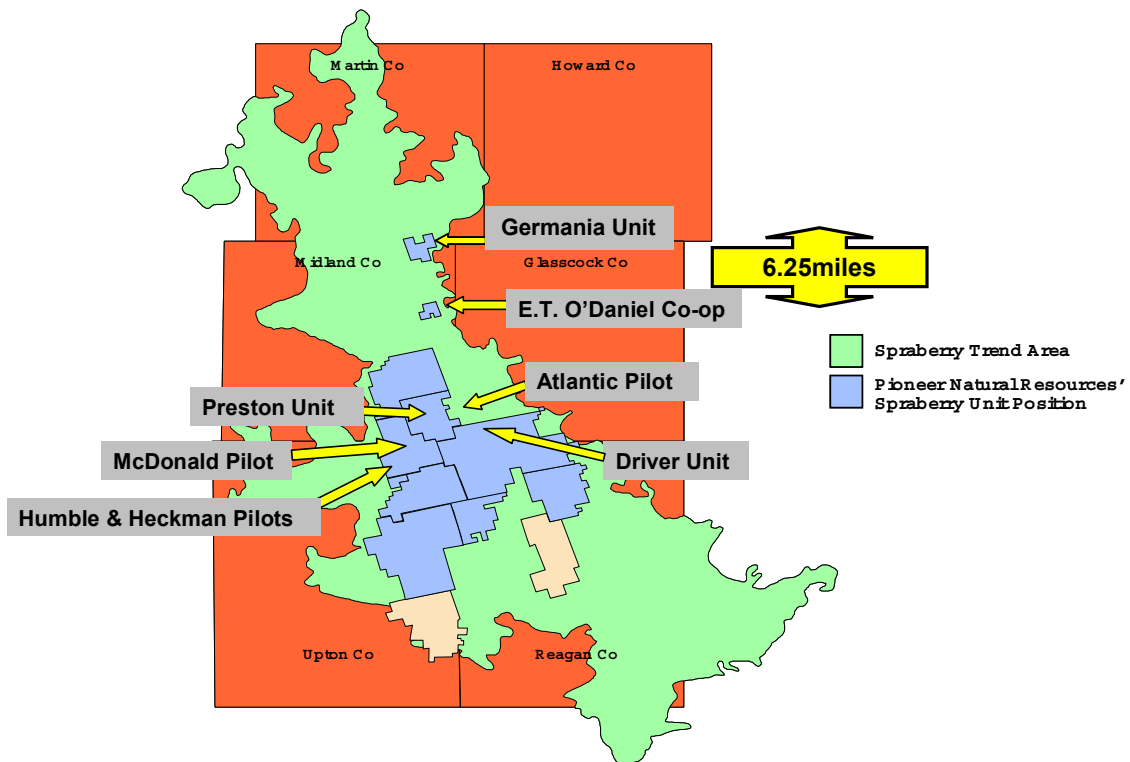


Fig. 1.1 – Unit locations within the Trend area. ET O’Daniel and Germania units approximately 6miles apart

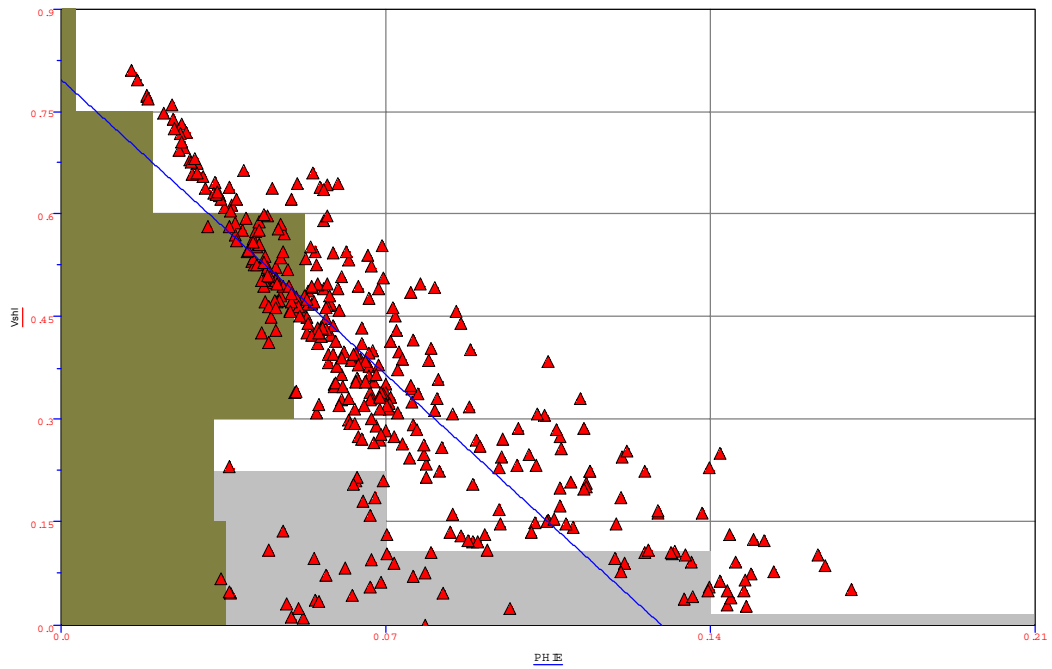


Fig. 1.2 – Crossplot of Shale volume and Effective porosity for well ETO#47. A qualitative estimator for rock types A, B and C

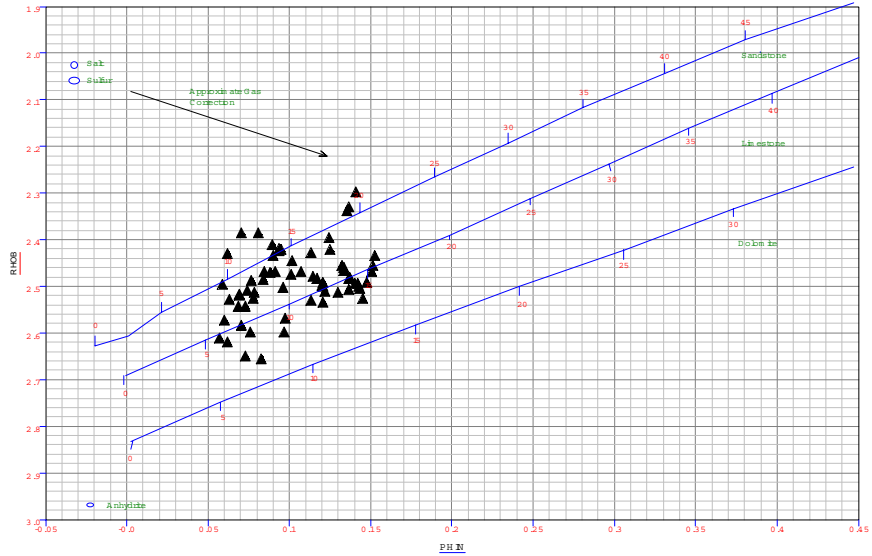


Fig. 1.3a – 1U interval in ETO37, showing the cluster of data points about the sandstone / limestone marker.

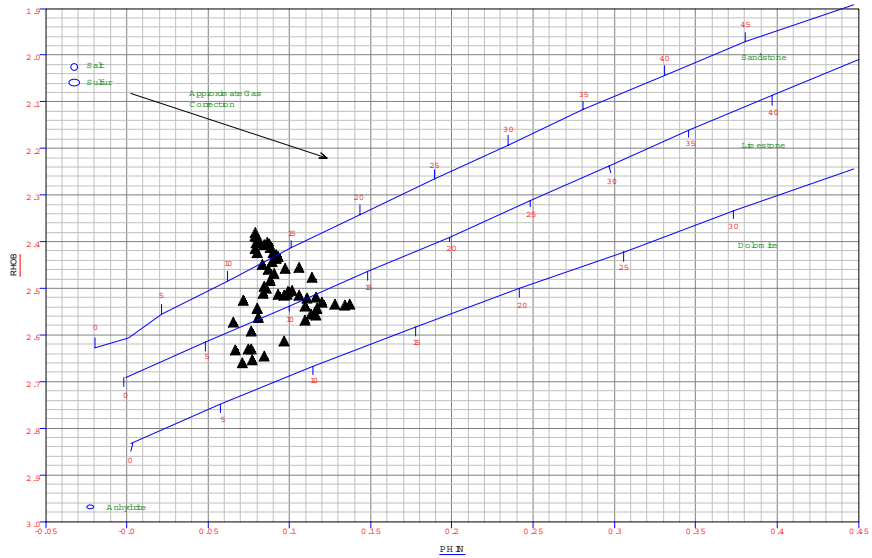


Fig. 1.3b – 5U interval in ETO37, similar distribution is seen as with the 1U interval

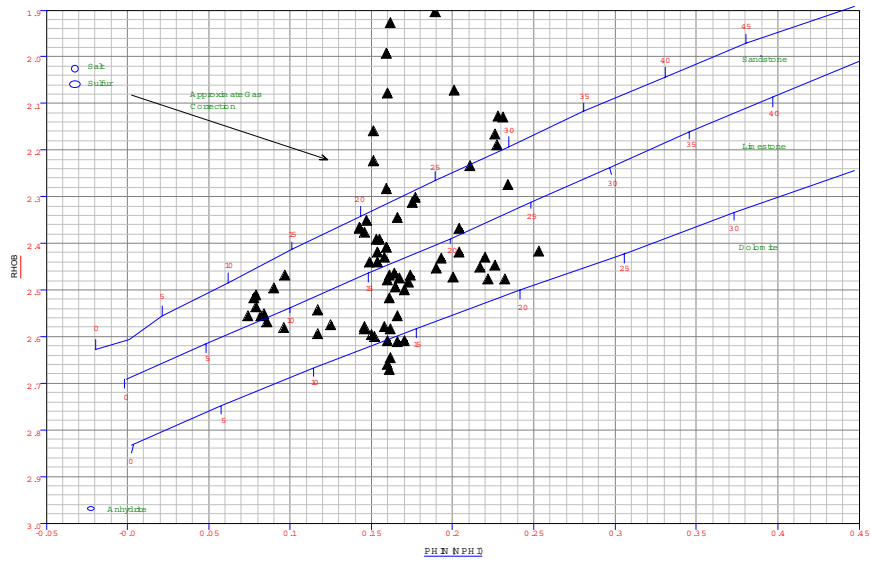


Fig. 1.3c – 1U interval in ETO39, showing the range of data points spread across the sandstone, limestone and dolomite regions.

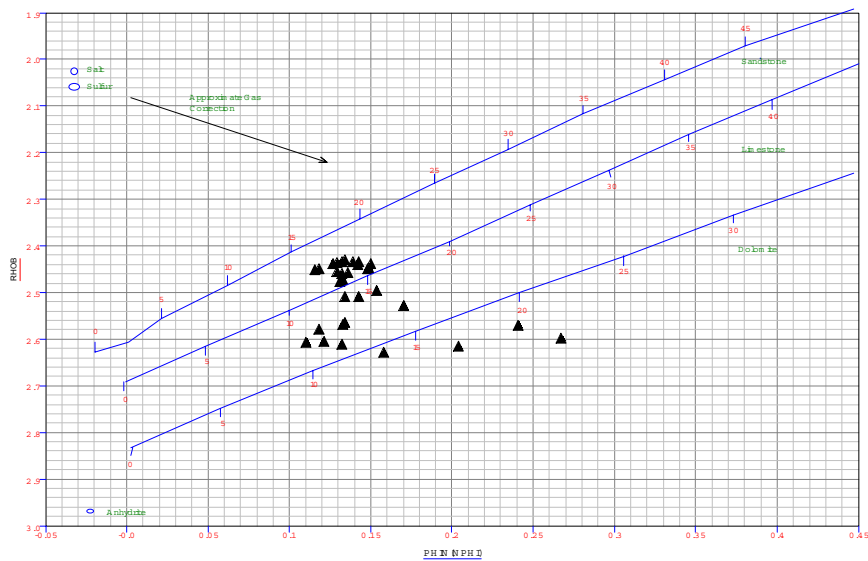


Fig. 1.3d – 5U interval in ETO39, showing little sandstone and more of limestone and dolomite.

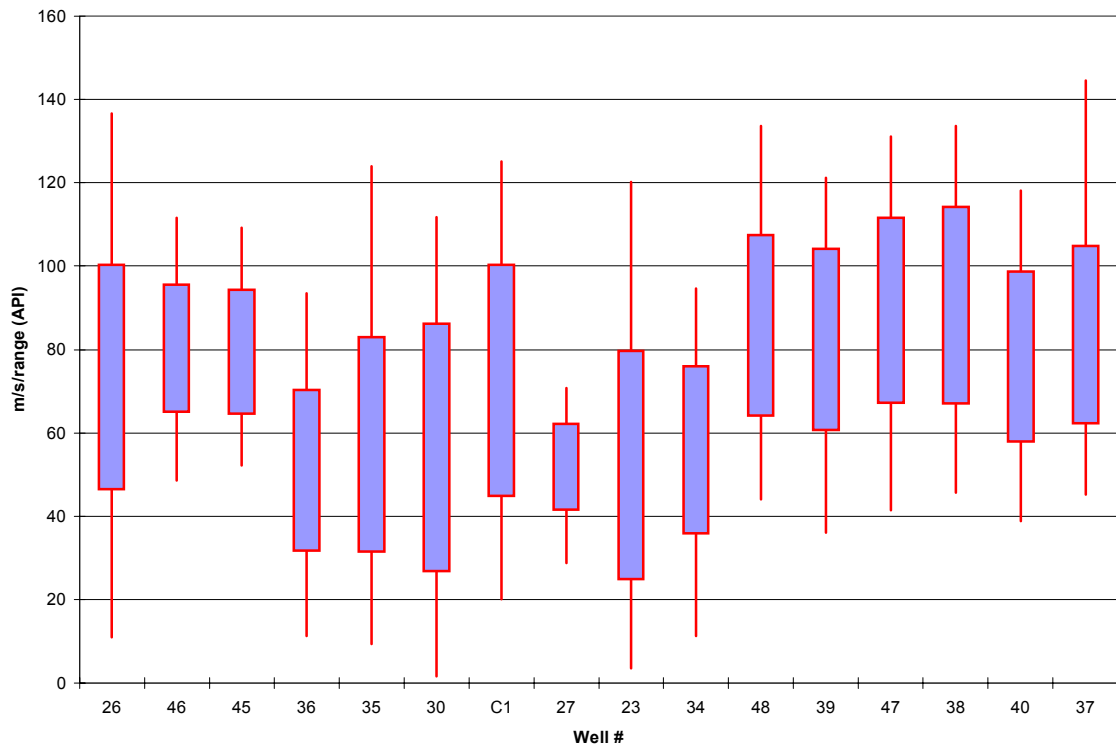


Fig. 1.4 - Variations in response from the gamma ray curves. High and low values, and bars representing 1 standard deviation from the mean GR values on a well by well basis.

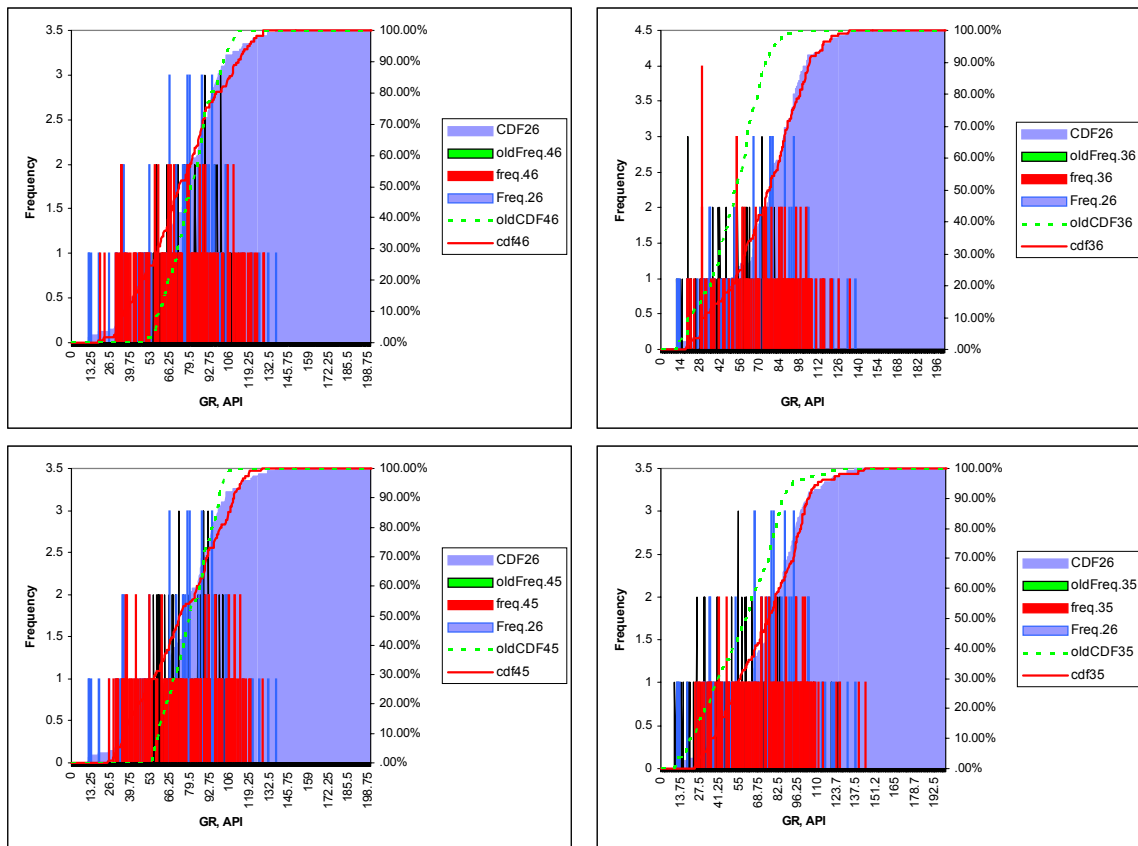


Fig. 1.5 - Histogram and CDF for wells 35, 36, 45 and 46, before and after normalizing against well Brunson 'C'1

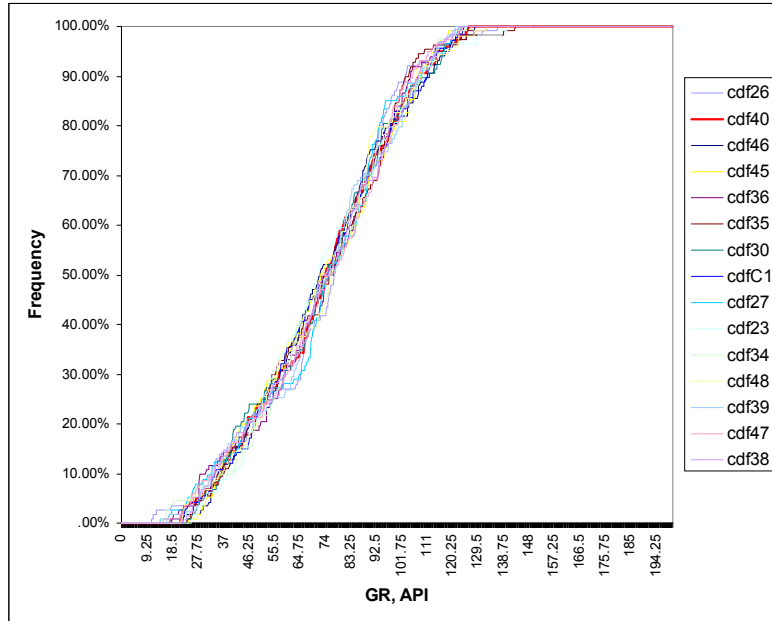


Fig. 1.6 – The corrected gamma ray distribution for all ETO’Daniel wells in the database, normalized range between 20 – 140 GR API units.

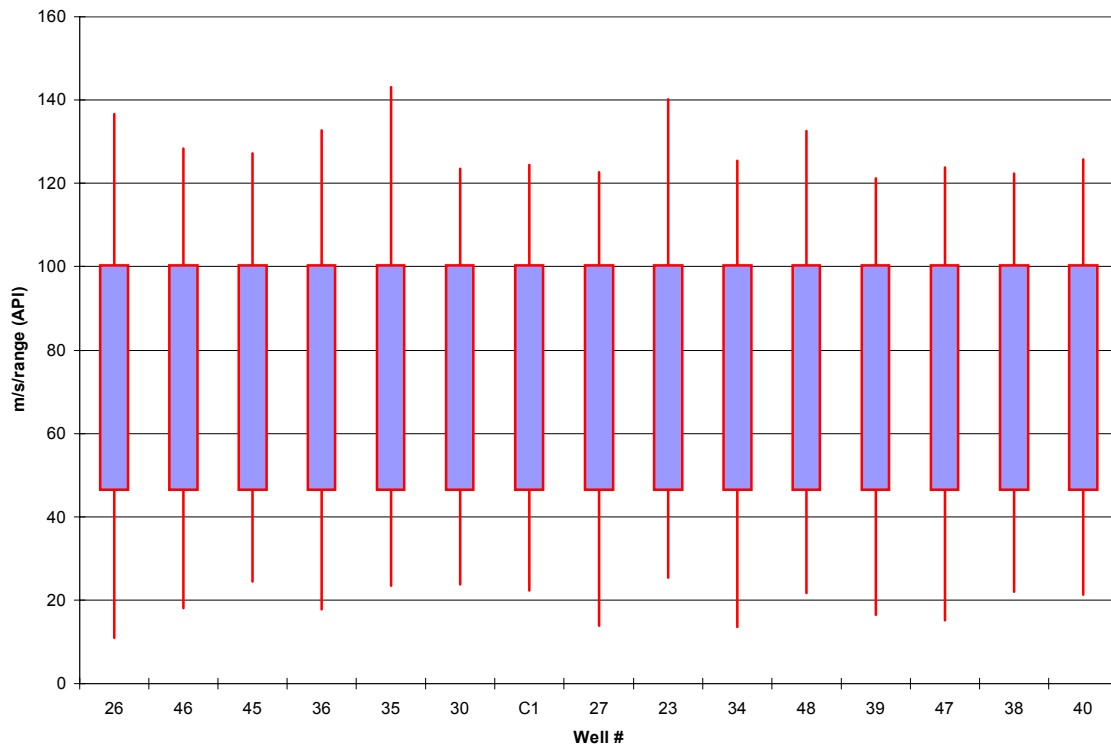


Fig. 1.7 – The normalized gamma ray values within the 1U and 5U regions of the upper Spraberry. Extreme values still vary, but mean and standard deviations from the mean are consistent.

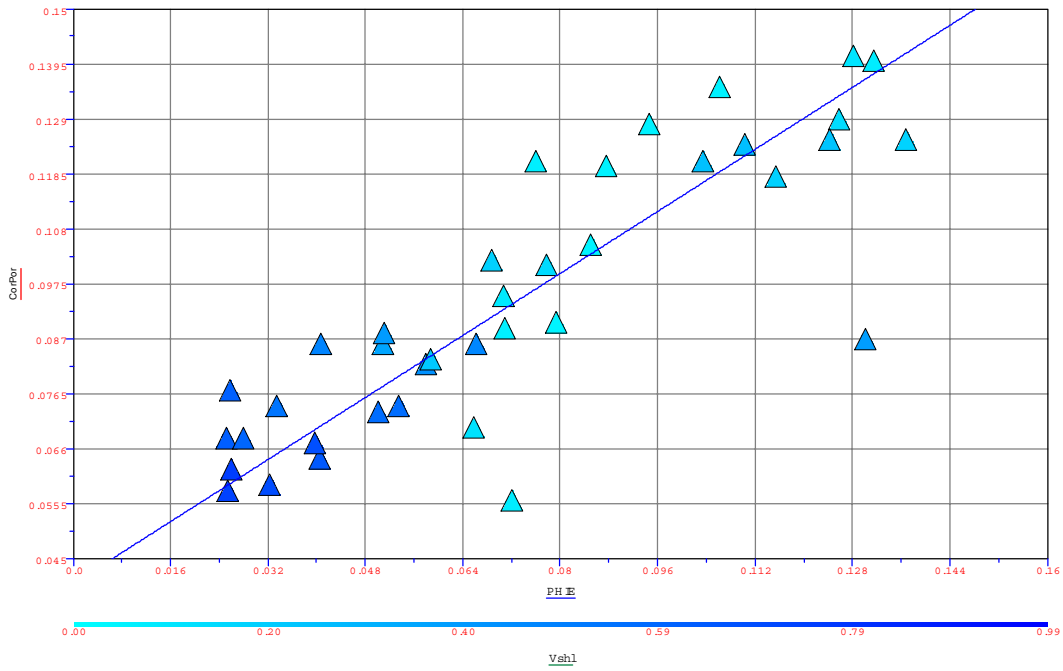


Fig. 1.8 - Cross plot core porosity vs. log porosity for ETO'Daniel 39 (1U sand)

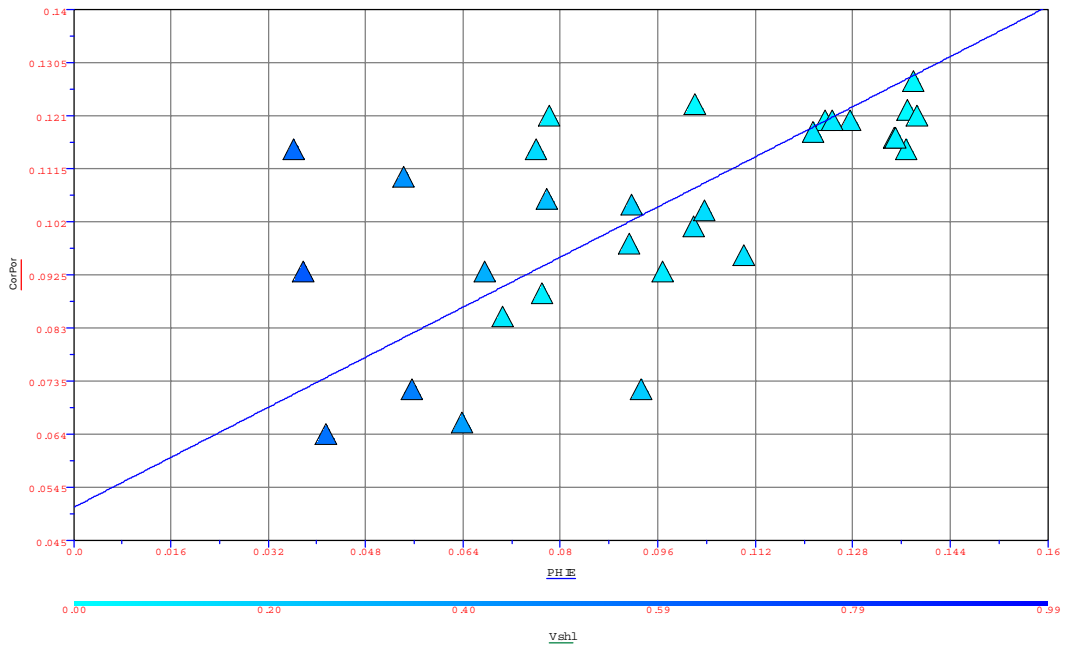


Fig. 1.9 - Cross plot core porosity vs. log porosity for ETO'Daniel 39 (5U sand)

Well ETO 39
 Well ID 42329340970000
 Field SPRABERRY (T)
 County MIDLAND
 State TEXAS
 Country USA
 Legal Description TWP: - Range: - Sec.
 Well Status OIL

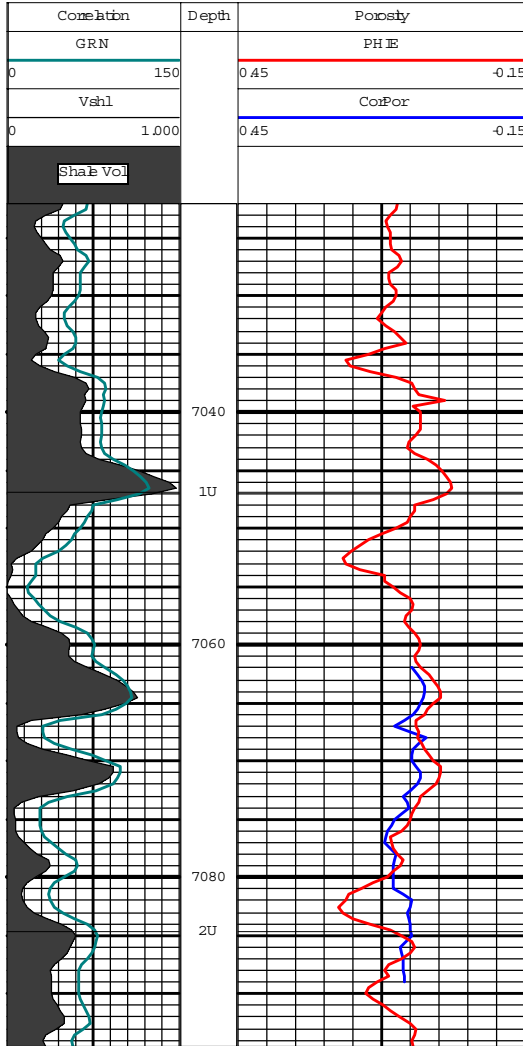


Fig. 1.10a – Log playback showing core porosity and log porosity in interval 1U well ETO39

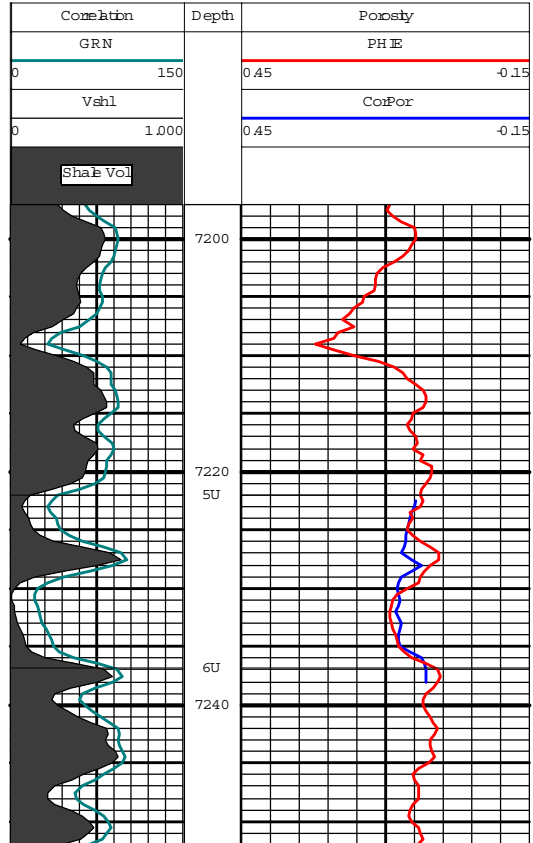


Fig. 1.10b – Log playback showing core porosity and log porosity in interval 5U well ETO39

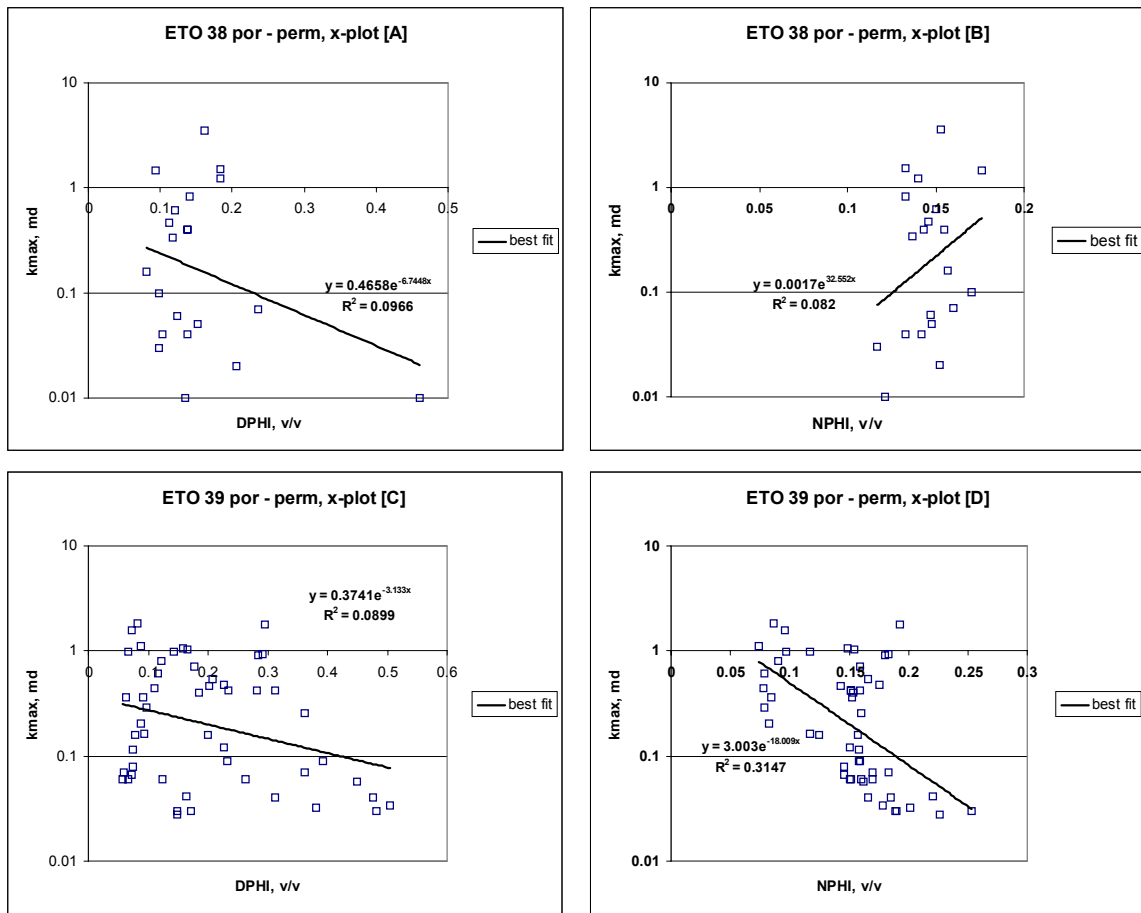


Fig. 1.11 a – d: Clockwise from upper left. ETO 38 and 39 crossplots for density and permeability using the Density and Neutron porosities respectively. Regression analysis is used to determine relationship.

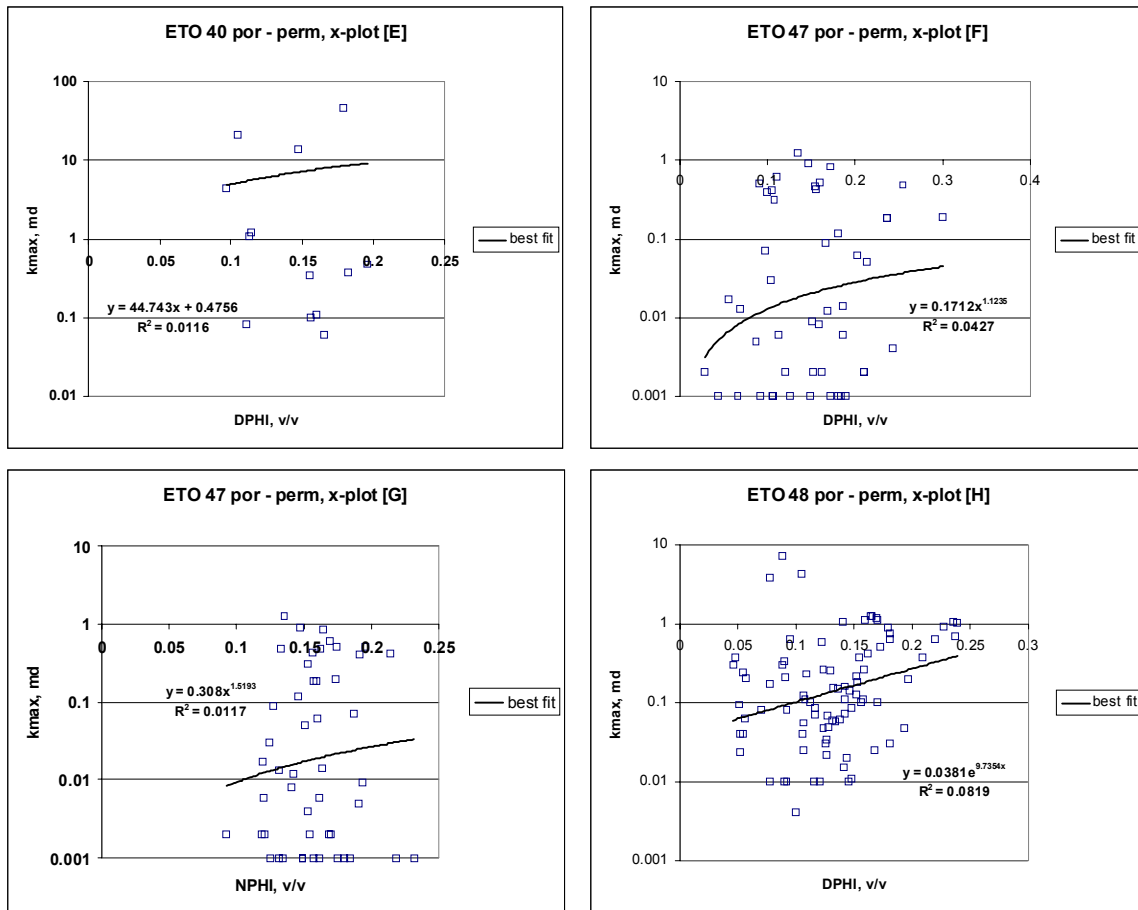


Fig. 1.12 a – d: Clockwise from upper left. ETO 39 and 40 crossplots for density and permeability using the Density and Neutron porosities respectively. Regression analysis is used to determine relationship.

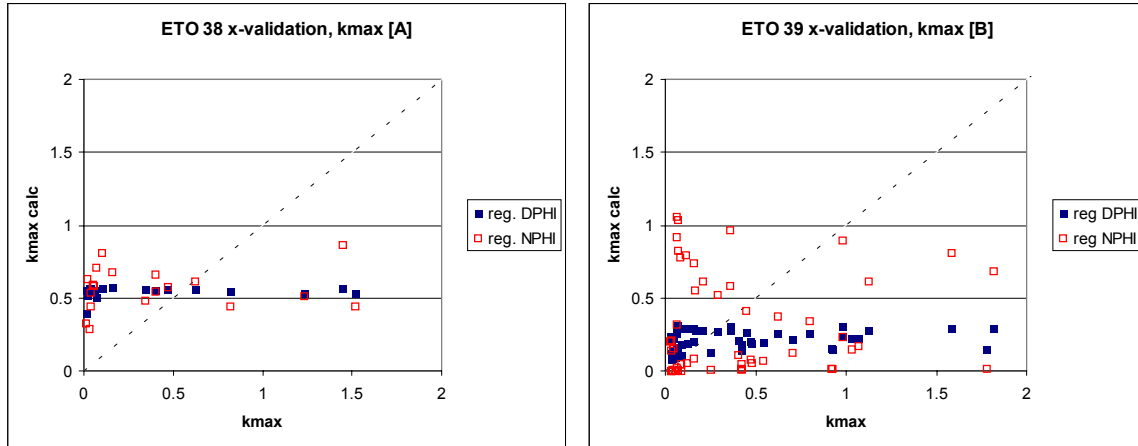


Fig. 1.13 – Cross validation for calculated permeability, using regression analysis

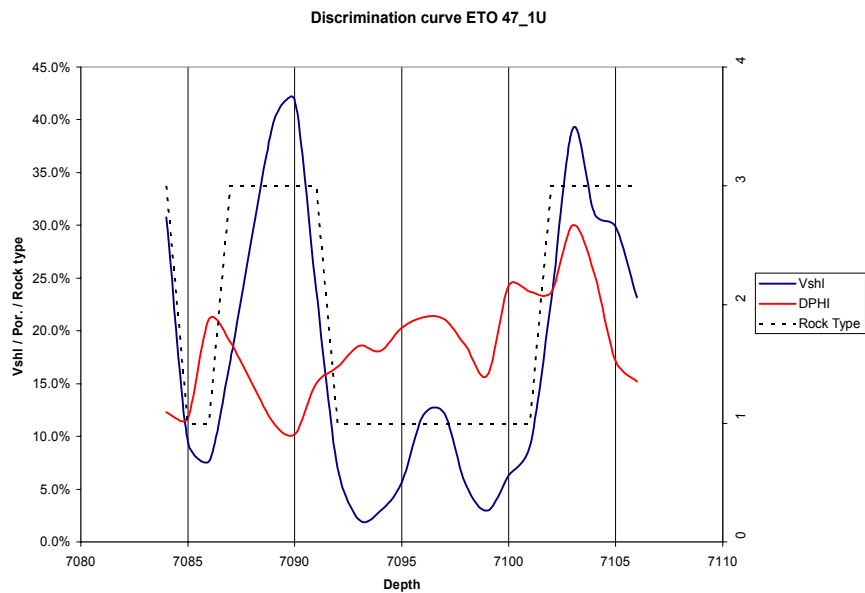


Fig. 1.14 – The DPFI / Vsh / RTYP_D discrimination curves eliminate any type 2 (B) rocks from the transformation data in the 1U interval (See Table 3.3 for data values)

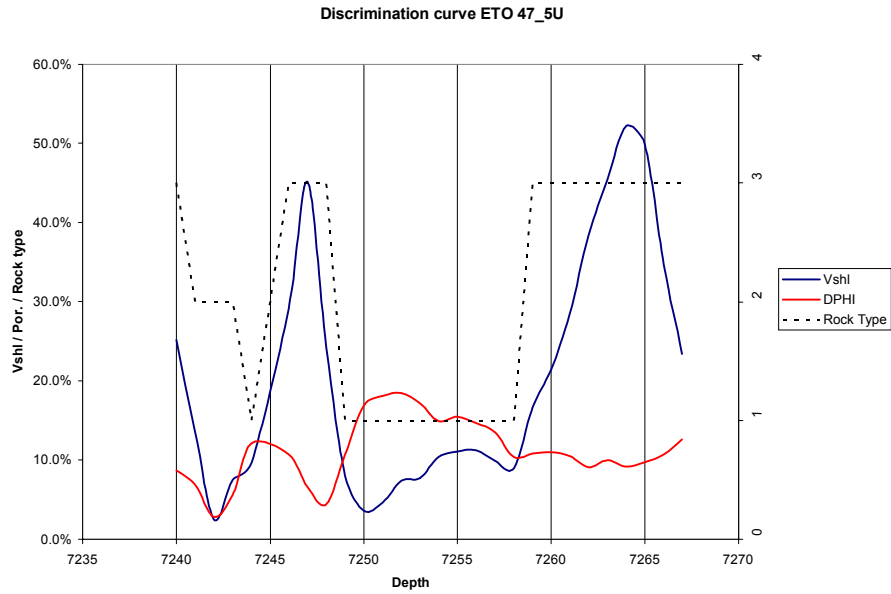


Fig. 1.15 – The DPHI / Vsh / RTYP_D discrimination curves shows significant intervals of type 1, and type 3 rocks and very little of type 2 in the upper region in the 5U interval (ETO47)

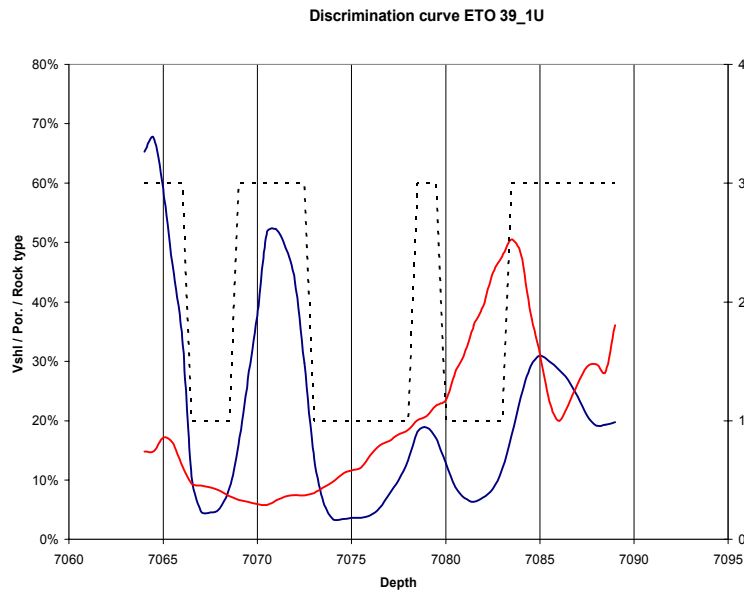


Fig. 1.16 – The DPHI / Vsh / RTYP_D discrimination curves for 1U interval (ETO39). Only type 1 and 3 are present in the interval (See Table 3.4 for data values)

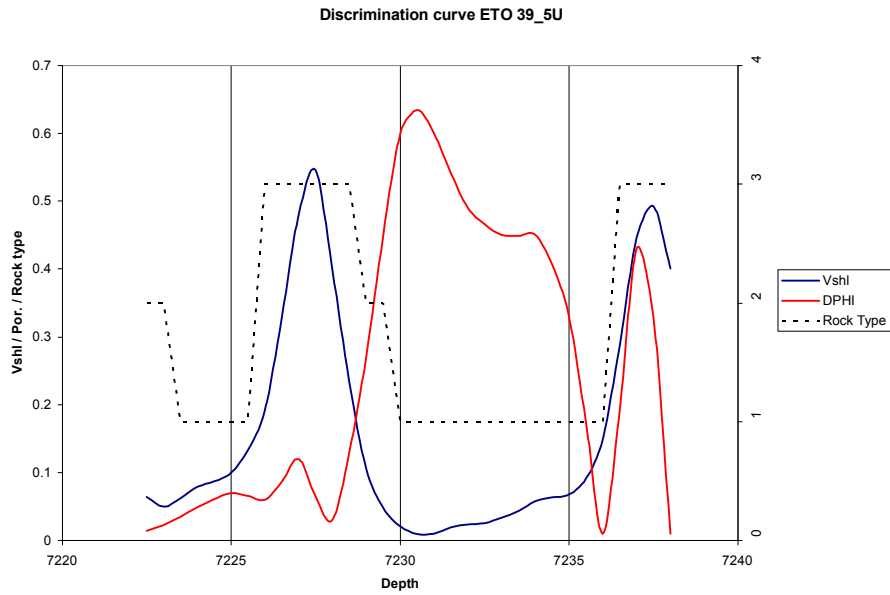


Fig. 1.17 – The DPHI / Vsh / RTYP_D discrimination curves for 5U interval (ETO39). Type 1, 2 and 3 are present in the interval (See Table 3.4 for data values)

DPHI based regression

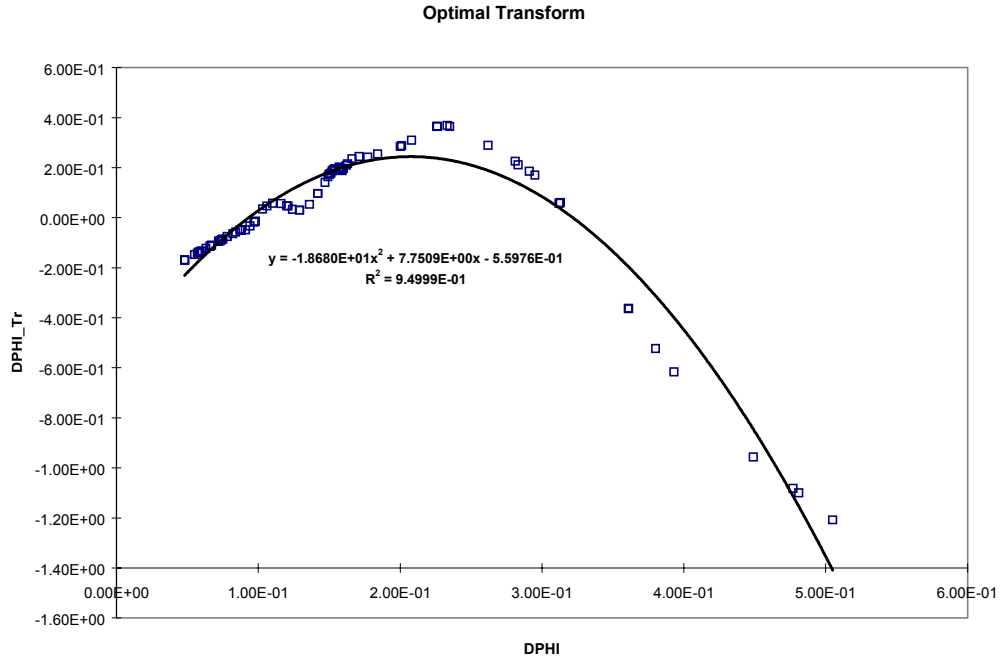


Fig. 1.18 – Optimal transformation of density porosity. Solid line represents a fitted 2nd order polynomial function

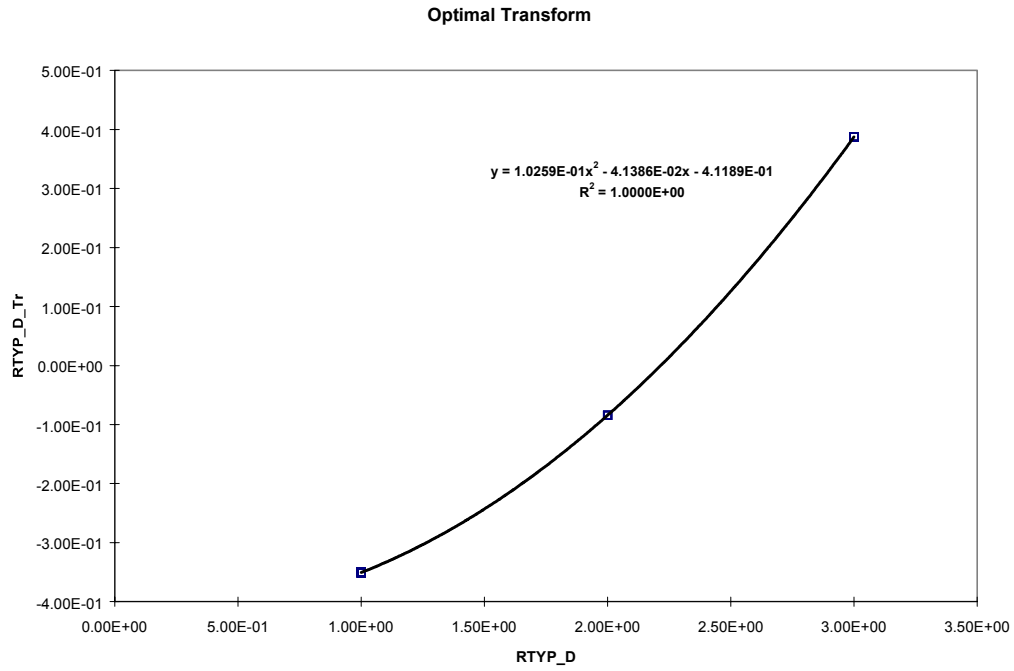


Fig. 1.19 – Optimal transformation of rock type. Solid line represents a fitted 2nd order polynomial function

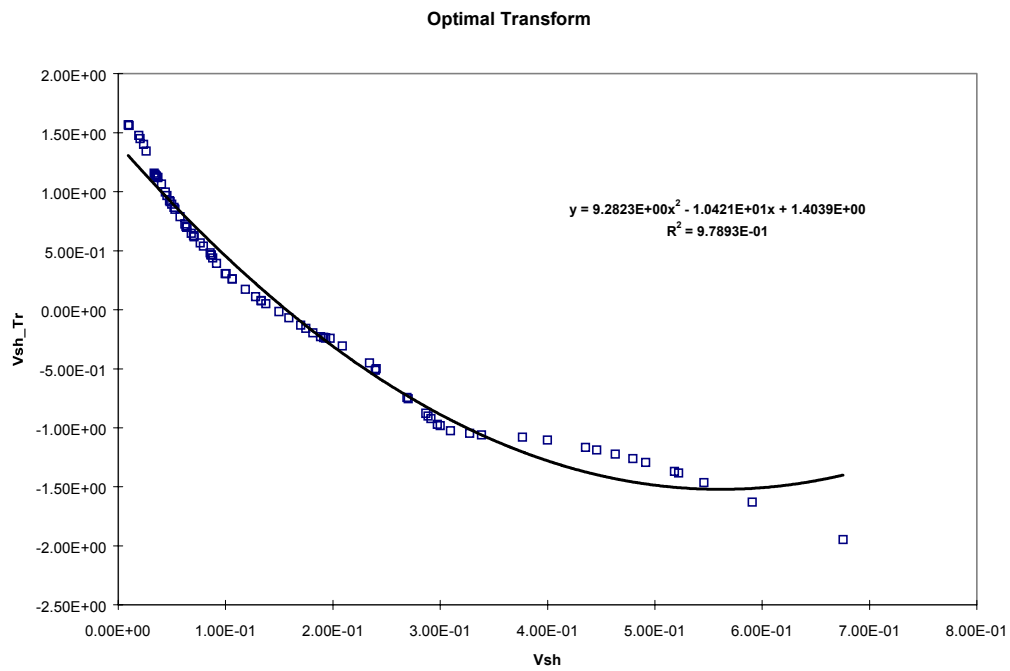


Fig. 1.20 – Optimal transformation of shale volume. Solid line represents a fitted 2nd order polynomial function

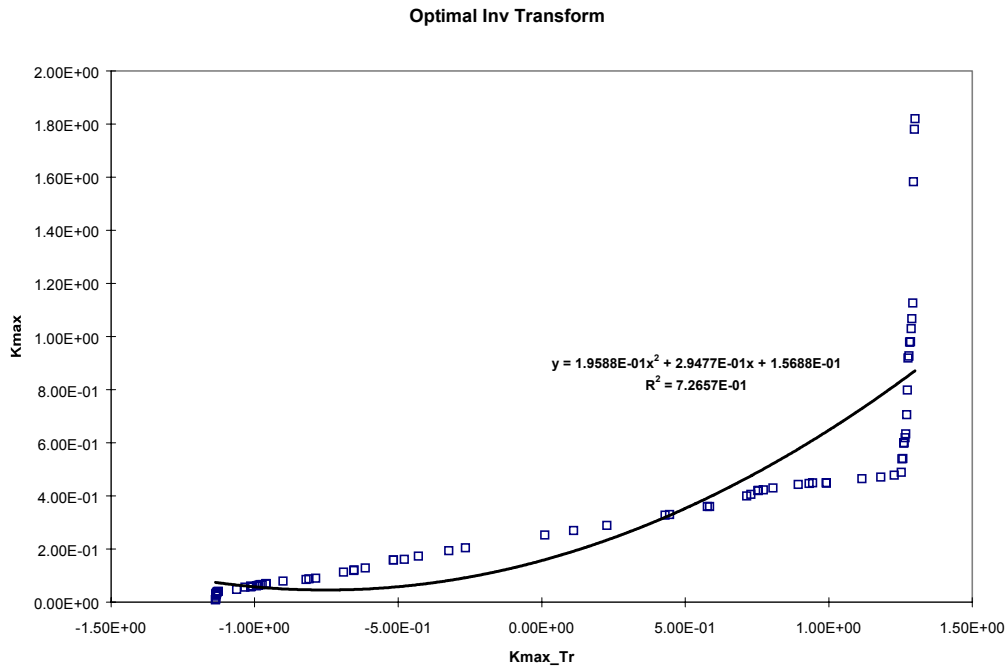


Fig. 1.21 – Inverse transform for permeability from given permeability data. Fitted by a 2nd order polynomial

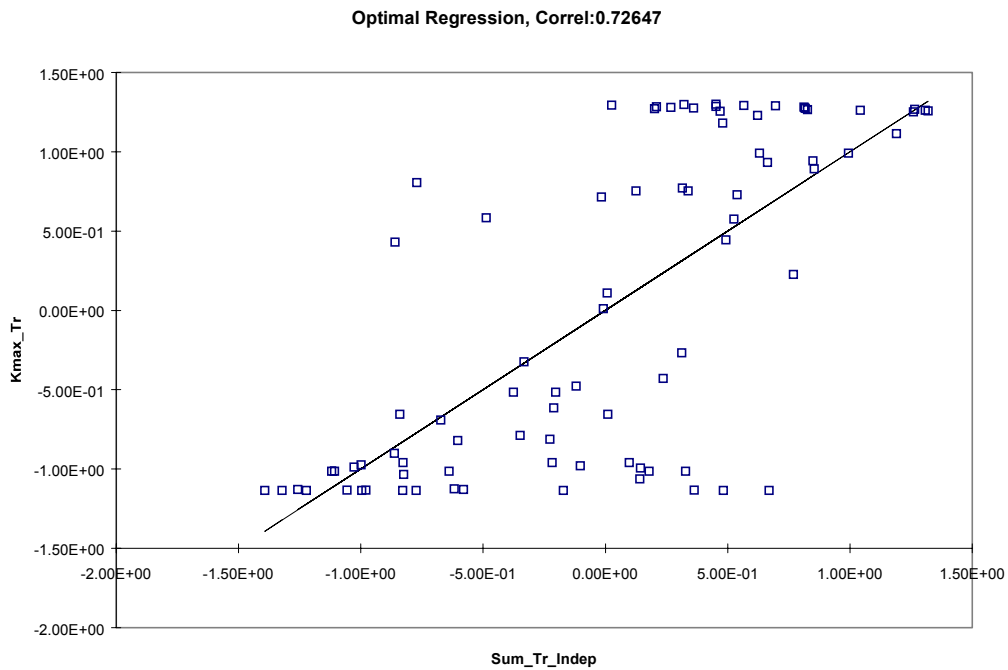


Fig. 1.22 – Optimal regression for transformed dependent variable (k) and sum of transformed independent variable (Vshl, R_Type, ϕ)

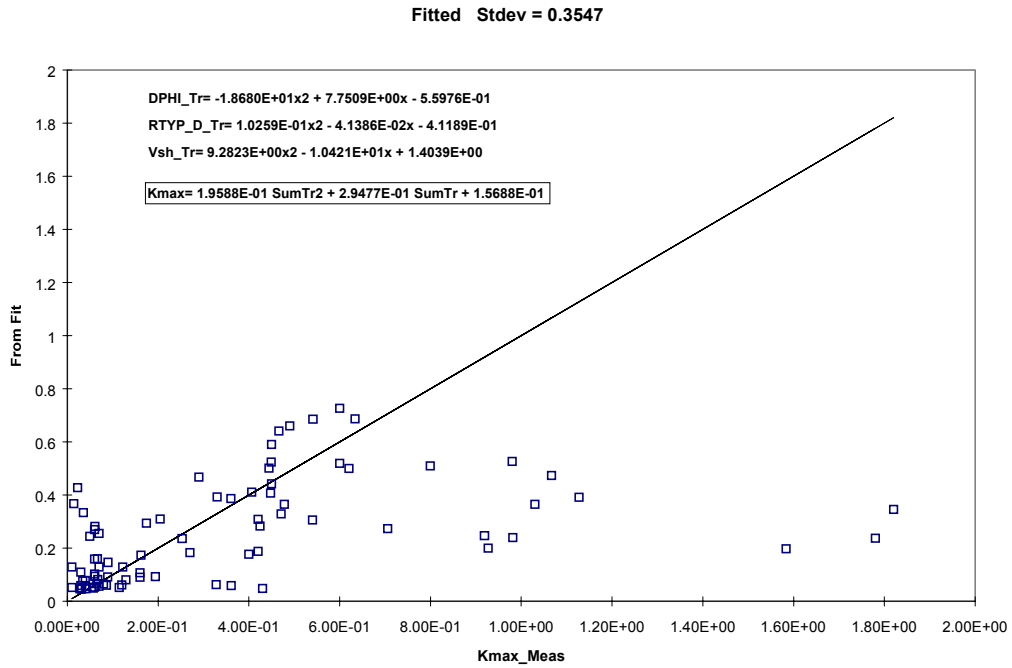


Fig. 1.23 – Optimal regression for back transformed data set

NPHI based regression

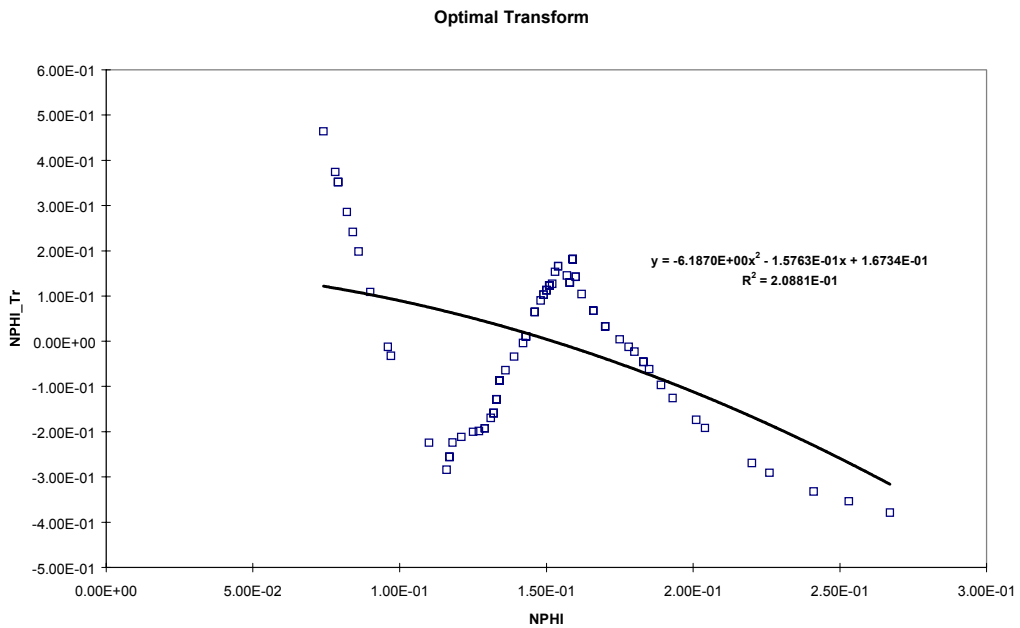


Fig. 1.24 – Optimal transformation of Neutron porosity. Solid line represents a fitted 2nd order polynomial

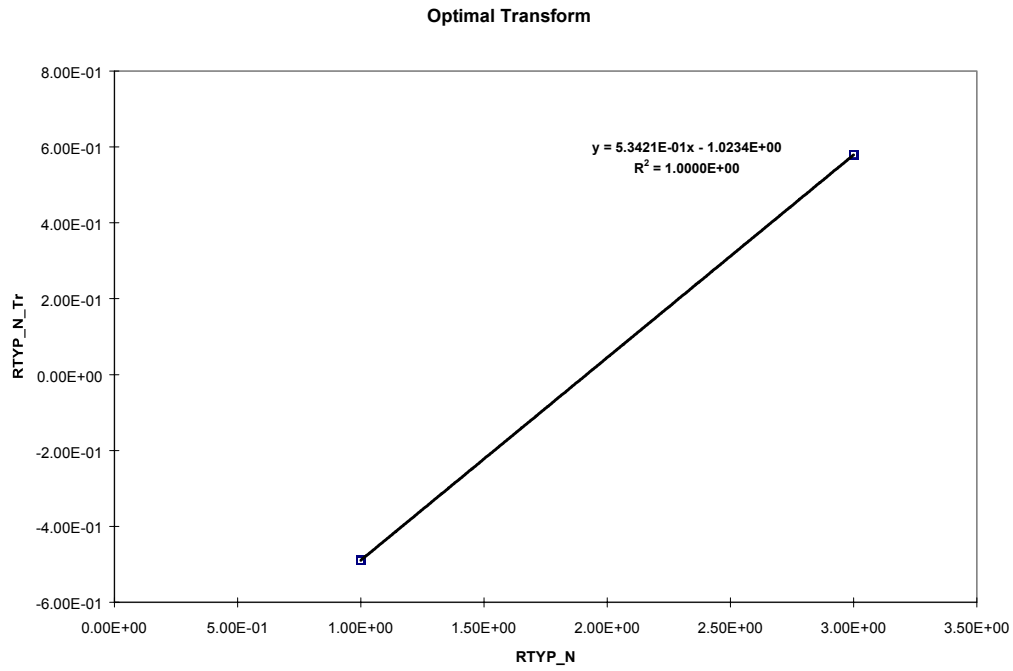


Fig. 1.25 – Optimal transformation of rock type. Linear transformation

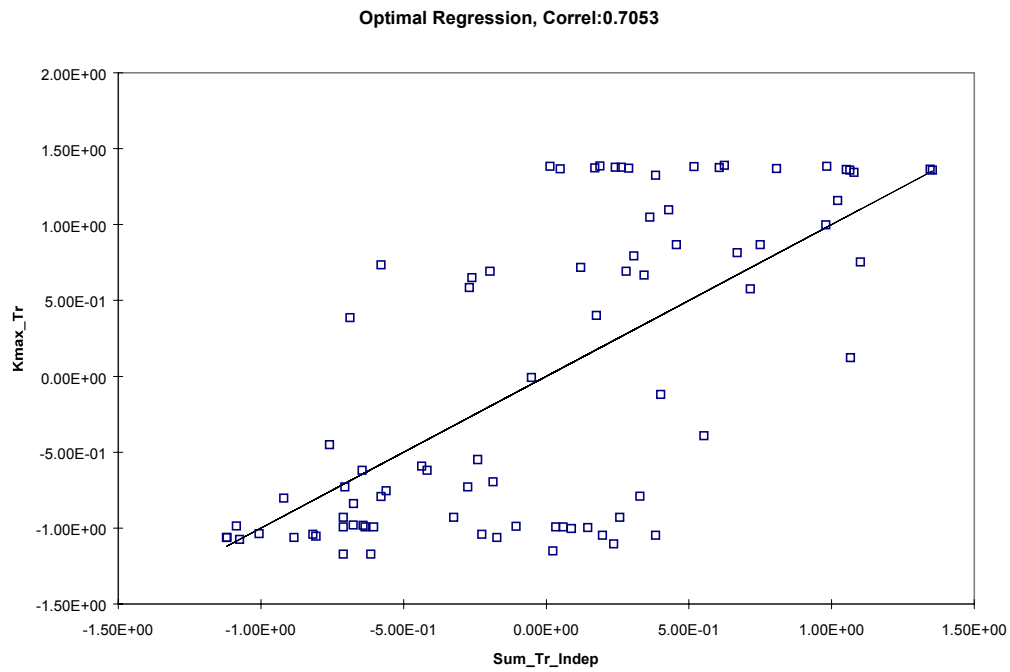


Fig. 1.26 – Optimal regression for transformed dependent variable (k) and sum of transformed independent variable (Vshl, R_Type, ϕ)

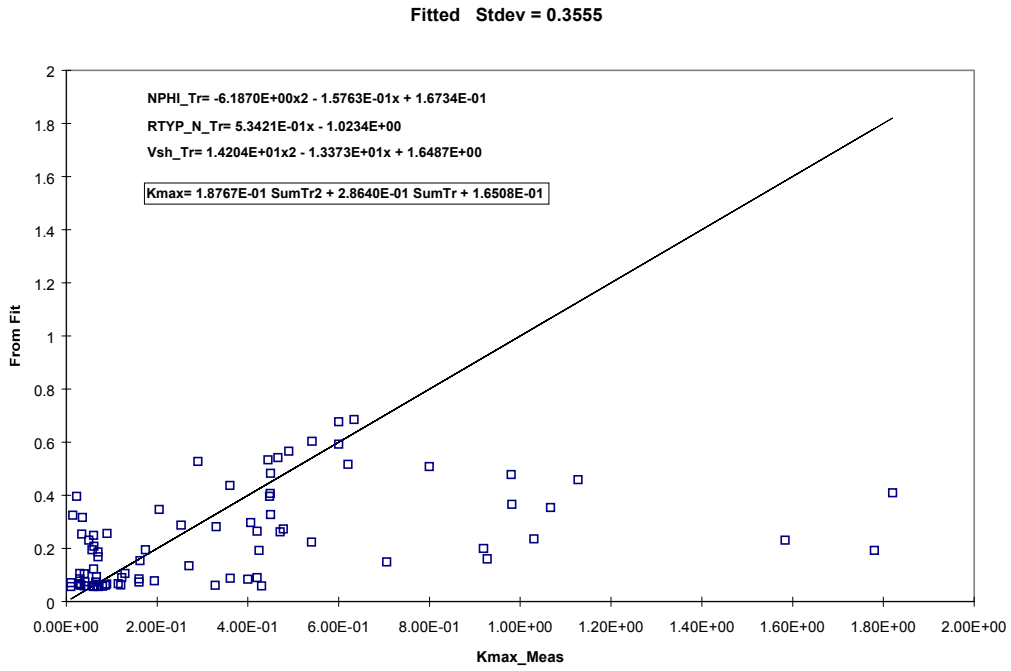


Fig. 1.27 – Optimal regression for back transformed data set

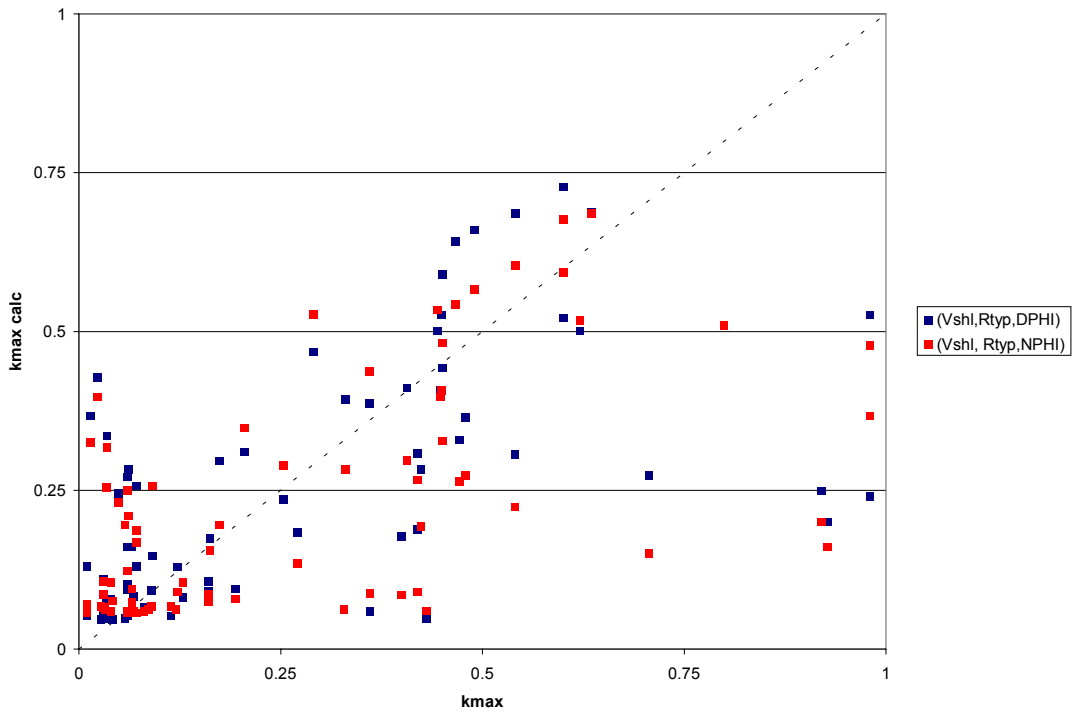


Fig. 1.28 – Cross-validation of regression derived predictions for permeability for rock types 1, 2 and 3 (Density and Neutron)

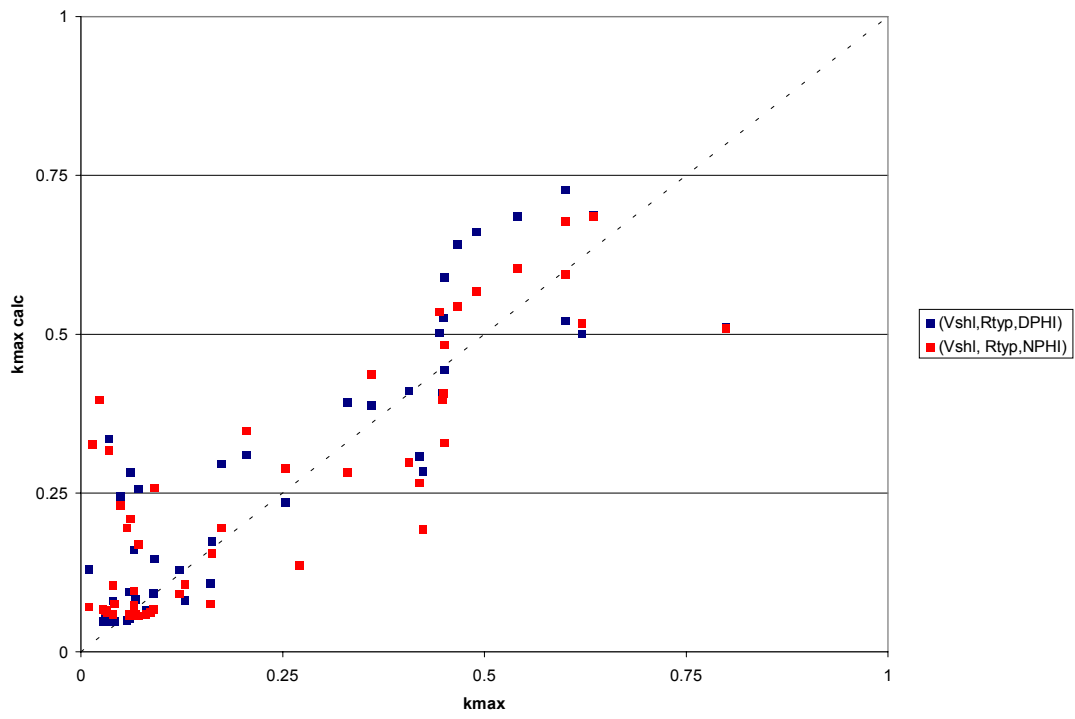


Fig. 1.29 – Cross-validation of regression derived predictions for permeability for rock type 1 (Density and Neutron)

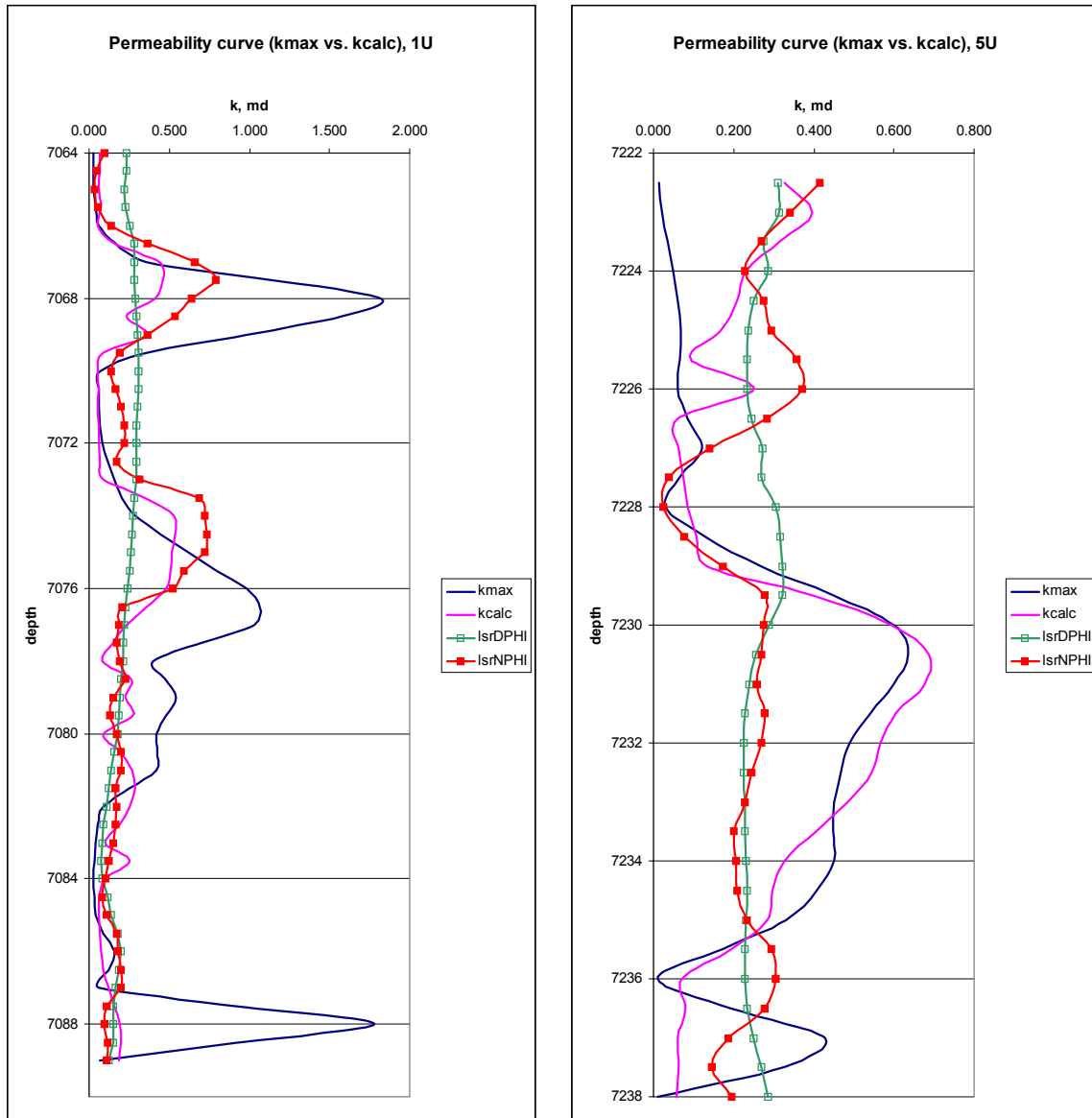


Fig. 1.30 – Playback of transforms obtained by univariate regression (NPHI and DPHI) and multivariate regression (NPHI)

Well ETO 38
 Well ID 4232934100000
 Field SPRABERRY (T
 County MIDLAND
 State TEXAS
 Well Status OIL

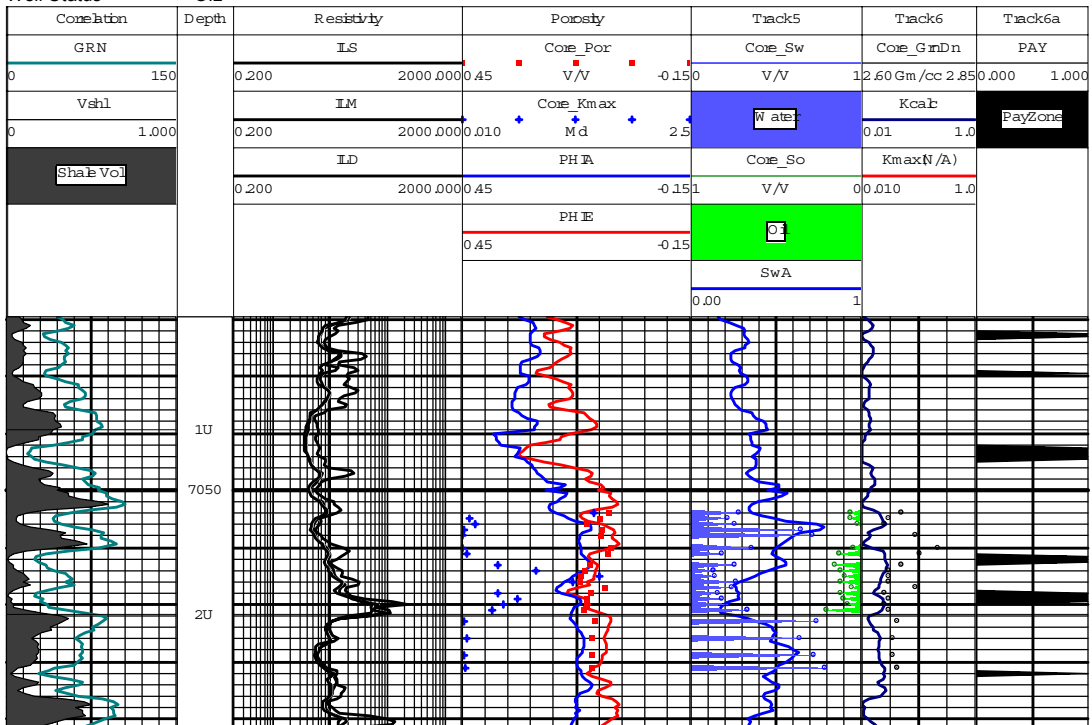


Fig. 1.31 – Saturation profile matched for 1U (ETO38) using a R_w 0.080 ohm

Well ETO 40
 Well ID 42329341010000
 Field SPRABERRY (T
 County MIDLAND
 State TEXAS
 Well Status OIL

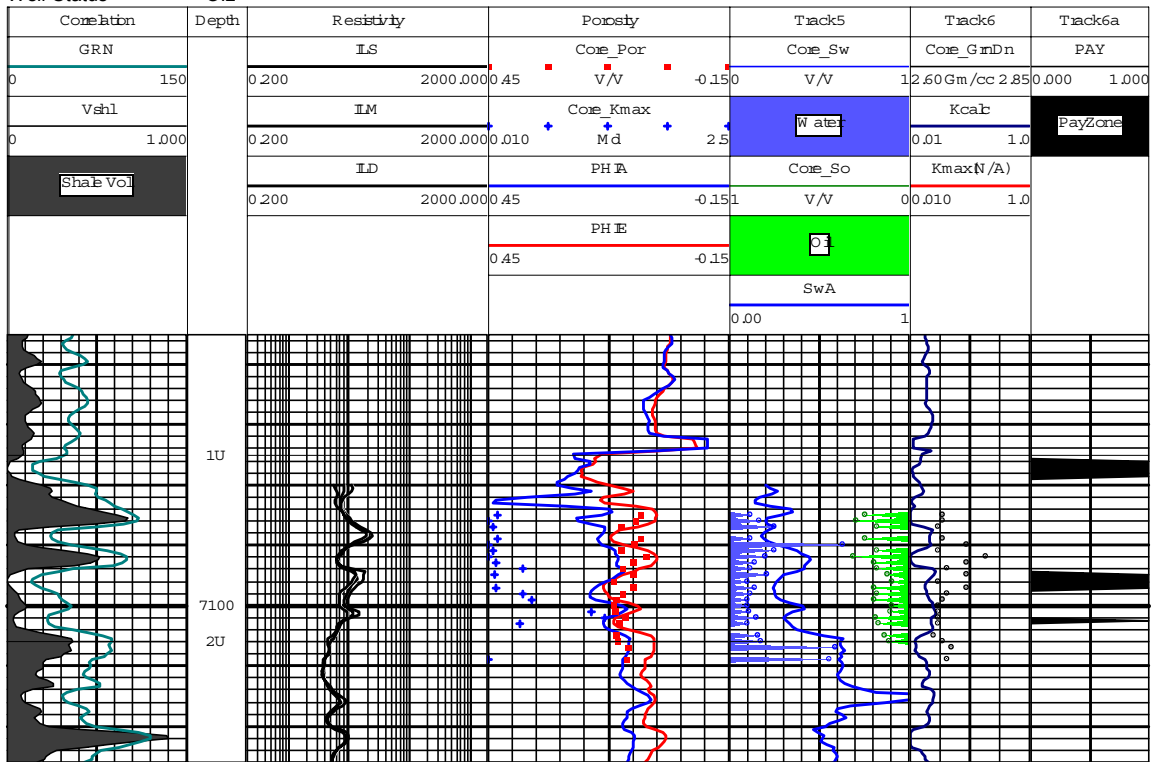


Fig. 1.32 – Saturation profile matched for 1U (ETO40) using Rw 0.080 ohm

Well ETO 40
 Well ID 42329341010000
 Field SPRABERRY (T
 County MIDLAND
 State TEXAS
 Well Status OIL

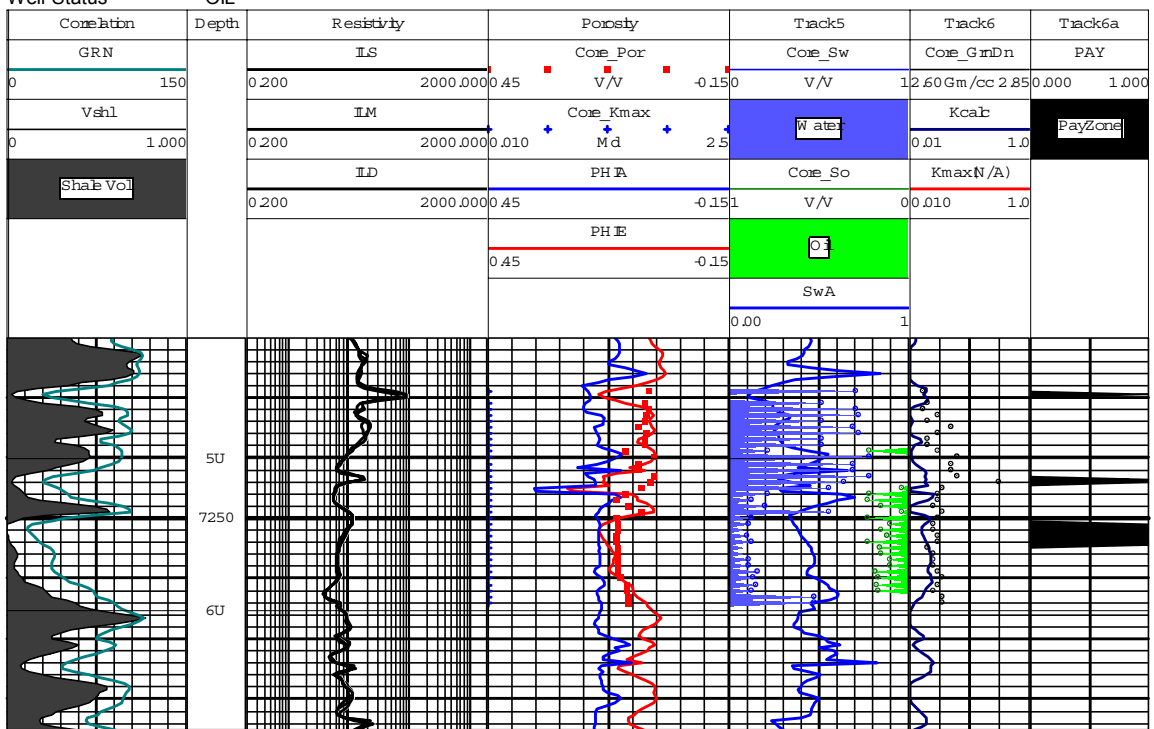


Fig. 1.33 – Saturation profile matched for 5U (ETO40) using R_w of 0.080 ohm

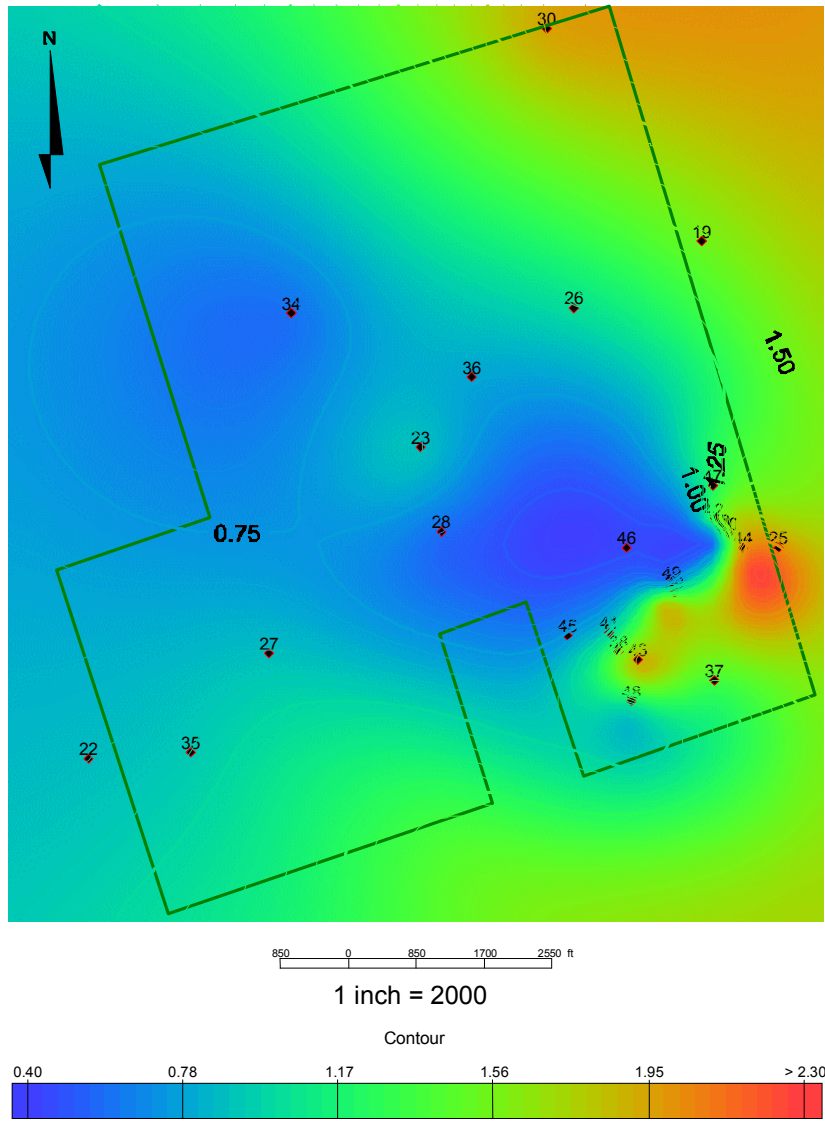


Fig. 1.34 - 1U Porosity-Net pay product map in the ET O'Daniel unit

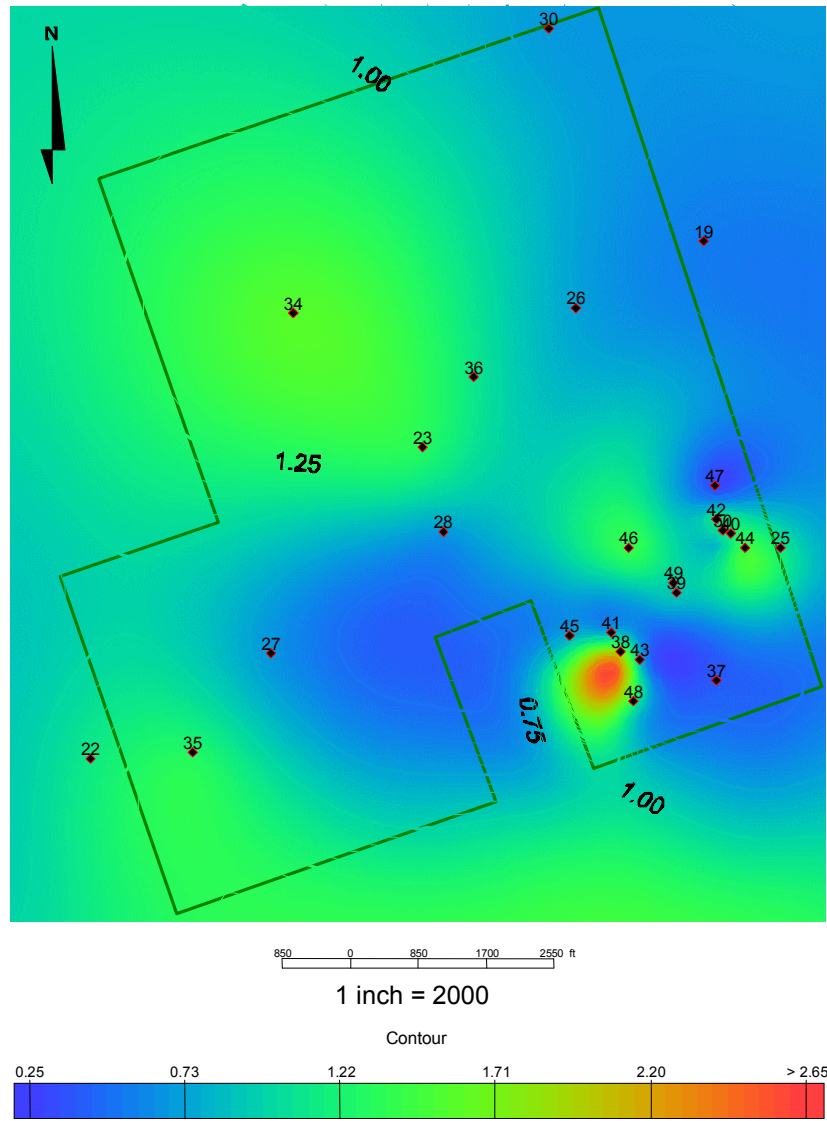


Fig. 1.35 - 5U Porosity-Net pay product map in the ET O'Daniel unit

Well GSU 146A
 Well ID 42329348880000
 Field
 County
 State
 Well Status OIL

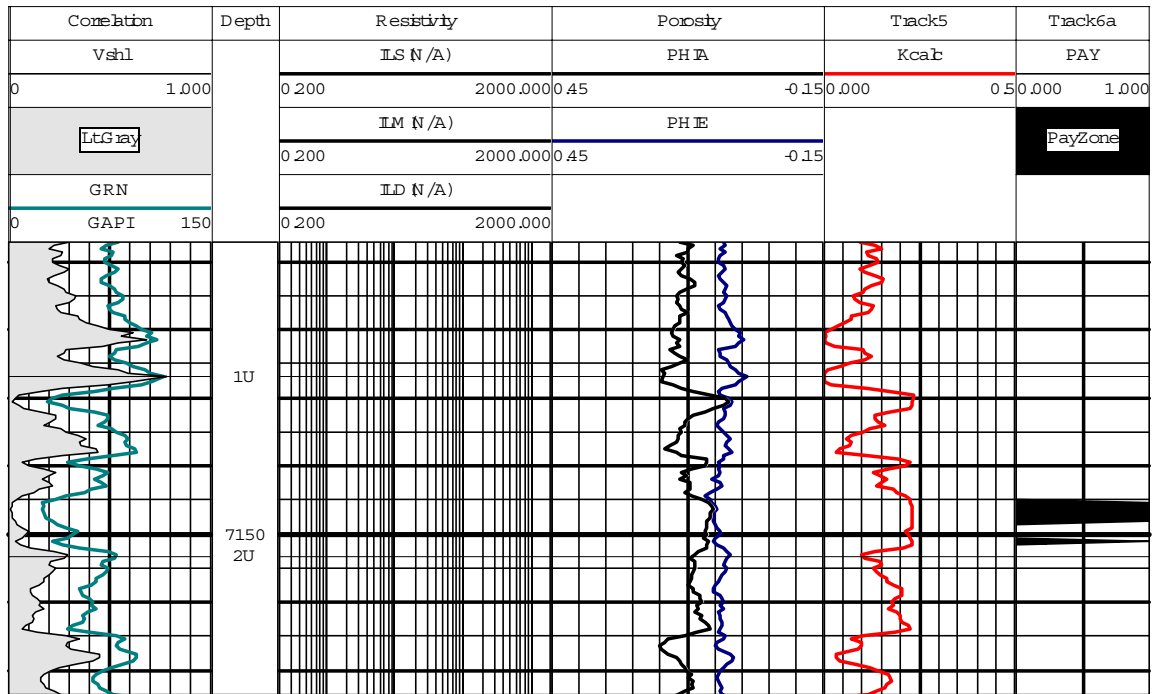


Fig. 1.36 – Pay zone prediction based on rock model for 1U interval (GSU146A)

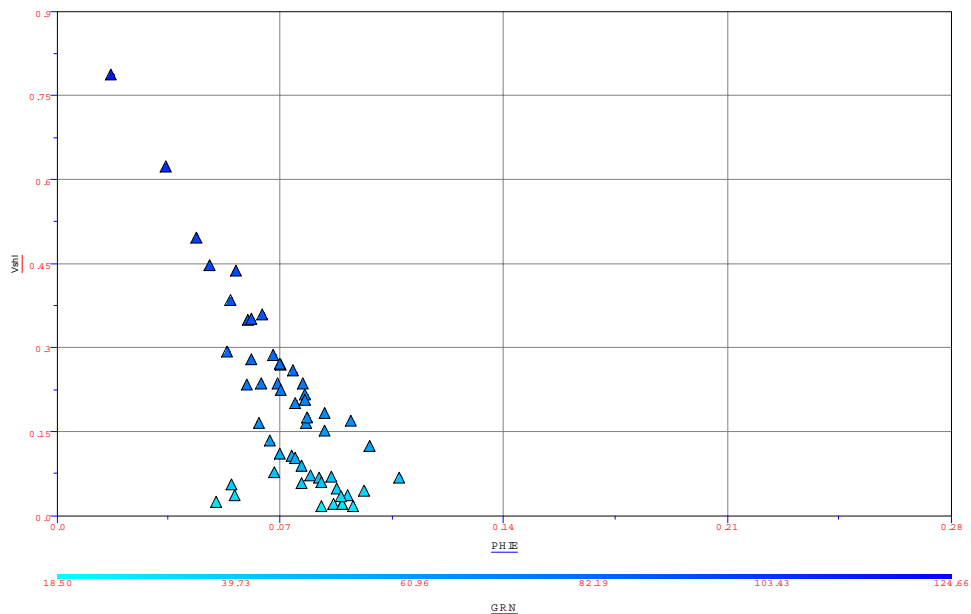


Fig. 1.37 – Quantitative estimate of rock types in 1U (GSU146A) from V_{shale} porosity crossplot

Well GSU 146A
 Well ID 42329348880000
 Field
 County
 State
 Well Status OIL

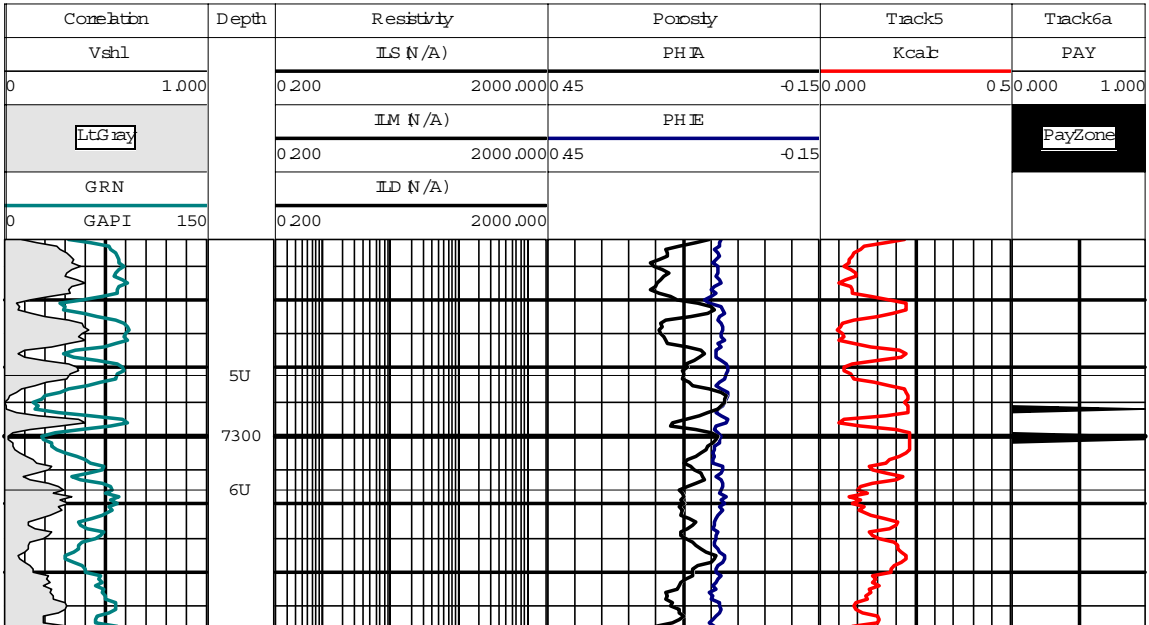


Fig. 1.38 – Pay zone prediction for 5U (GSU146A), showing small ‘Type A’ pay interval.

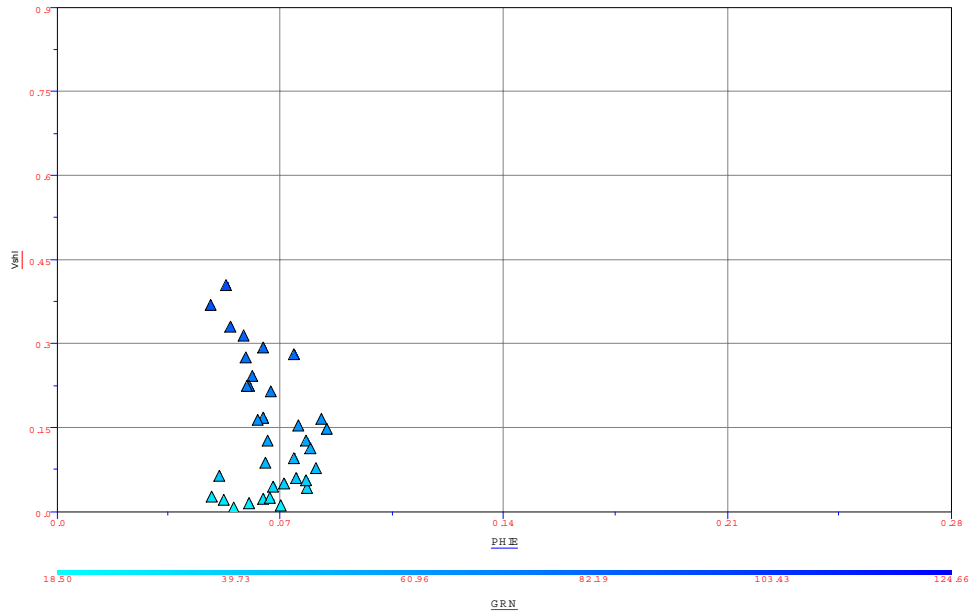


Fig. 1.39 – V_{shale} – porosity crossplot for 5U (GSU146A) shows low percentage of ‘Type A’ reservoir rock

Well GSU 214A
 Well ID 42329347700000
 Field GSU
 County MIDLAND
 State TEXAS
 Well Status

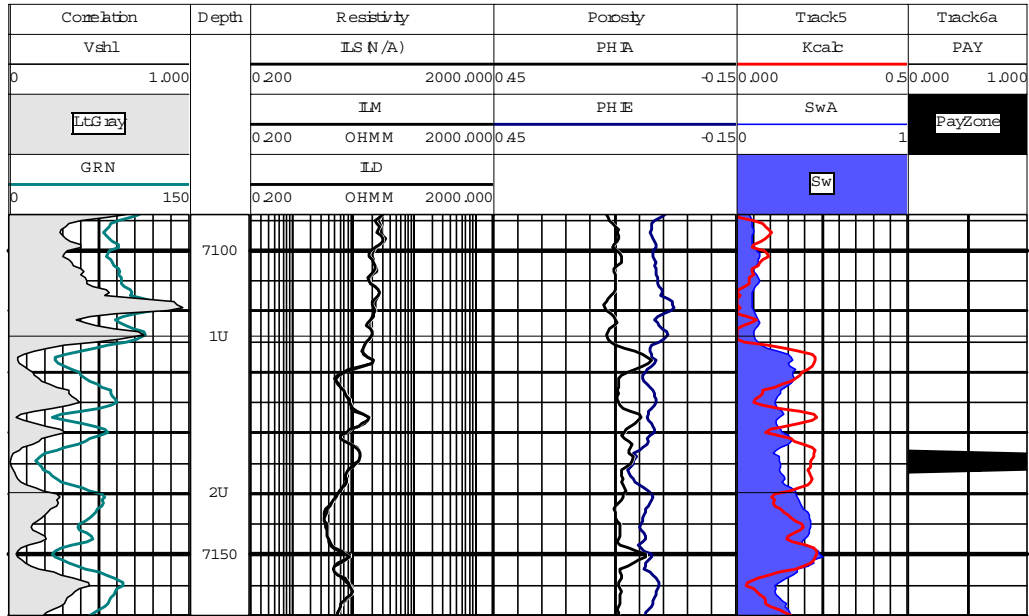


Fig. 1.40 – Pay zone prediction for 1U (GSU214A)

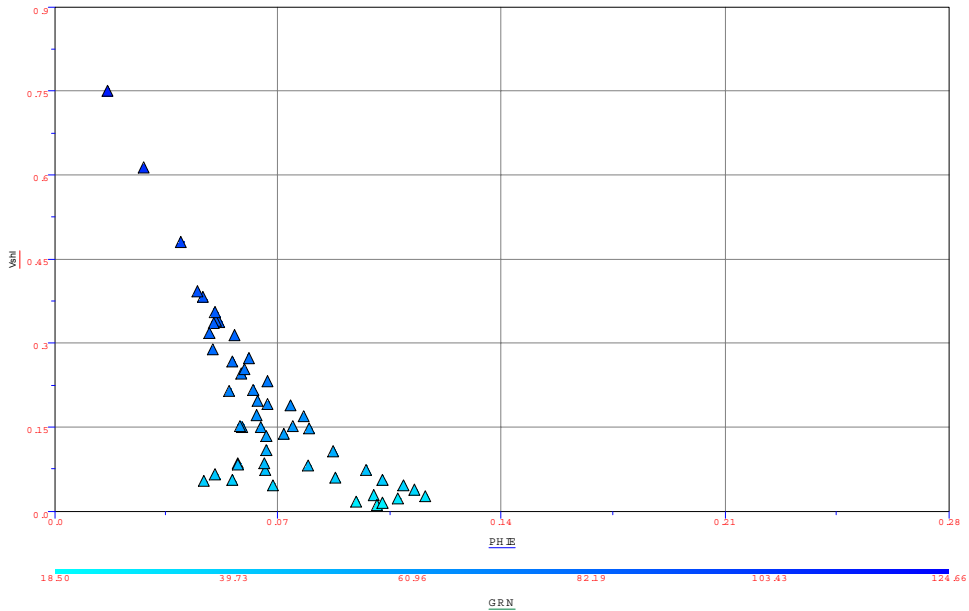


Fig. 1.41 – V_{shale} crossplot for 1U in GSU 214A

Well GSU 214A
 Well ID 42329347700000
 Field GSU
 County MIDLAND
 State TEXAS
 Well Status

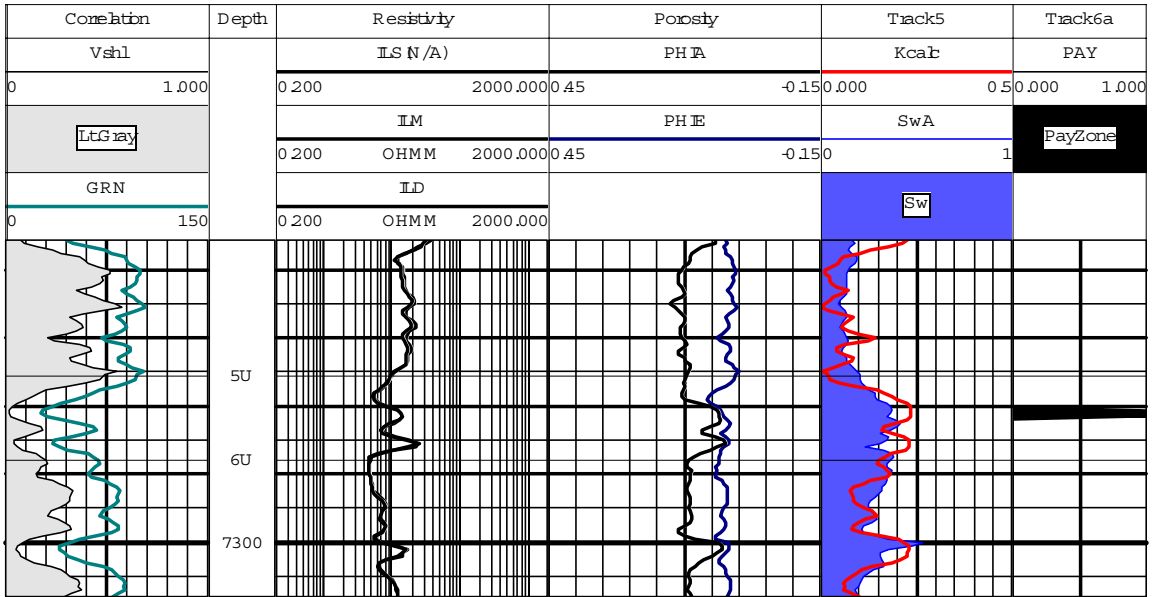


Fig 1.42 – Pay zone prediction for 5U (GSU214A)

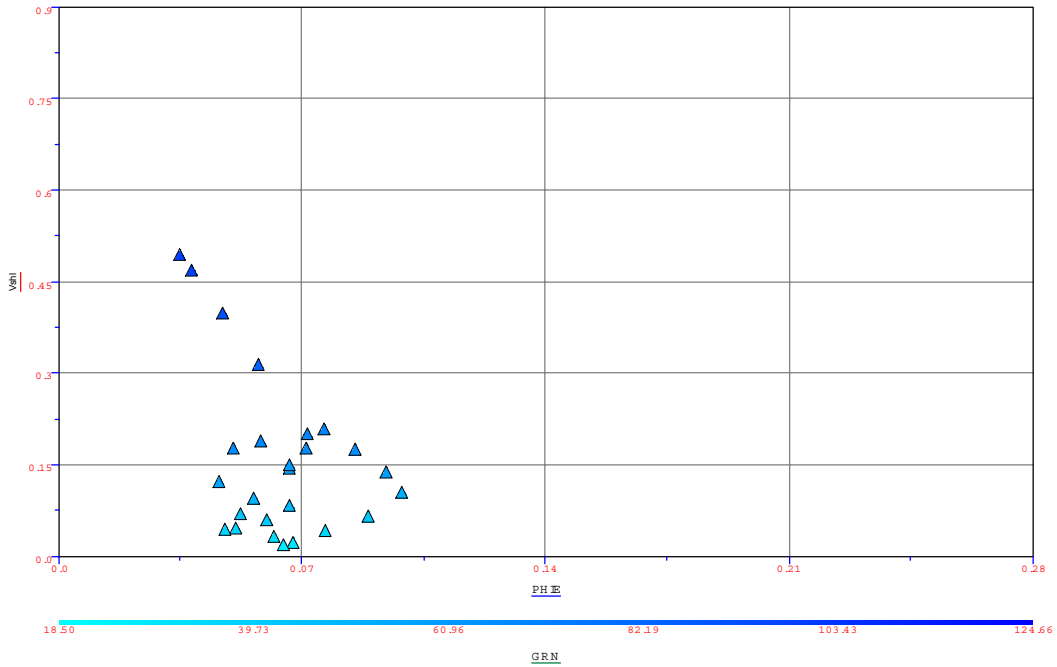


Fig. 1.43 – V_{shale} crossplot for 5U in GSU 214A, showing very small amount of ‘Type A’ rock in interval

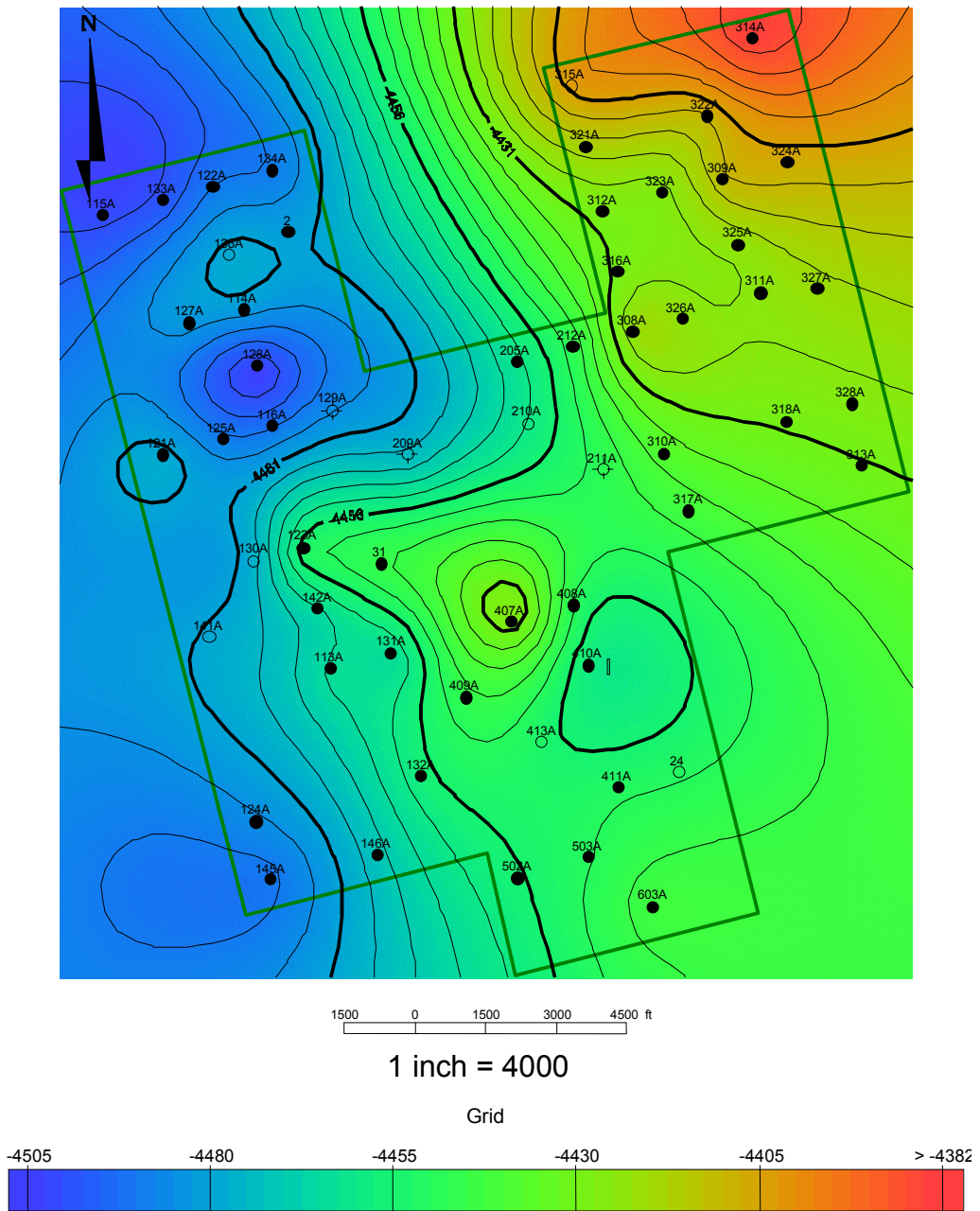


Fig. 1.44 - Structure map of the IU interval

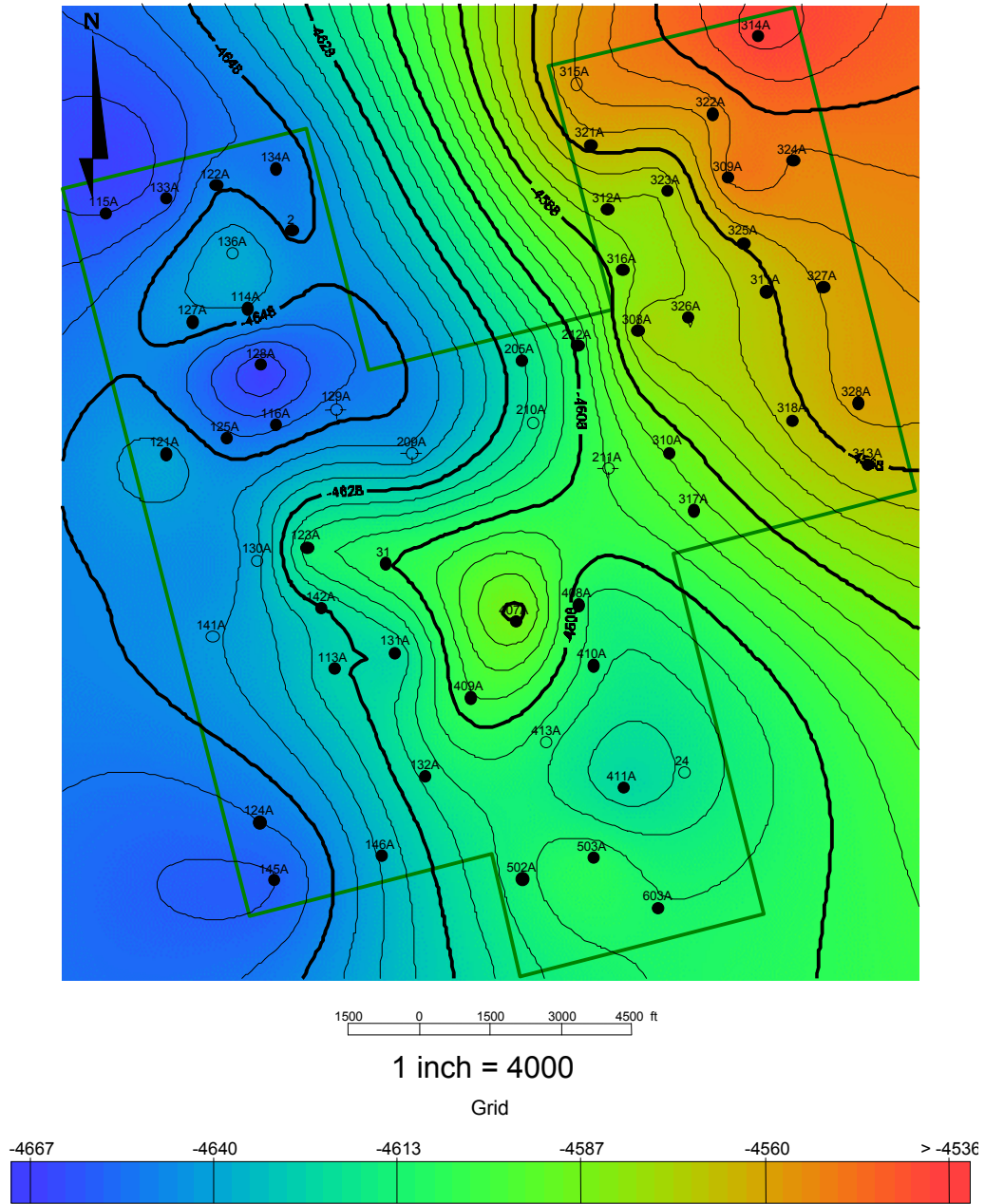
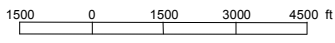
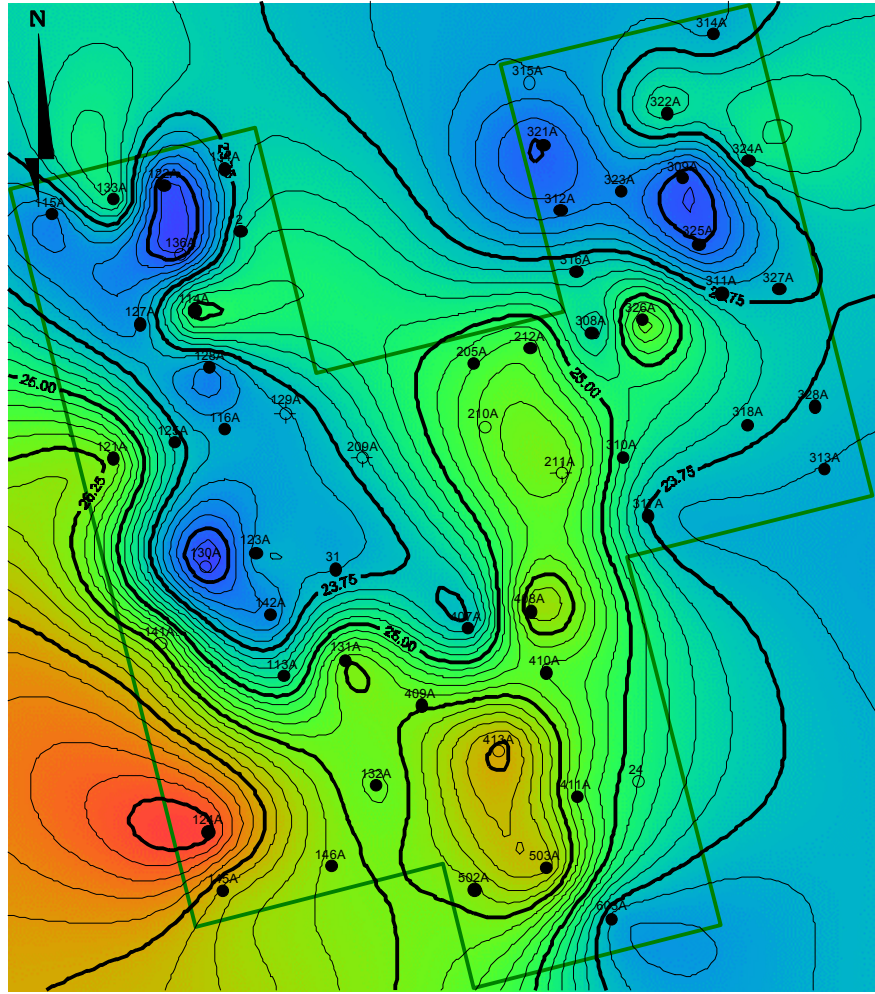


Fig. 1.45 - Structure map of the 5U interval



1 inch = 4000 feet

Grid

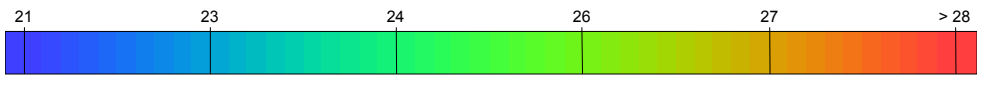


Fig. 1.46 - Gross Thickness of 1U interval

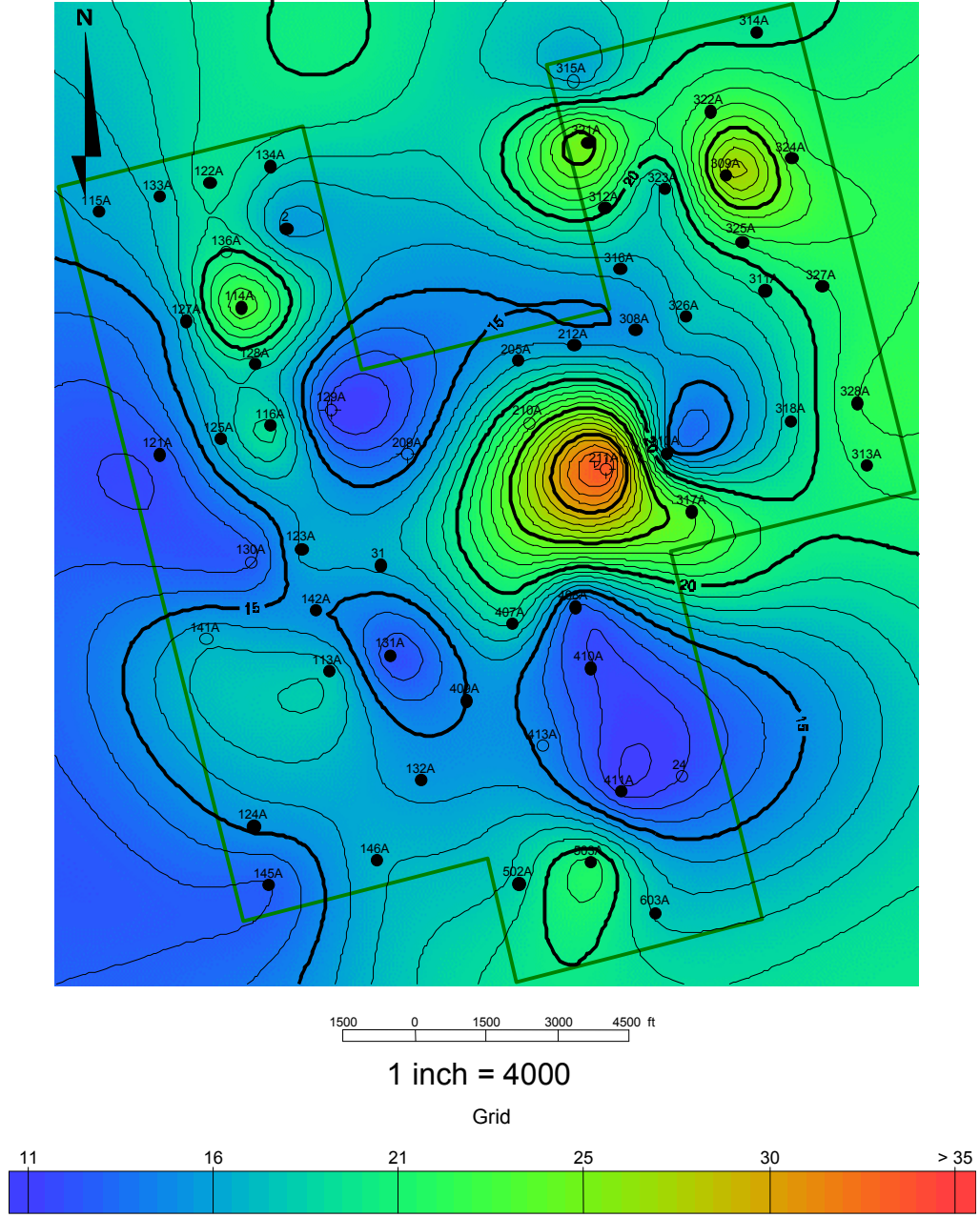


Fig. 1.47 - Gross Thickness of 5U interval

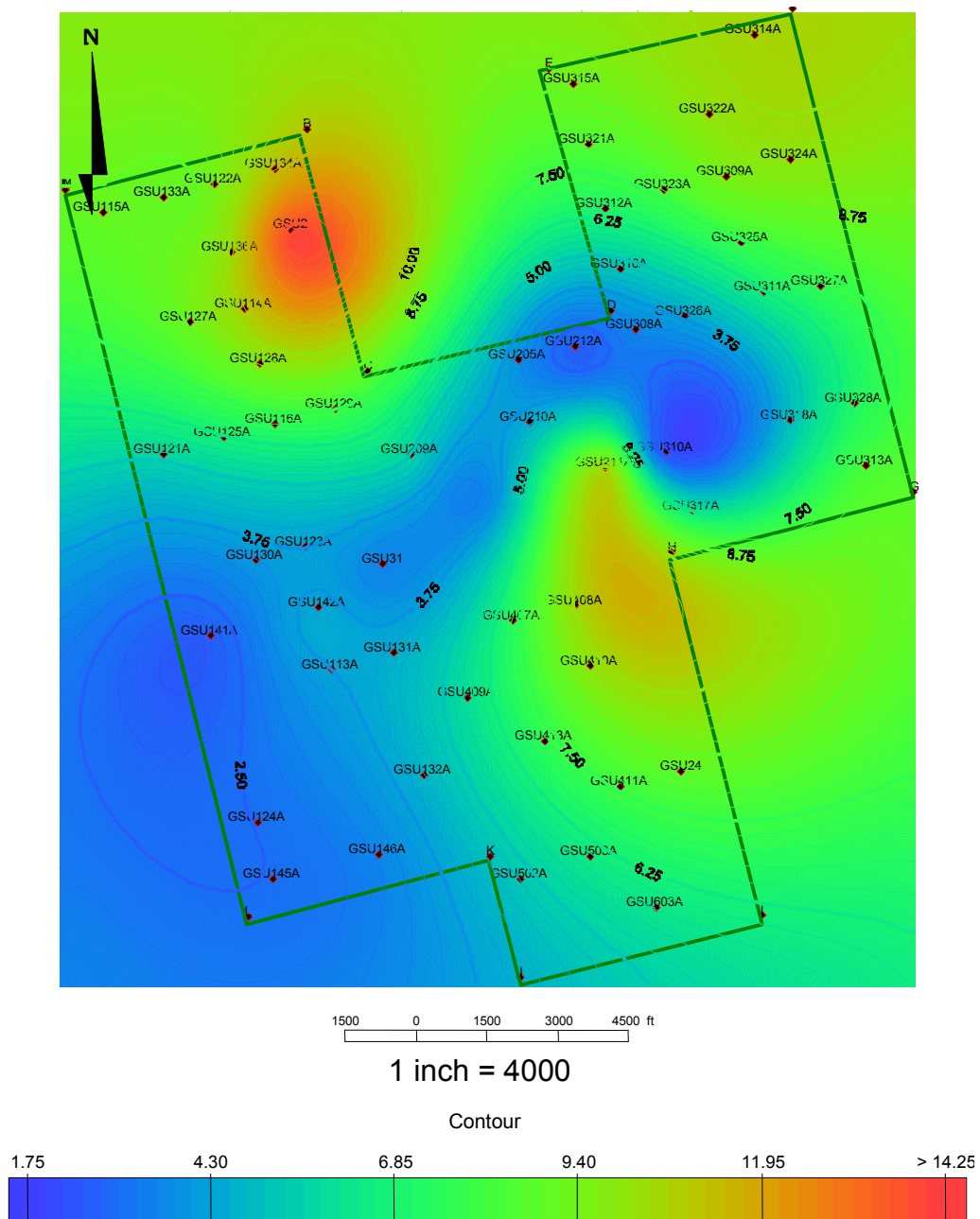


Fig. 1.49 – Net thickness map of 5U interval

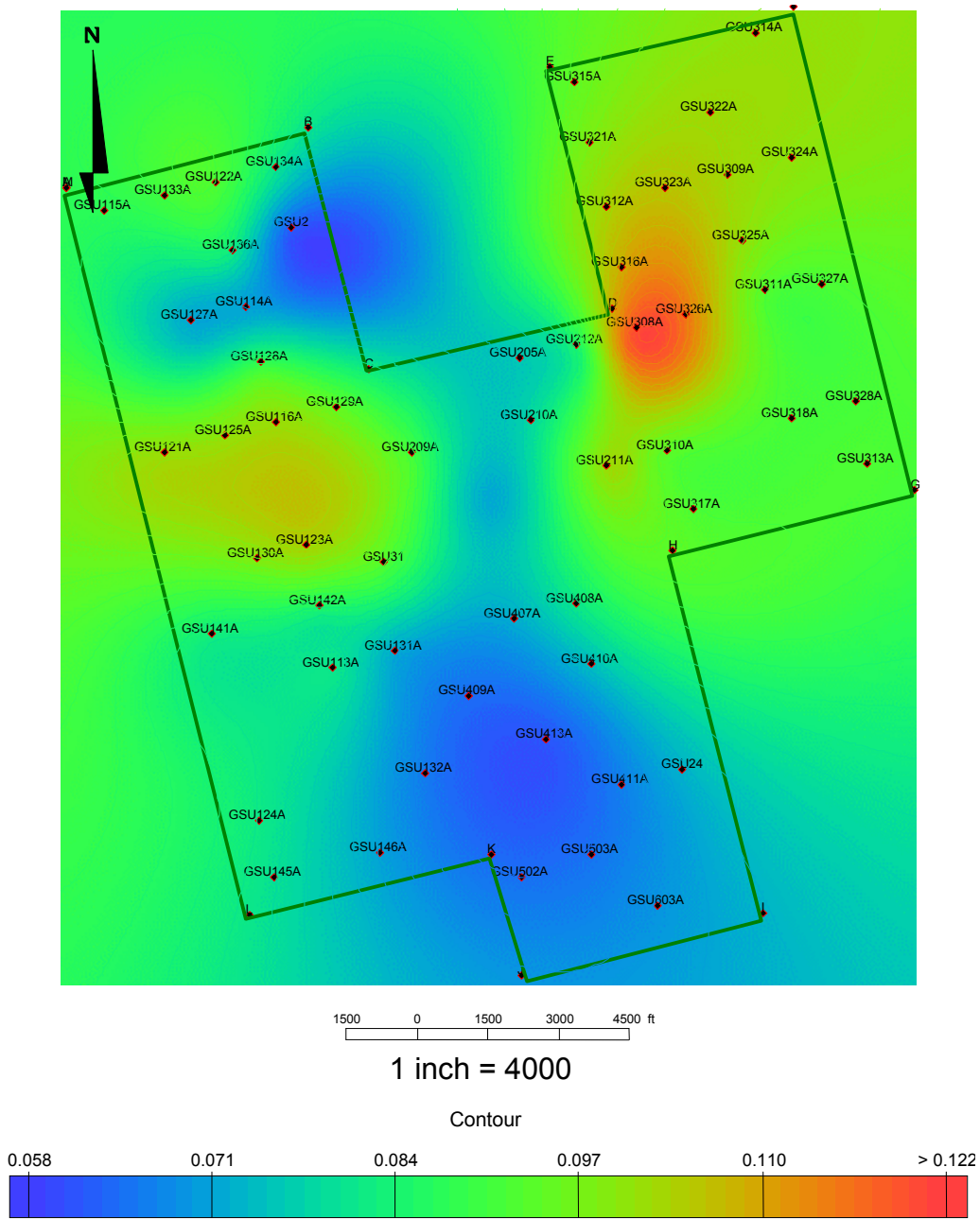


Fig. 1.50 – Porosity Map of 1U interval

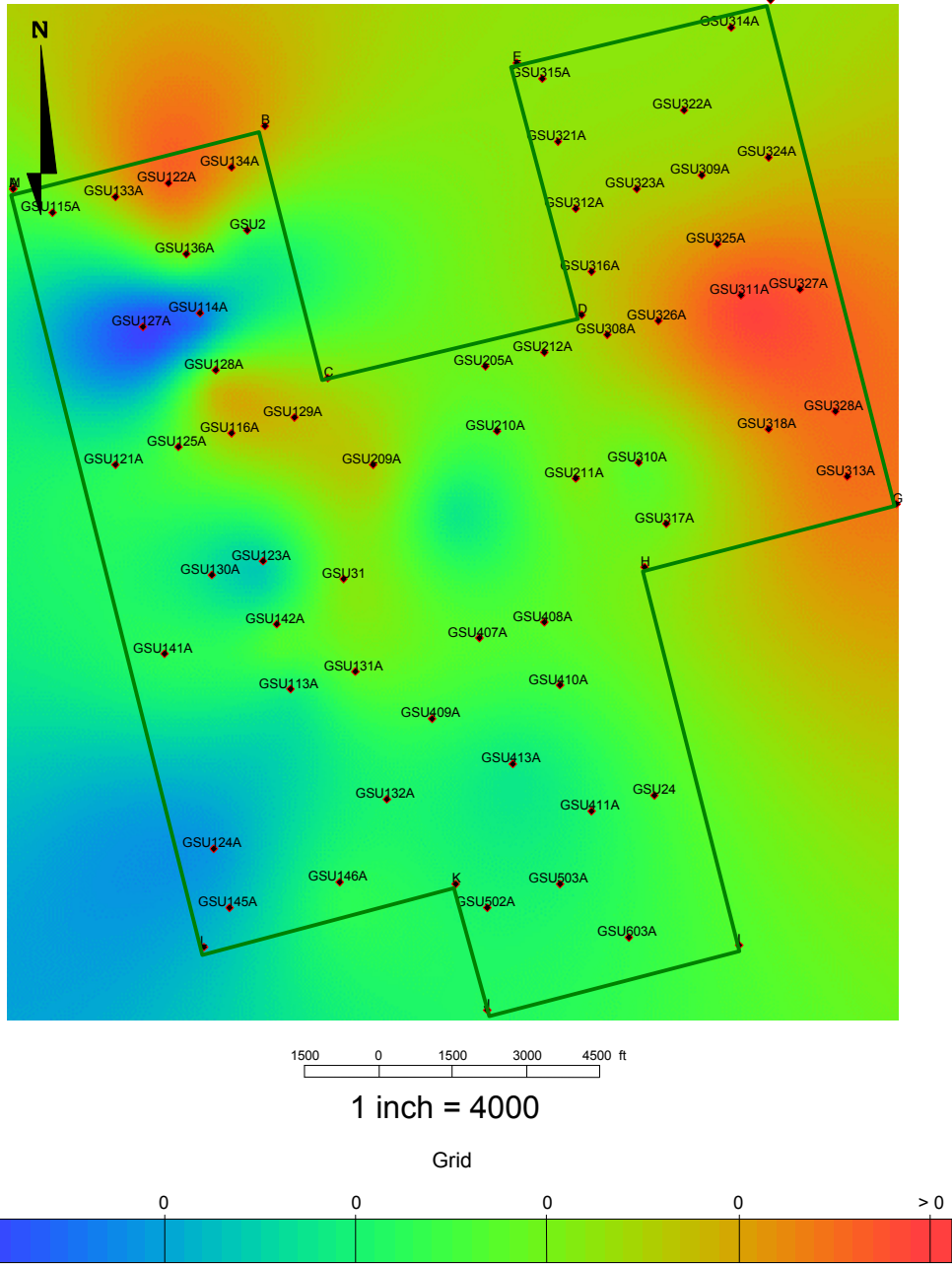


Fig. 1.51 – Porosity Map of 5U interval

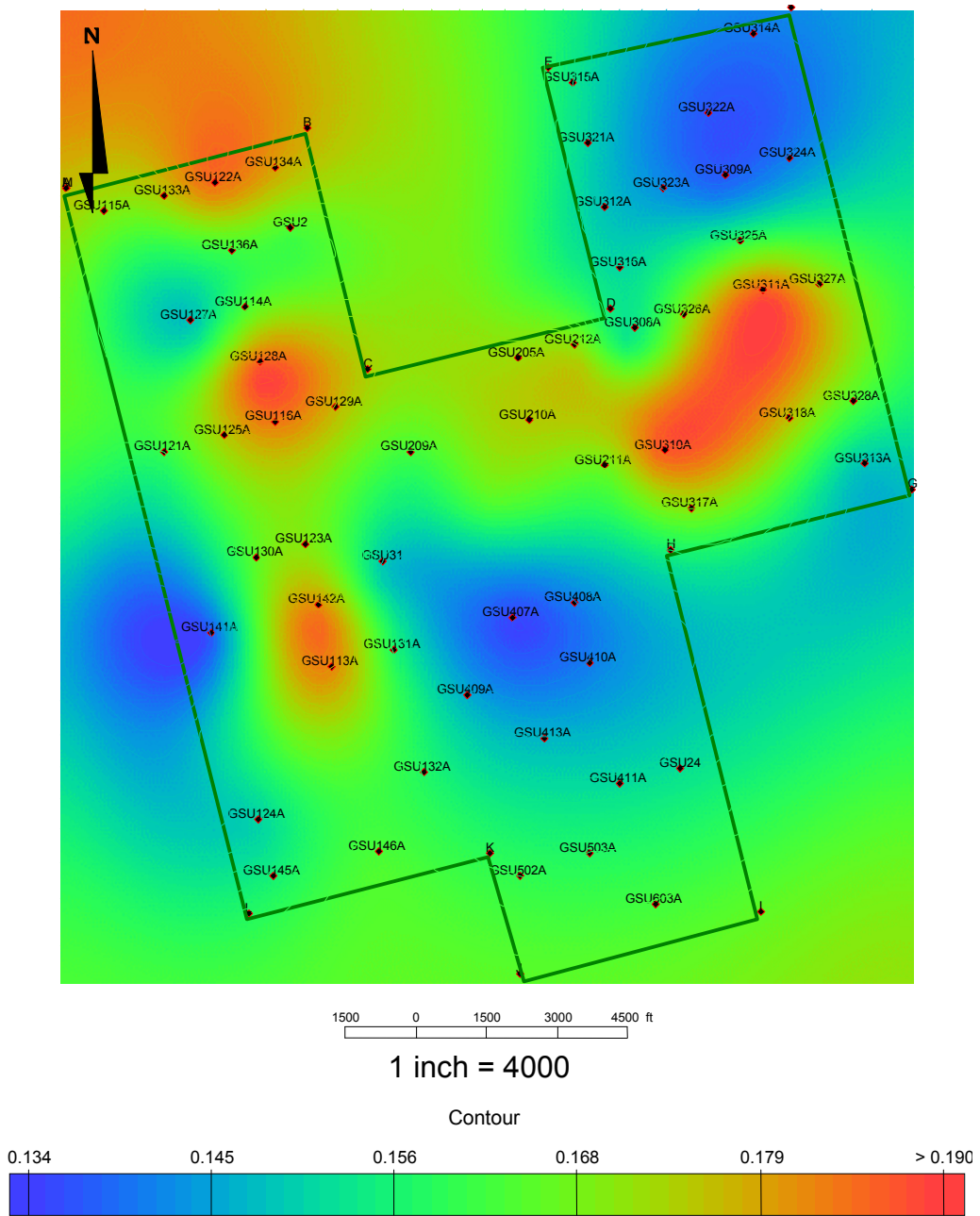


Fig. 1.52 – Permeability Map of 1U interval

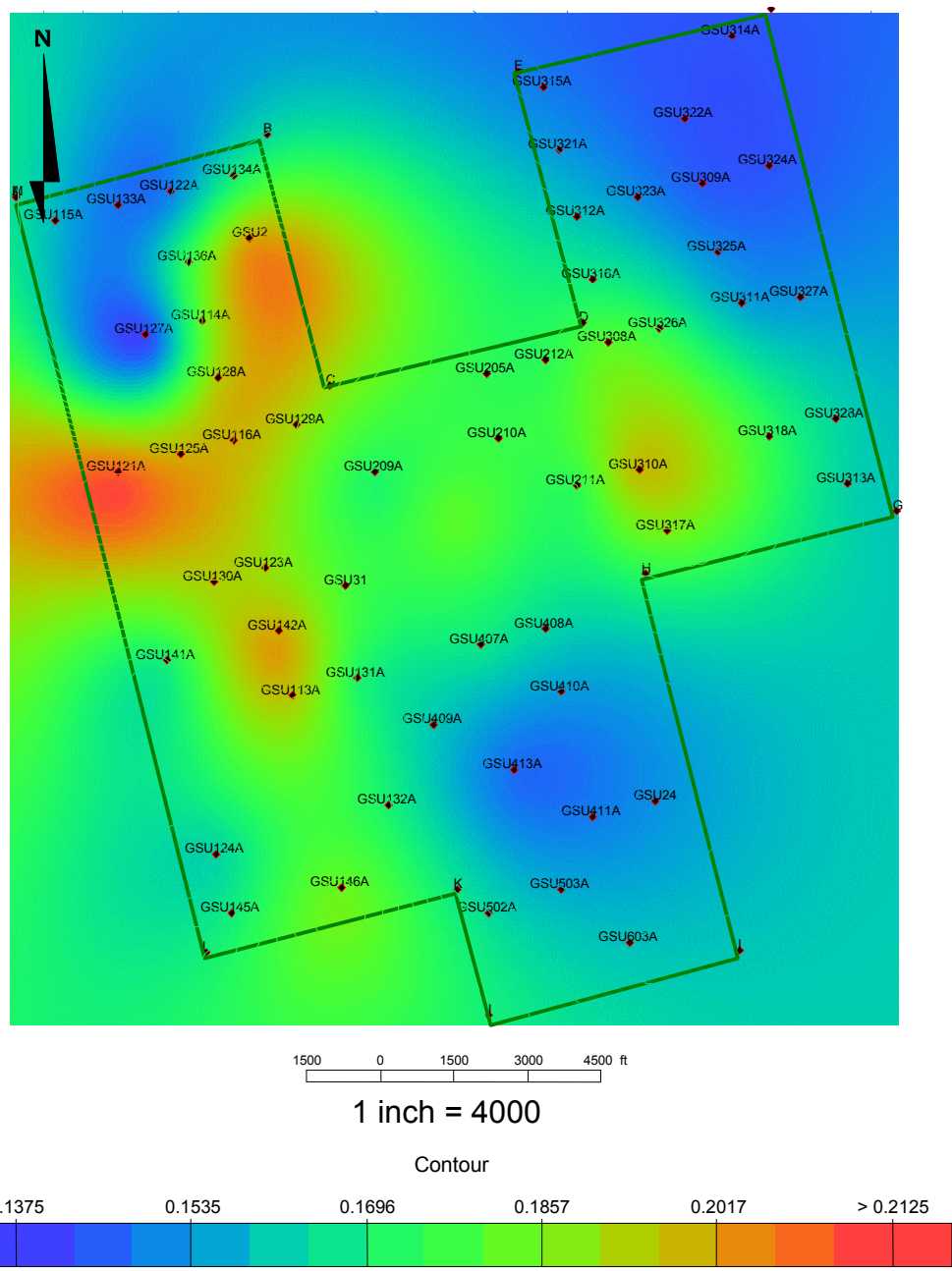


Fig. 1.53 – Permeability Map of 5U interval

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II. GERMANIA SPRABERRY FIELD DEMONSTRATION STATUS

2.1 Introduction

The response of water injection was observed through each of production wells, located on-trend and off-trend from injection wells and analyzed through production database management developed using Oil Field Manager (OFM™) and Field Management Database Software (FMDS), software we developed for better managing, predicting and tracking the production for this area. In this period we continue our effort to make the software more general, robust and add more features. The development of this software is presented chapter 3 and the manual of the software is listed in Appendix-A.

In our previous results, we forecast the incremental oil recovery due to waterflood in other pilot area, which was applied to the Germania Spraberry Unit (GSU,) and requested management approval of this project (Schechter *et al.*)¹ The project was approved and we proposed the new location of injectors based on the existing injectors' location and response of previous injectors to producers. The old pilot can be seen in Fig. 2.1. We also identified the wells that have casing leaks using OFM based on the plot of water-oil ratio. The new pilot consists of six injectors, three wells converted to water injection (17, 407A and 410A,) two wells returned to water injection (11W and 22W) and a new injection well (214W) as shown in Fig. 2.2. The water injection began on Feb 3, 2003 with a constant rate of 270 BWPD of each well (Fig. 2.3.) The amount of water injected was determined based on Voidage Replacement Ratio (VRR). VRR is the ratio between injected reservoir volume and produced reservoir volume, which is expressed in the following equation:

$$VRR = \frac{B_w(I_w)}{B_o q_o + B_w q_w + q_o(GOR - R_s)B_g}$$

where :

- B_w = Water formation volume factor (STBW/BBL)
- B_o = Oil formation volume factor (STBO/BBL)
- B_g = Gas formation volume factor (SCF/BBL)
- I_w = Water injection rate (BBL/DAY)
- q_o = Oil production rate (BBL/DAY)
- q_w = Water production rate (BBL/DAY)
- GOR = Gas oil ratio (SCF/STB)
- R_s = Solution gas (SCF/STB)

In waterflooding practice, VRR is kept to be at one, in order to balance the amount of water injected and the amount of fluid produced. If the VRR is greater than 1, the reservoir is over-injected or vice versa. In the Germania unit, we maintained the VRR is equal to one as shown in Fig. 2.4

The total amount of water that has been injected, up to September 30, 2003, was about 370,000 BBLs (Fig. 2.5). If we compare this injection amount to ET O'Daniel, the wells located in the on-trend direction i.e. Brunson F-1 and C-2 have responded to water

injection (Fig. 2.6). We overlapped the ET O'Daniel map onto the Germania map (Fig. 2.7). The star symbols show the wells responded during water injection in the ET O'Daniel. Close to the star symbol in the O'Daniel map, we found that well #308A and 309A responded to water injection. Production GSU well 308A has increased from average 10 bopd to 19 bopd (Fig. 2.8.) The water production from this well shows a similar response to oil production rate, which indicates this well is strongly dependent on water injection. Meanwhile, well 309A produced at a high water rate and no increase in its oil rate (Fig. 2.9.) The response of observation production wells is summarized in Fig. 2.10.

The difference in run time may cause difficulty in analyzing the waterflood responses. The run time of almost all observation wells are plotted in Fig. 2.11. We found that several wells produced high water rate (408A, 409A, 206A and 406A). Three of these wells were closed later on. We also found that the run time has an influence to total fluid produced as shown in Fig. 2.12.

We can see that the production wells located on trend direction start responding to water injection. The production wells located close to injection wells produced high water production with no oil production as expected. Three of four production wells, 409A, 406A and 403A that produced high water production were closed in order to reduce the water breakthrough and allow water to spread further.

Individual wells were observed, as well as the group of the wells in each track. We observed the water injection response in the track 2, 3 and 4 daily bases. Large increases in oil rate can be observed from the GSU tracts due to the new production wells (Figs. 2.13 – 2.15.) Four new production wells were completed in this area as shown in Fig. 2.16. All four wells have high average of oil and water rates as shown in Fig. 2.17. The increase in tract 2 production was due to well #213A. Well #213A produced at peak rate of 229 bopd at initial production on 9/24/03 (Fig. 2.18.) Current production is steady to 123 bopd. The increase in tract 3 production was due to well #331A. Well # 331A was completed on 10/5/03 with initial rate of 47.5 bopd and the production increased to 87 bopd on 10/16/03 (Fig. 2.19). The increase in tract 4 production was due to well #413A. Well #413A produced at peak rate of 87 bopd at initial production on 9/24/03. Current production (10/17/03) is 27.1 bopd (Fig. 2.20). We can see that a new well in tract 3, which is located in the on-trend direction, keeps increasing after completion. Meanwhile, the new wells in tracts 2 and 4 (located in off-trend direction) originally had high initial production, but saw their production decrease dramatically after some time.

2.2 Summary

1. The wells start responded to waterflood. We can see definite response in the new wells in tract 3.
2. The new production wells and inconsistent run time make it difficult to analyze waterflood responses.

2.3 References

1. Schechter *et al.*: "Preferred Waterflood Management Practices for the Spraberry Trend Area," Semi-Annual Report (DOE Contract No.: DE-FC26-01BC15274), Oct 2002 – March 2003.

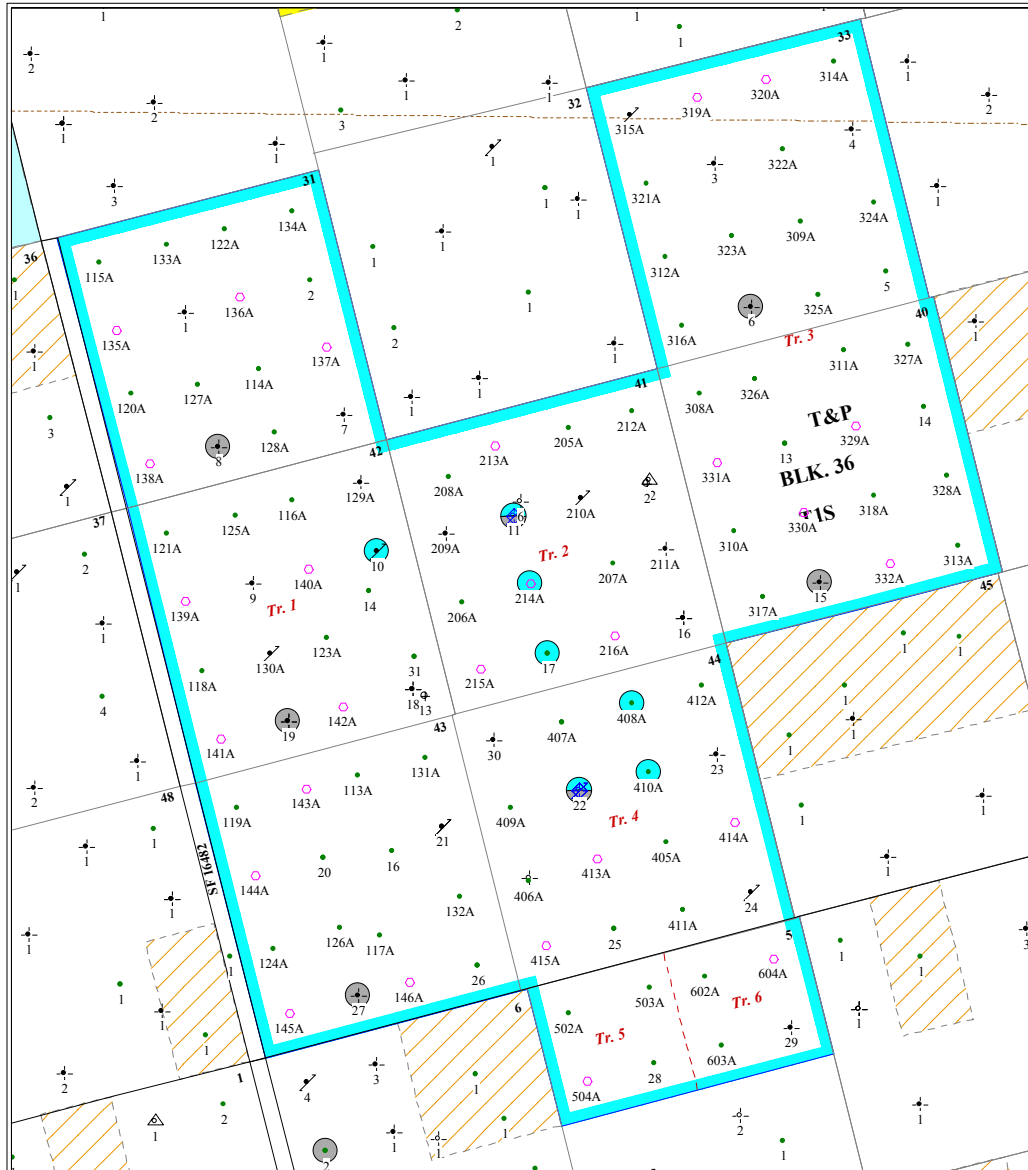


Fig. 2.1 – Location of old water injection wells in Germania Spraberry Unit

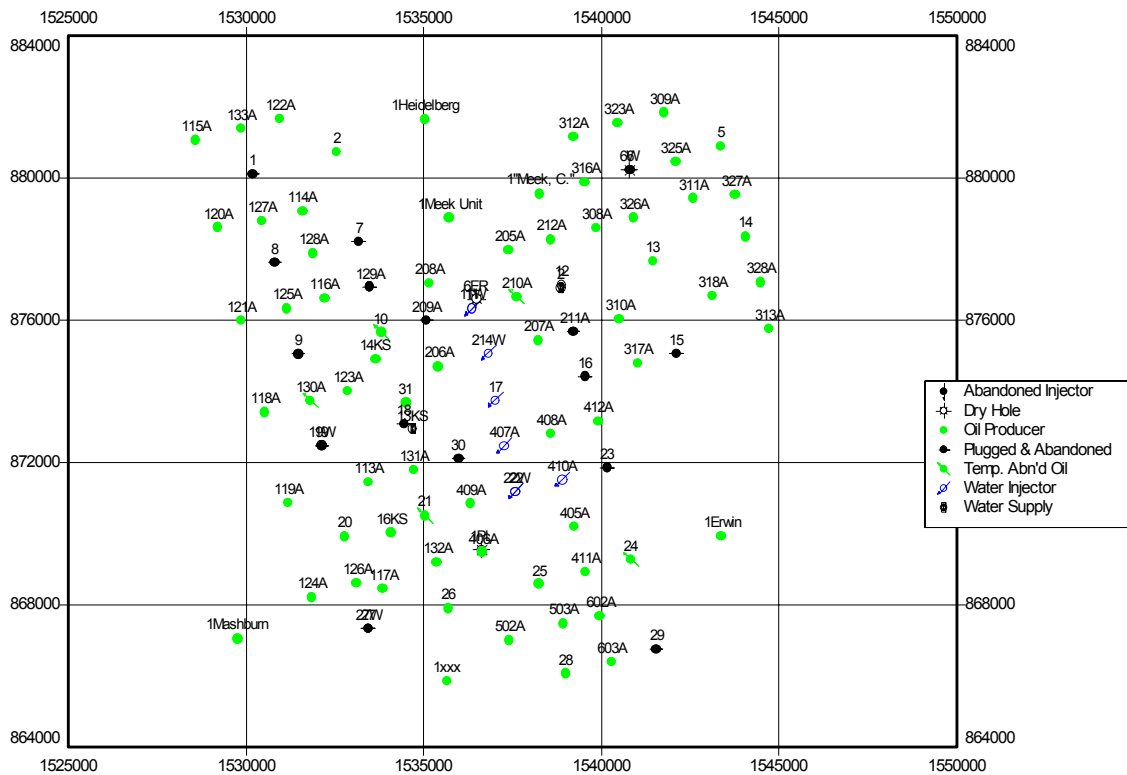


Fig. 2.2 – Location of new water injection wells in Germania Spraberry Unit

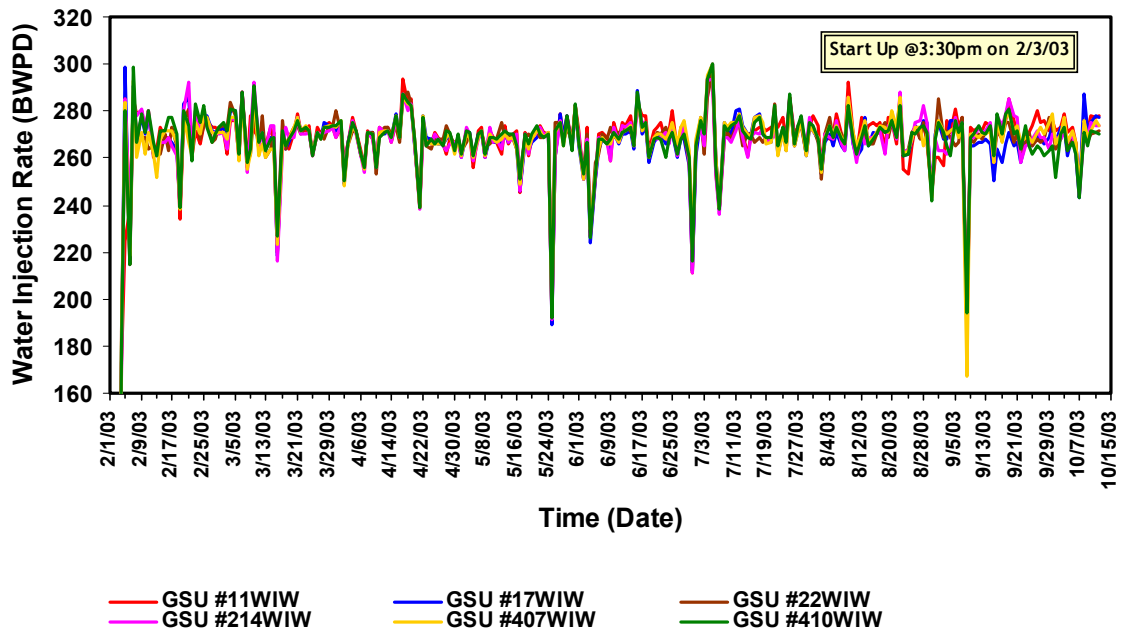


Fig. 2.3 – Water injection rate from six injectors

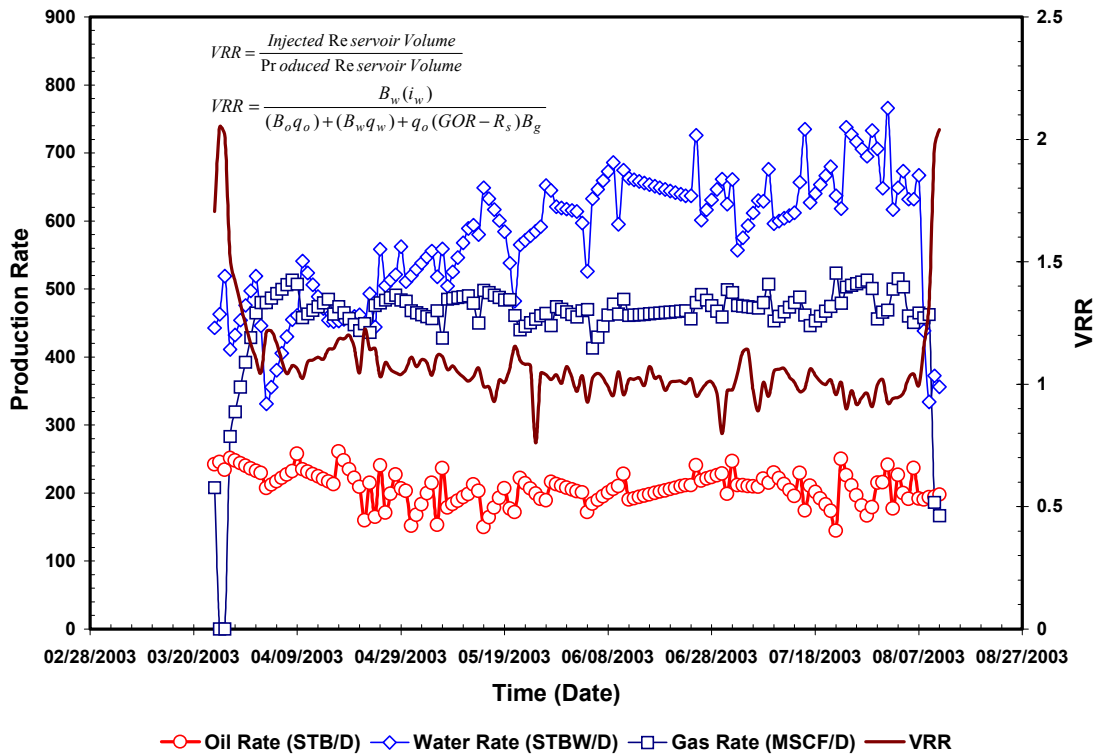


Fig. 2.4 – Voidage Replacement Ratio (VRR) of GSU production rate.

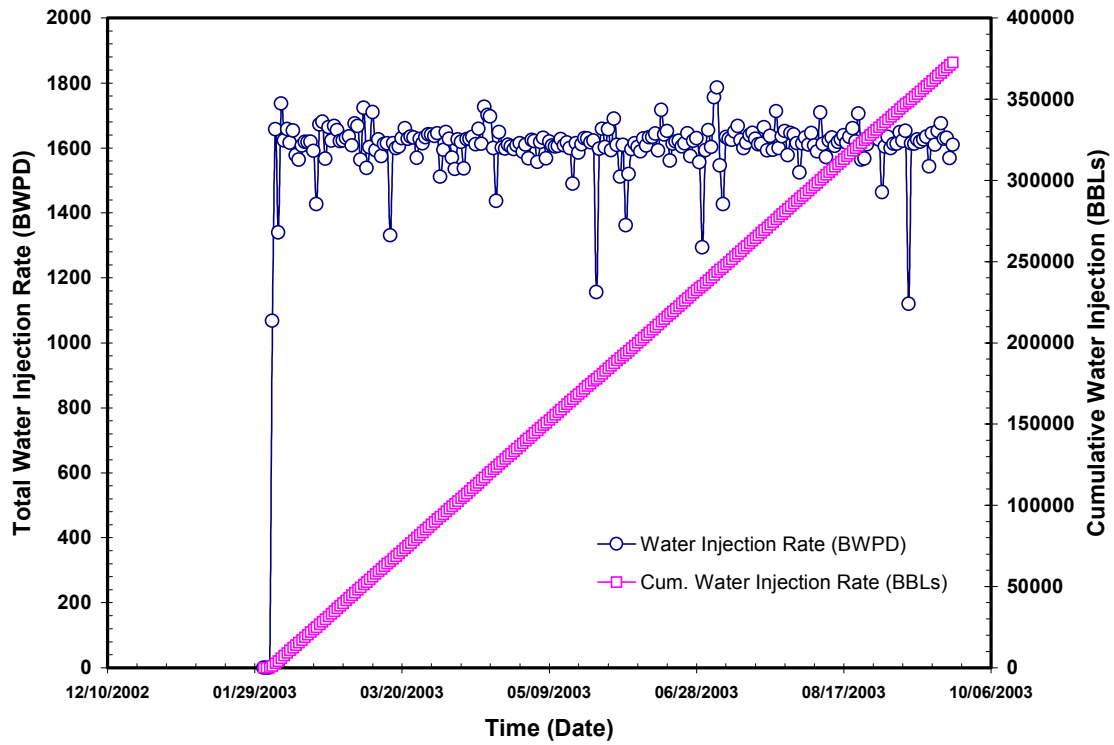


Fig. 2.5 – GSU water injection

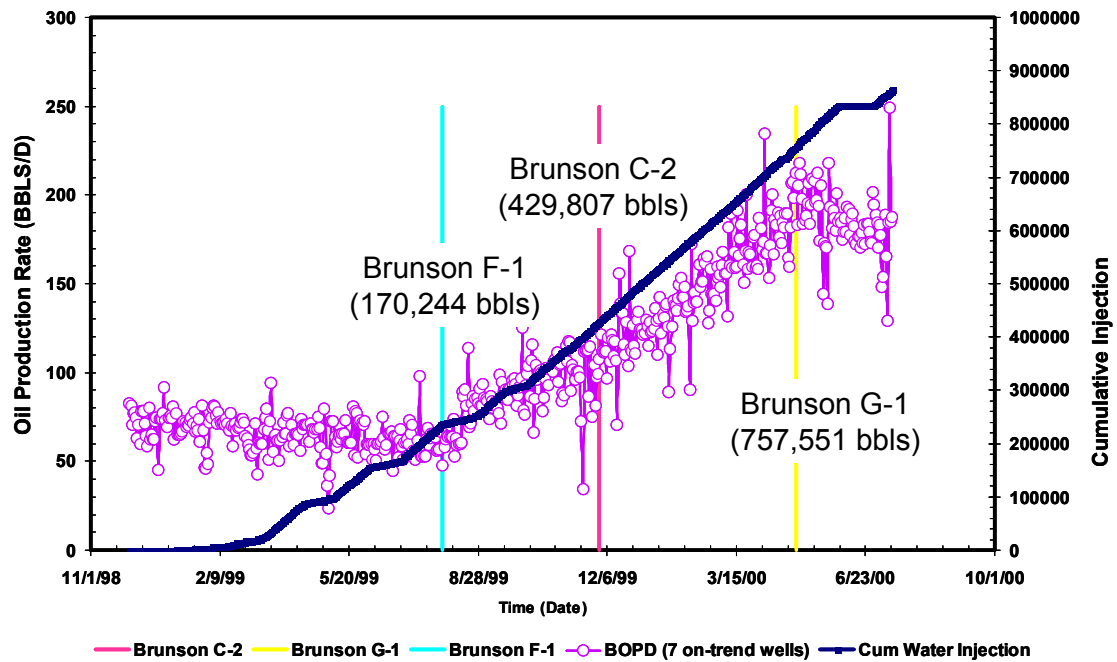


Fig. 2.6 – Volume of water injection until on-trend production wells start responding

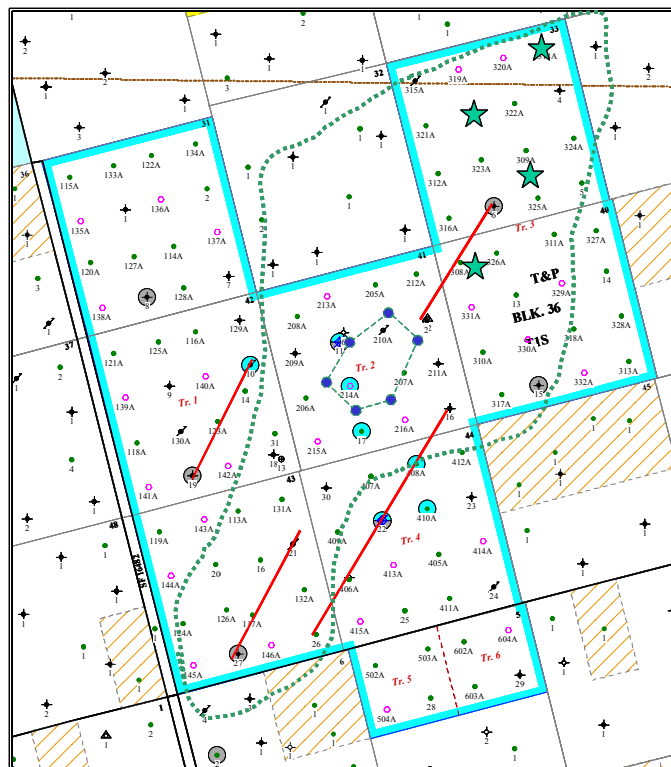


Fig. 2.7 –Waterflood response map from ET Odaniel is overlapped to GSU Pilot

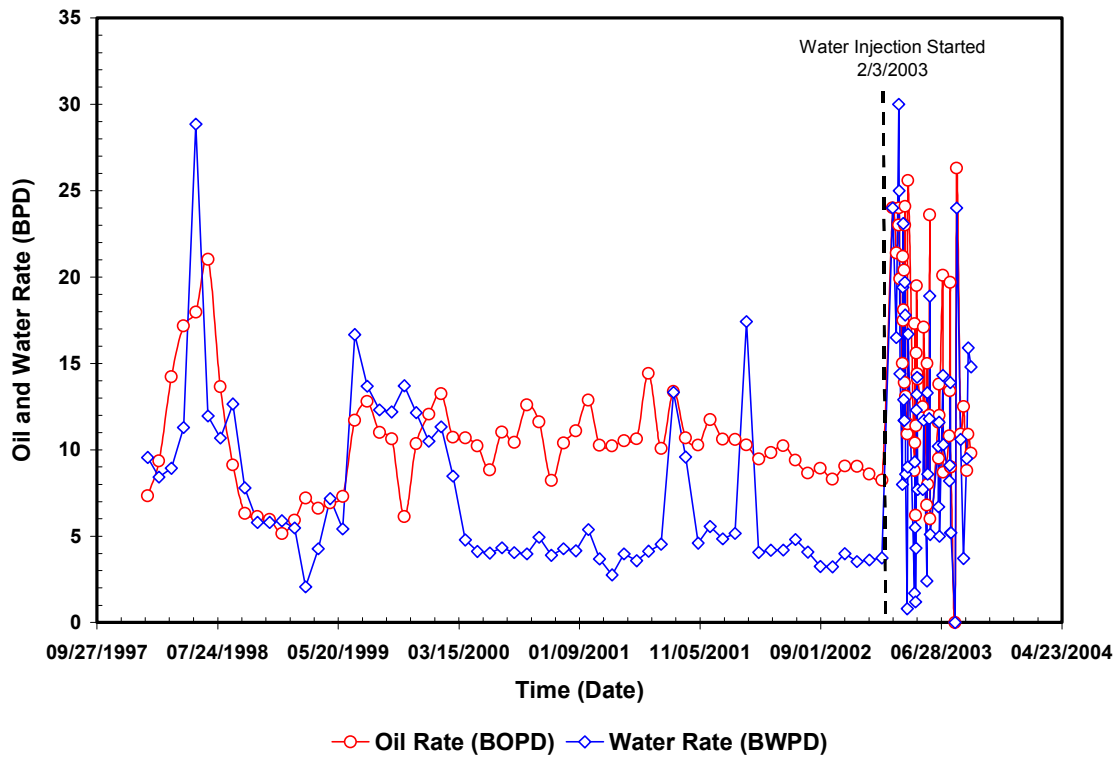


Fig. 2.8 – Oil and water production rate well #308A

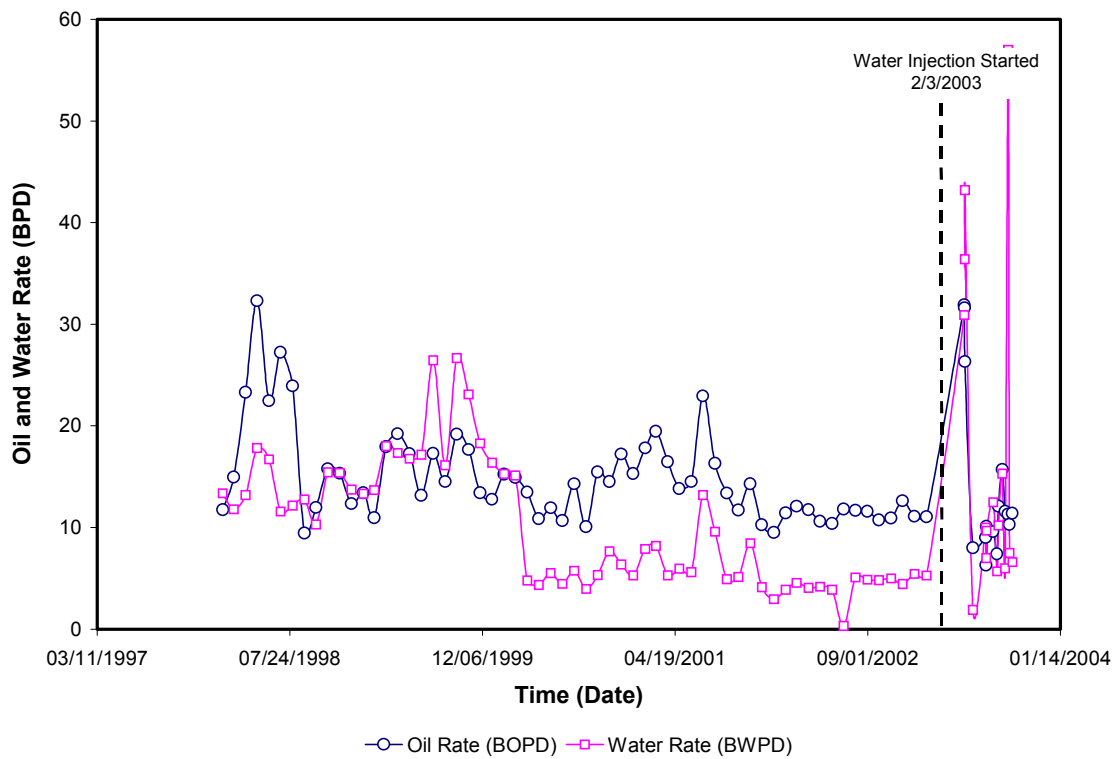


Fig. 2.9 – Oil and water production rate well #309A

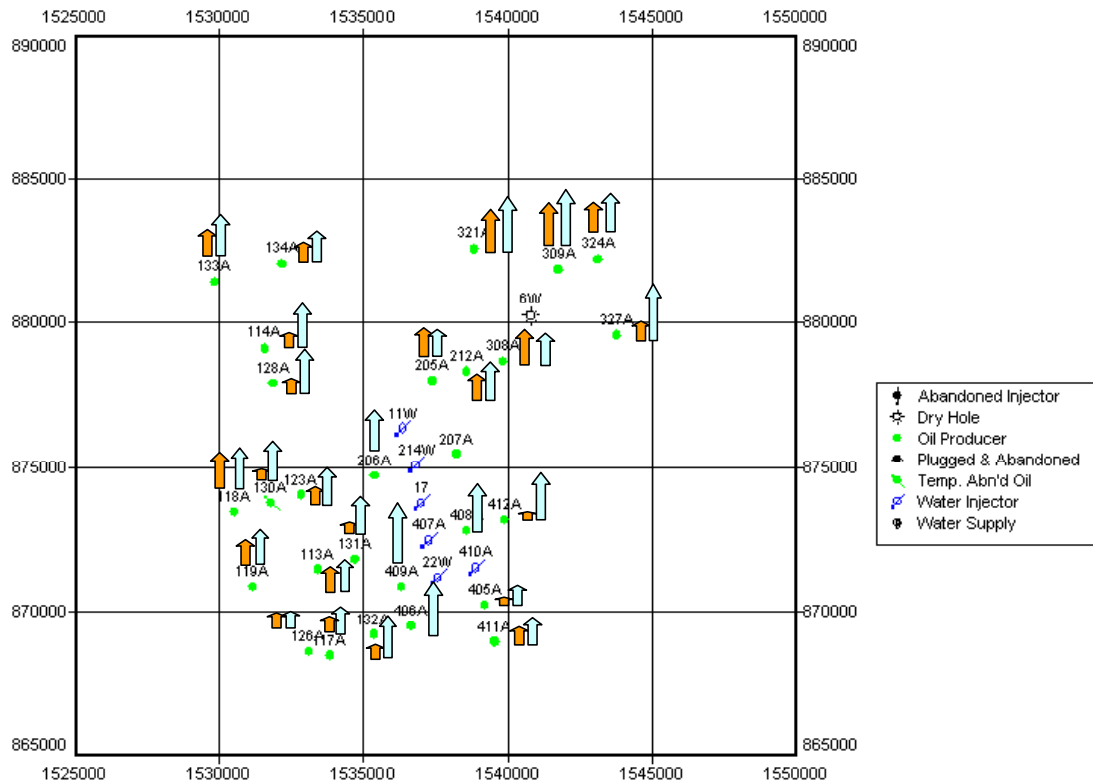


Fig. 2.10 – Response of production wells on water injection as of July 15, 2003

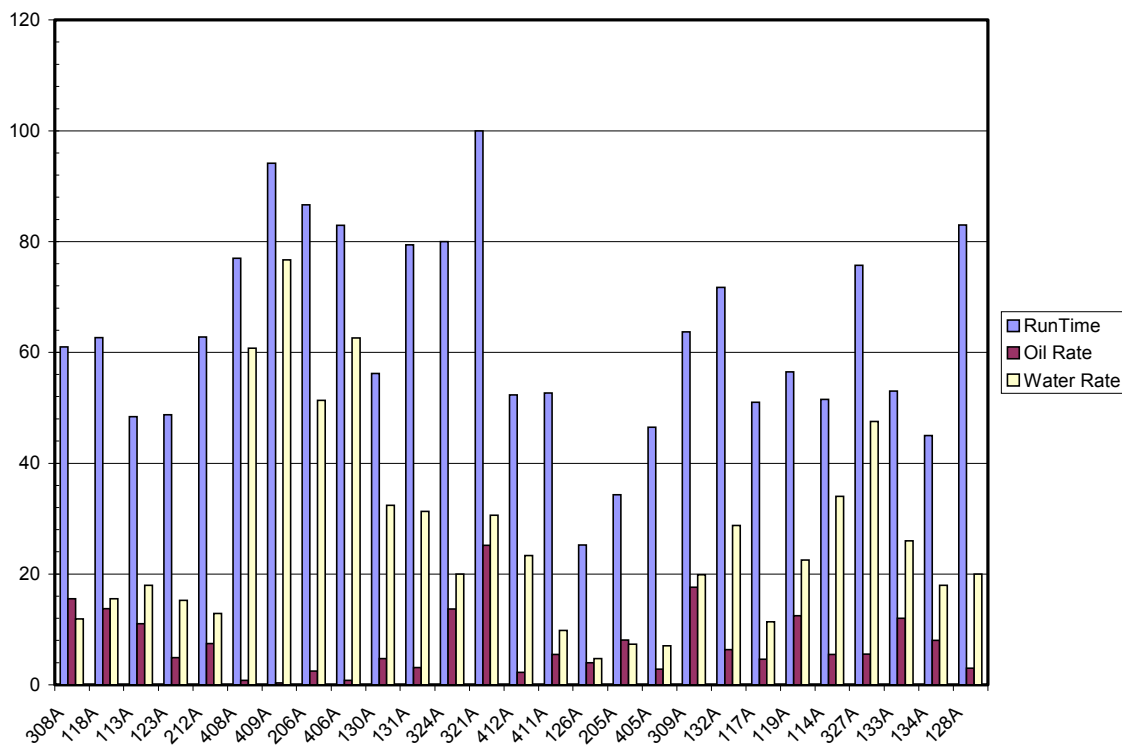


Fig. 2.11 – Run time, oil rate and water rate averages as of July 15, 2003

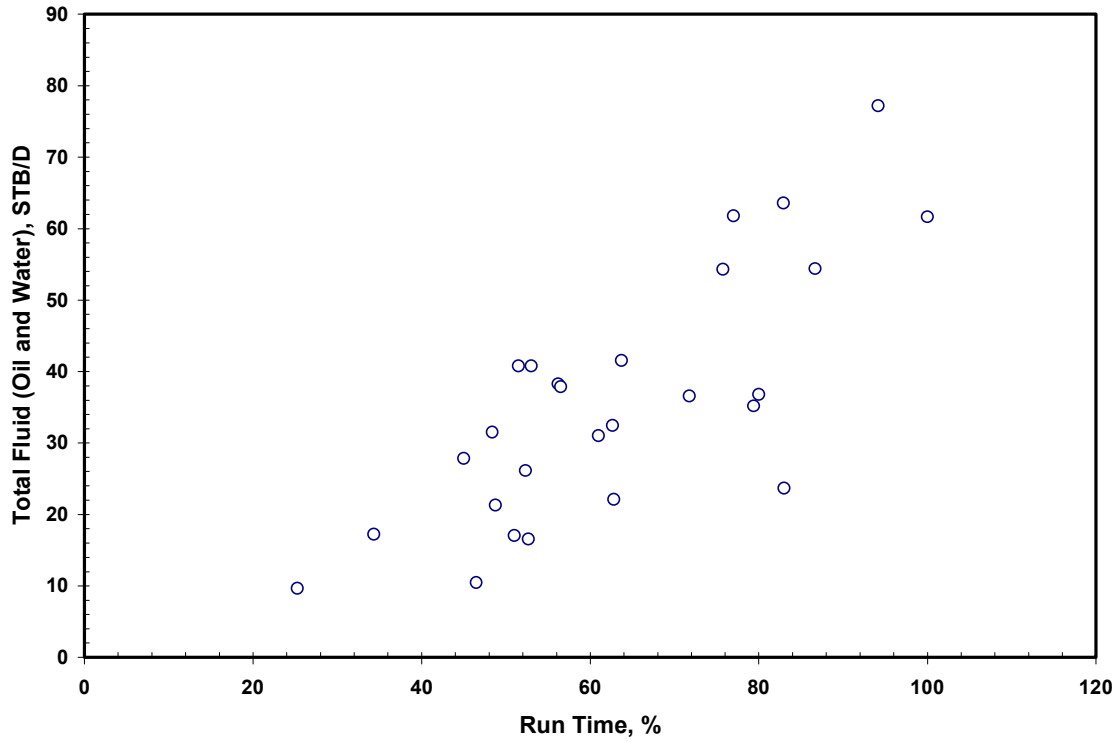


Fig. 2.12 – Run time vs total fluid rate

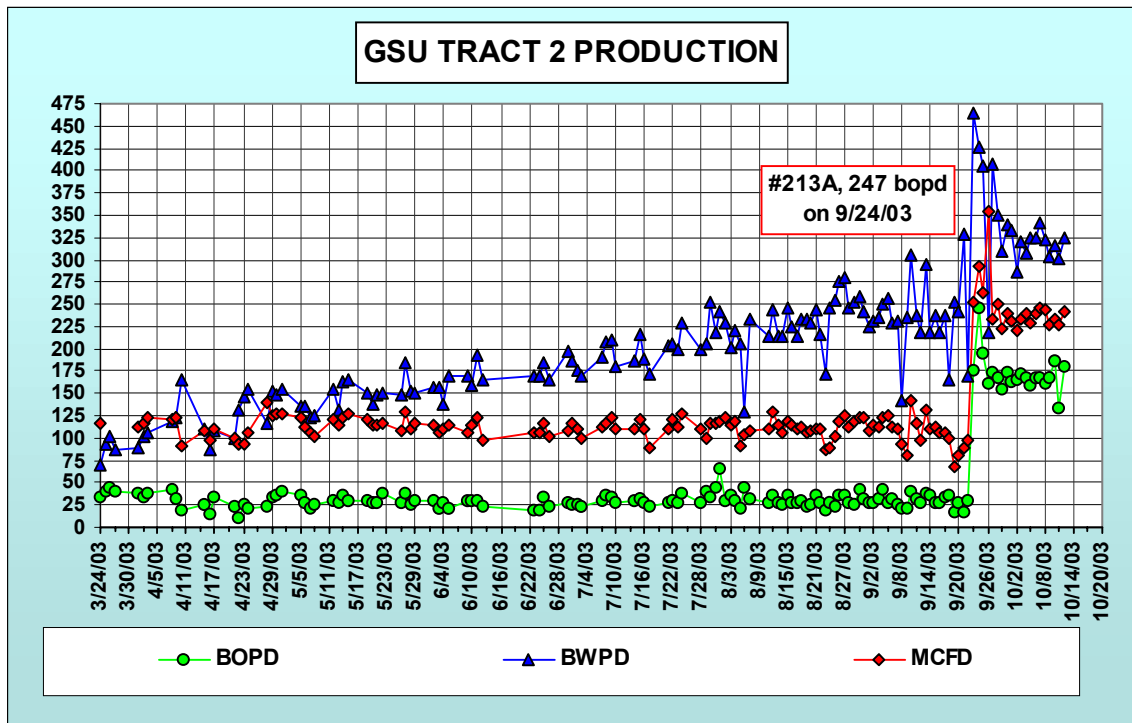


Fig. 2.13 – GSU Tract 2 production

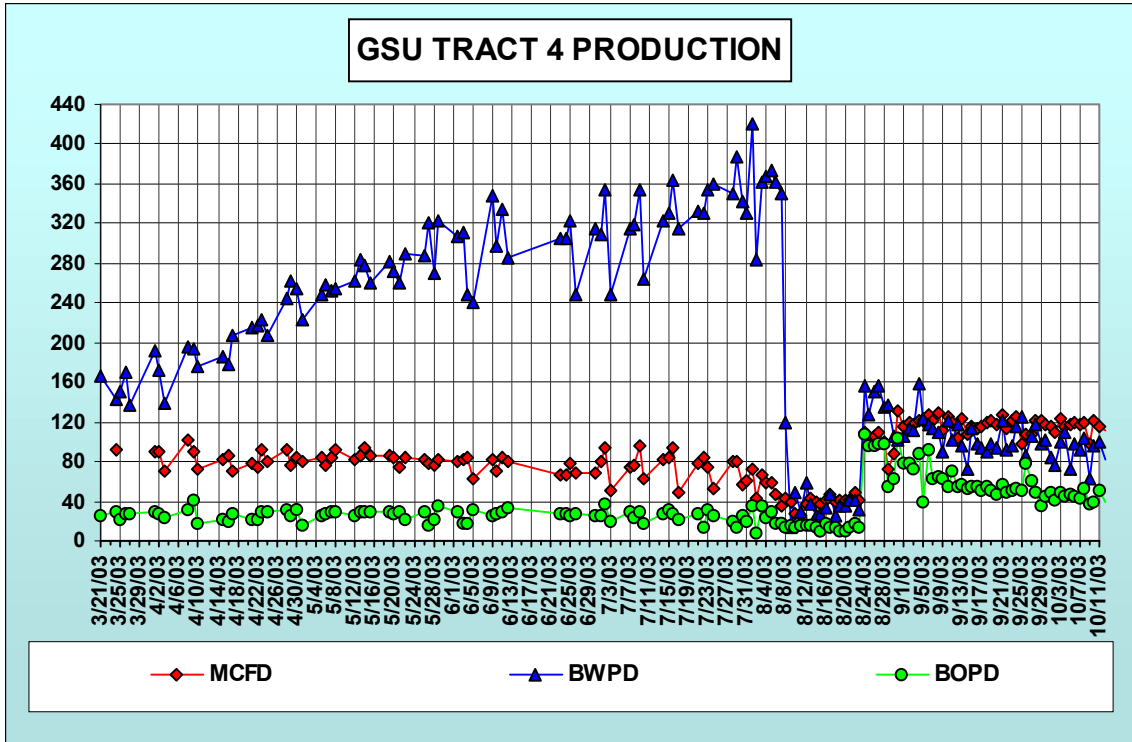


Fig. 2.14 – GSU Tract 4 production

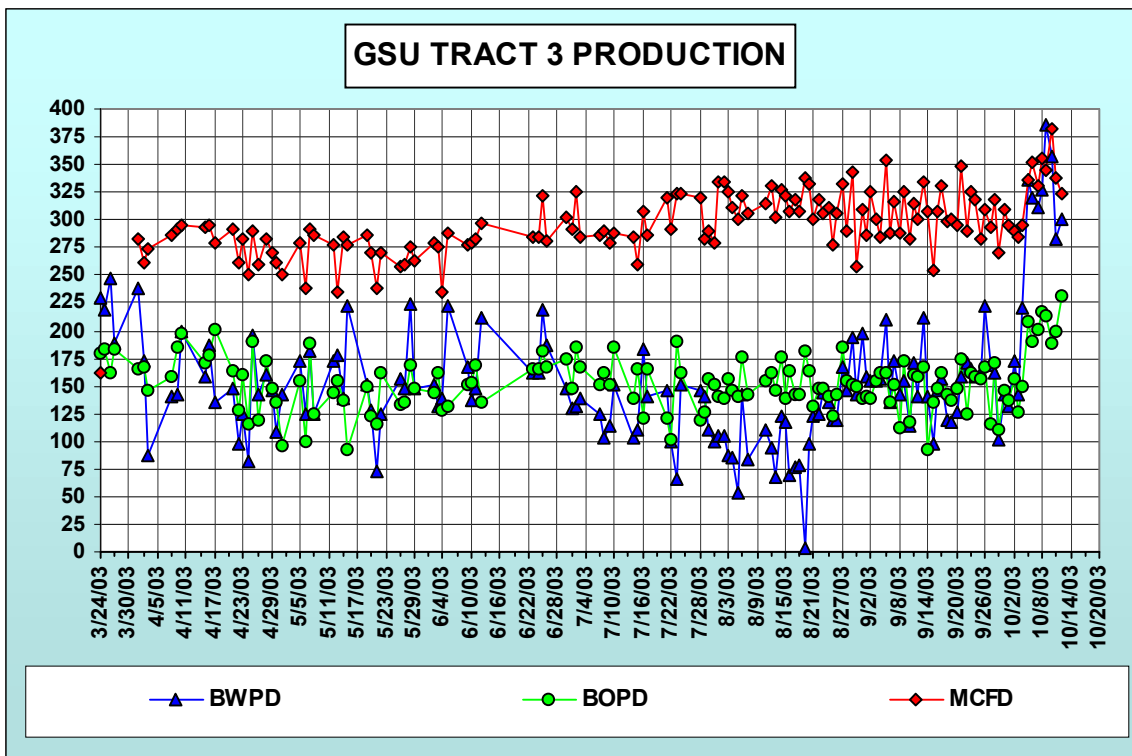


Fig. 2.15 – GSU Tract 3 production

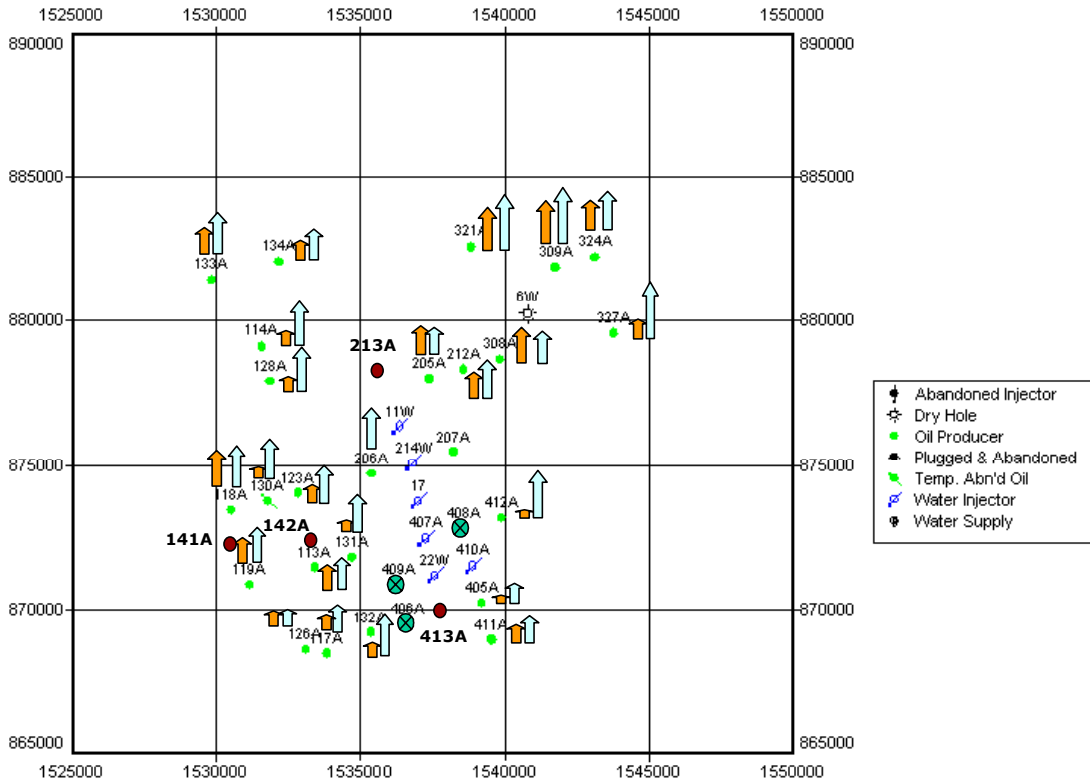


Fig. 2.16 – Response of production wells on water injection as of Sept 30, 2003

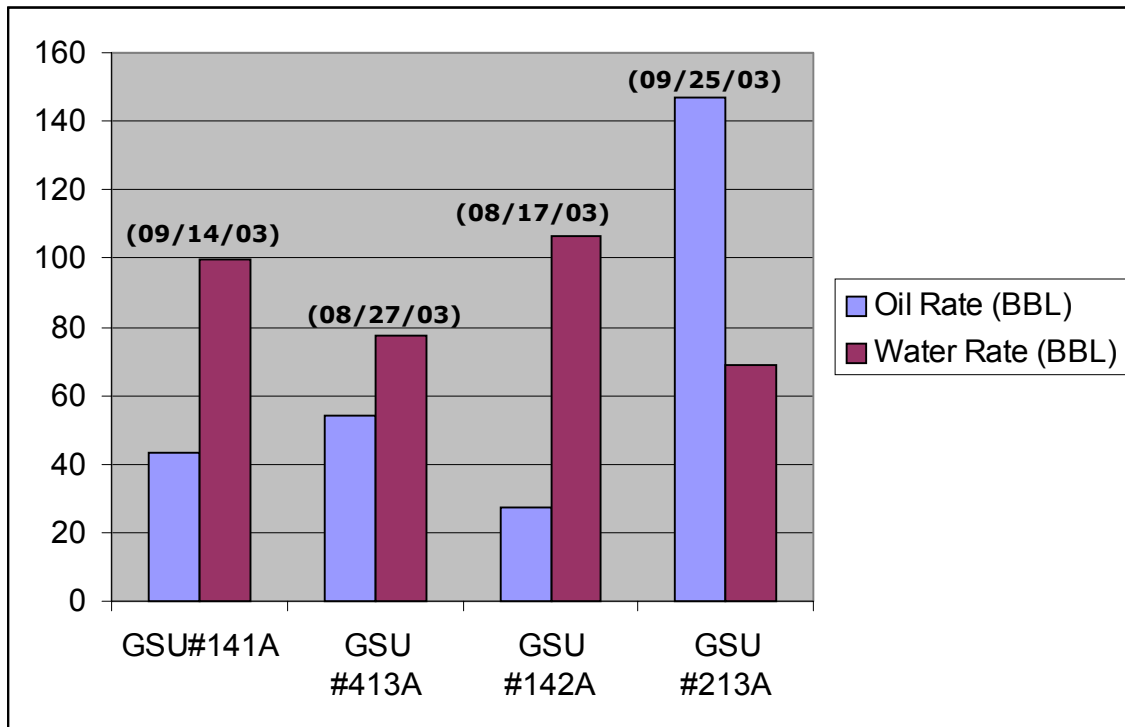


Fig. 2.17 – Average of oil and water rates of new wells as of Sep 30, 2003

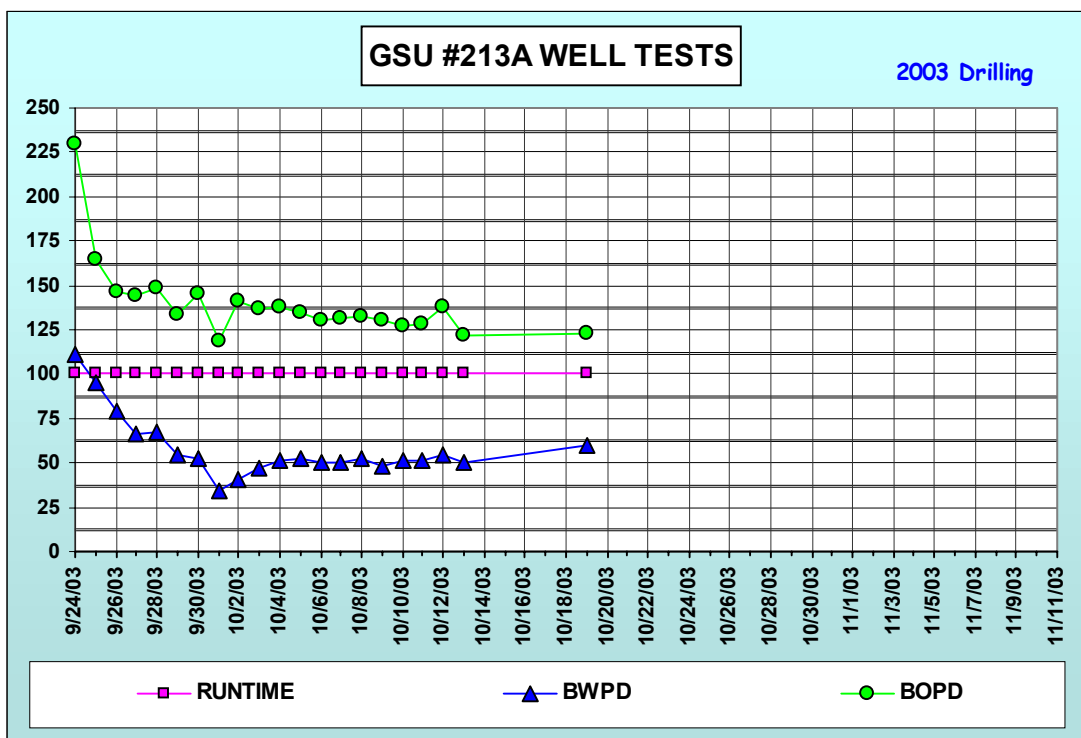


Fig. 2.18 – New well in Tract 2 (#213A) shows decreasing production after high initial production rate.

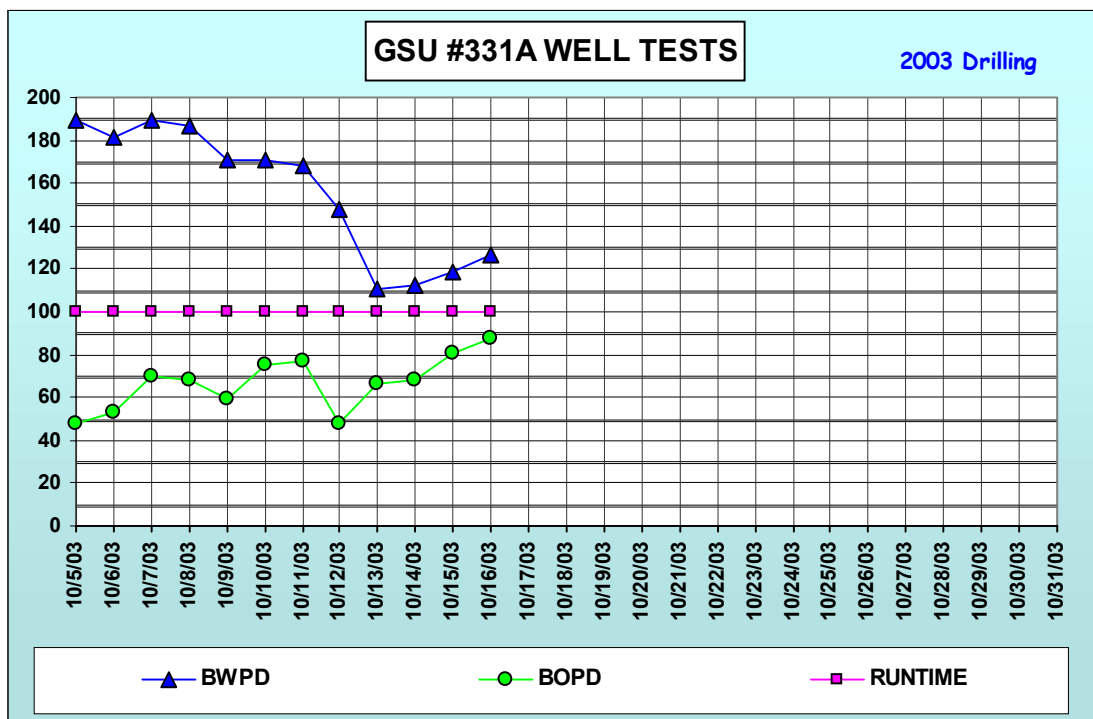


Fig. 2.19 – New well in Tract 3 (#331A) shows increasing production after the completion.

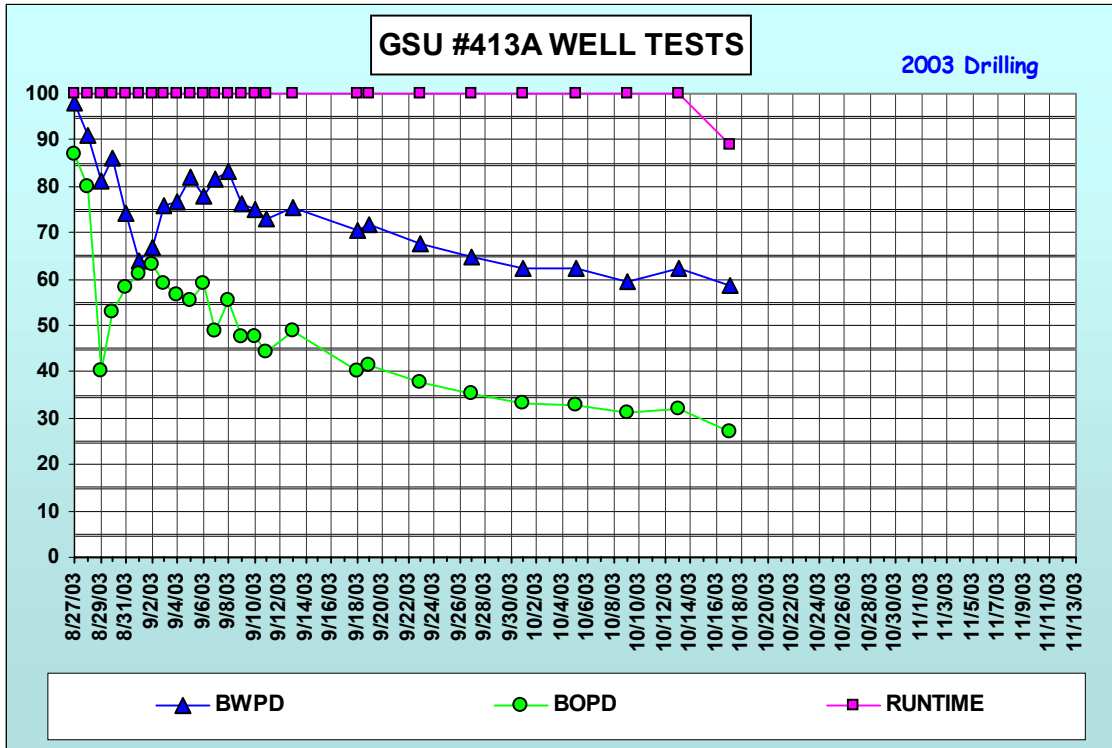


Fig. 2.20 – New well in Tract 4 (#413A) shows decreasing production after a high initial production rate.

III. DEVELOPMENT OF RESERVOIR MANAGEMENT DATABASE SOFTWARE

3.1 Introduction

Properly managing a reservoir that is so large and communicates, via the fractures, over great distances, poses a complicated technological and data management constraint. This problem acts as a deterrent for waterflood operations in Spraberry reservoirs. Reservoir engineering, by definition, requires precise injection, production and pressure data. Acquisition and control of this data has always been a constraint to providing the optimum method for water injection. The result is large volumes of oil that could have been recovered via water injection remain untapped. We believe by proper data acquisition and precise reservoir engineering techniques, any lack of confidence in waterflooding can be overcome.

In this report period, even though we are still using Oil Field Manager (OFM™) as our production database system, we continue developing our own database system to perform a better analysis and to develop software that is more users friendly. In our last report, we presented our database for specific Spraberry field only. In the current version, we develop the software for general purpose, so it can be used in any other field. This database software is written using a visual basic-object oriented programming language. It has the capability to perform similar tasks as the OFM database system such as decline curve analysis, material balances, bubble map plot and in addition it has more unique features in grouping the wells, performing decline curve analysis for well by well and a group of wells, displaying the graph in x-y plot, 2D and 3D map, and much more.

This program would be applicable for any type of reservoir. The recent progress is intended to show the use of this program for managing the data in the Germania Unit. Figure 3.1 shows the front page of the database software. The production and injection input data format follows the TOW data format for an easy access updating of the production data. Figure 3.2 shows the result of uploading the well location, well information, and production/injection data. Once we have uploaded the well data, we can zoom-in and zoom-out the picture to find specific information on a certain well in the cluster location (Fig. 3.3). The zoom-in result can be seen in Fig. 3.4. By pointing the cursor to a certain well, the menu bar in the right hand side shows some information on the selected well. Figure 3.4 shows the menu bars, File, Tool, Window and Help menus. File menu consists New Project, Open Project, Save Project, Save As Project and Exit menus. Tool menu consists Create Group, Load Group File, Interpolation options and Chart Container. Windows menu consists of Field Map, Data and Graph Viewer, Bubble Map, Decline Curve Analysis and Gas Material Balances and Help menu consists of Contents, Product Support, System Information and About menus. Figures 3.5 and 3.6 show example of the tabulated production history and oil production graph of well 207A and we can perform decline analysis with a user-defined range. There are three options for decline analysis: exponential, harmonic and hyperbolic declines. The program also allows user to select the best-fit option automatically based on extended Spivey algorithm

(1986). We can also to deselect some data points that may be excluded of finding the decline trend. The example of decline curve analysis using hyperbolic option is presented in Fig. 3.7.

There are many other features or applications of this software such as bubble map, isobaric map, PVT application, Material Balances that are presented in the Appendix of this report as the manual/tutorial.



Fig. 3.1—Front Page of Field Data Management Software

WELLID	NAME	Latitude	Longitude	X Coord	Y Coord	T. Depth	Status	Drilled by
76	14KS			1533644.3	874919	8050	OIL	
77	31			1534501.5	873684.9	4222	OIL	
78	16KS			1534080.2	870030.3	8115	OIL	
79	6ER			1536486.7	876605.3	8105	DRY	
80	205A			1537388.1	877975.8	8852	OIL	
81	407A			1537261.4	872457.9	8850	WINJ	
82	117A			1533847.4	868459.2	8850	OIL	
83	206A			1535407.6	874702.3	8850	OIL	
84	116A			1532204.9	876615.8	8875	OIL	
85	602A			1539955.5	867681	8025	OIL	
86	406A			1536651.2	869482.6	8850	OIL	
87	308A			1539847.4	878619.6	8850	OIL	
88	113A			1533430.1	871450.8	8860	OIL	
89	405A			1539220.8	870215.9	7950	OIL	
90	114A			1531587.7	879080.2	7943	OIL	
91	309A			1541755.5	881850.6	8070	OIL	
92	207A			1538231	875443	7950	OIL	
93	118A			1530526.7	873421.1	7986	OIL	
94	115A			1528586	881086.7	8051	OIL	

Fig. 3.2—Well Data Form

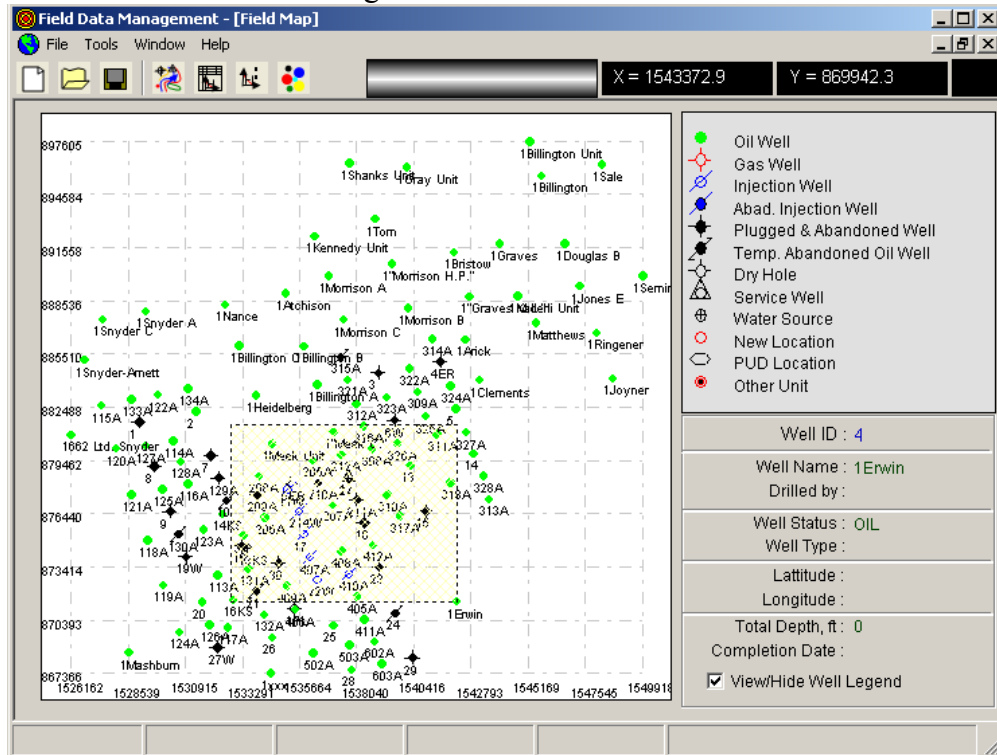


Fig. 3.3—Map of Germania Unit

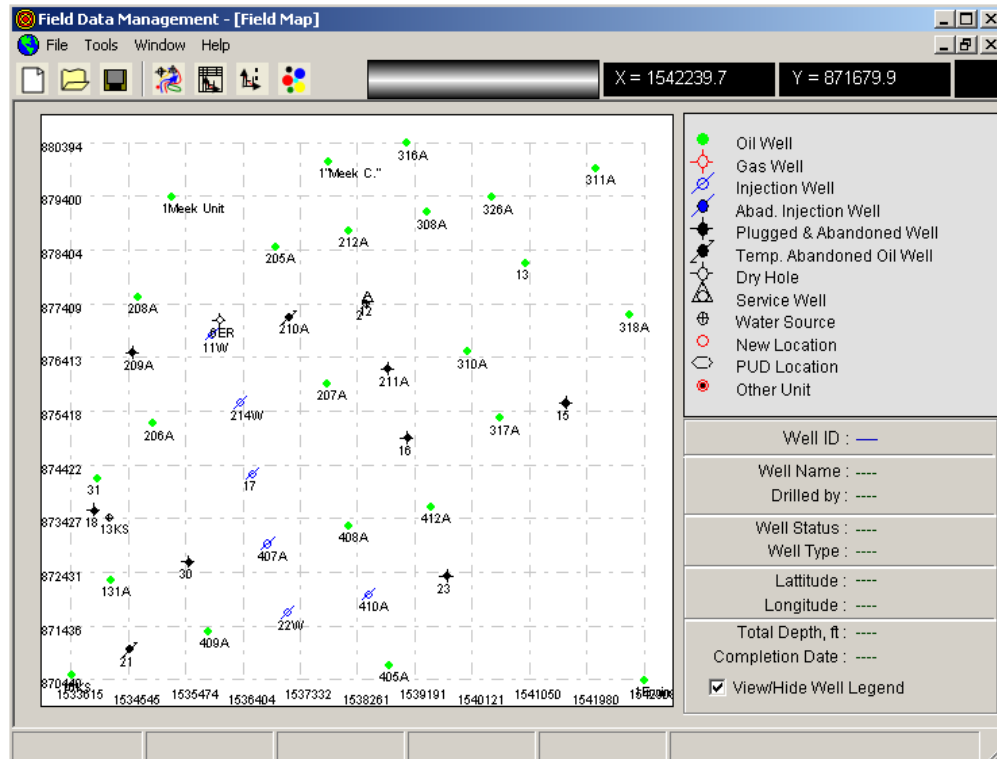


Fig.3.4—Zoom-in view of particular cluster

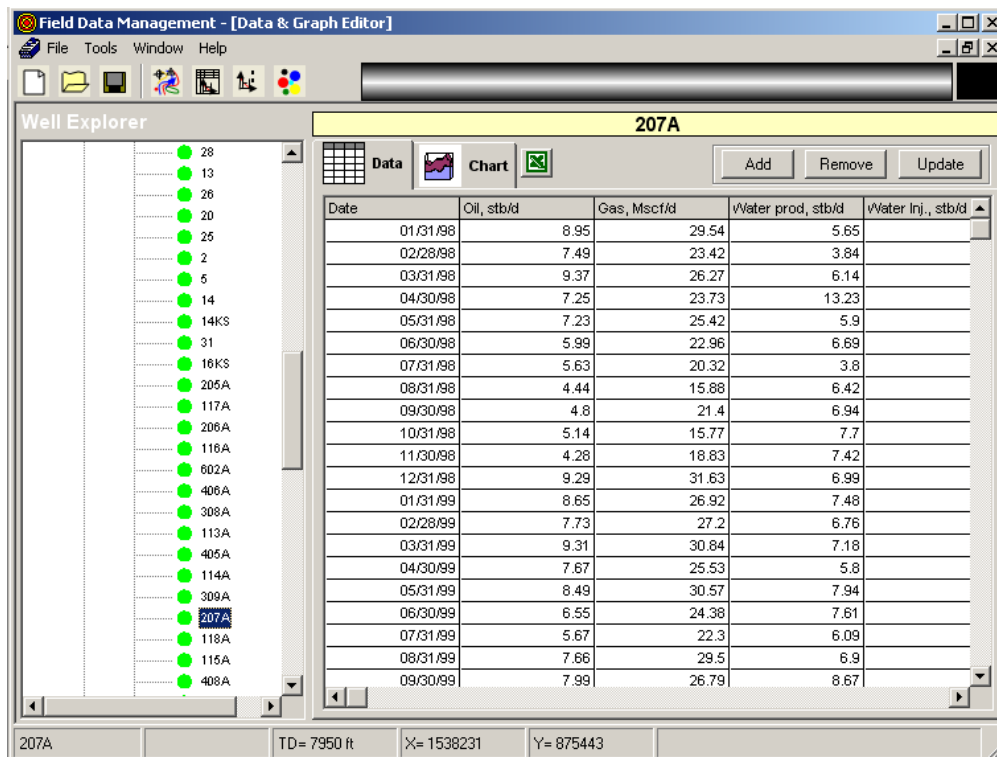


Fig. 3.5—Tabulated Production History Data of Well 207A

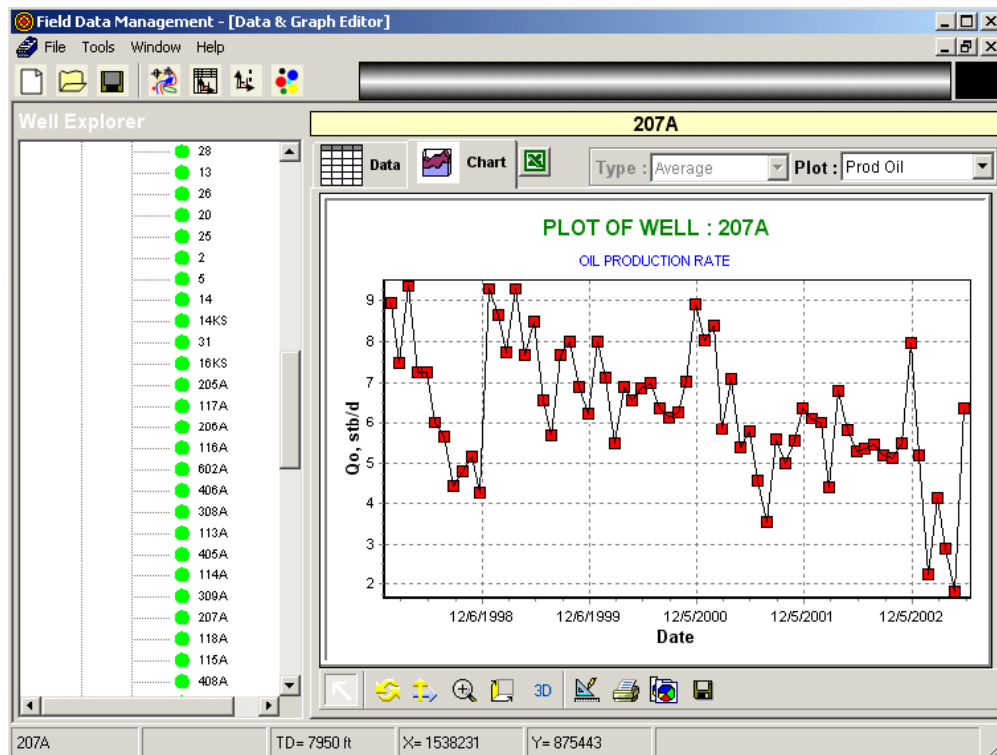


Fig. 3.6—Graph of Oil Production of Well 207A

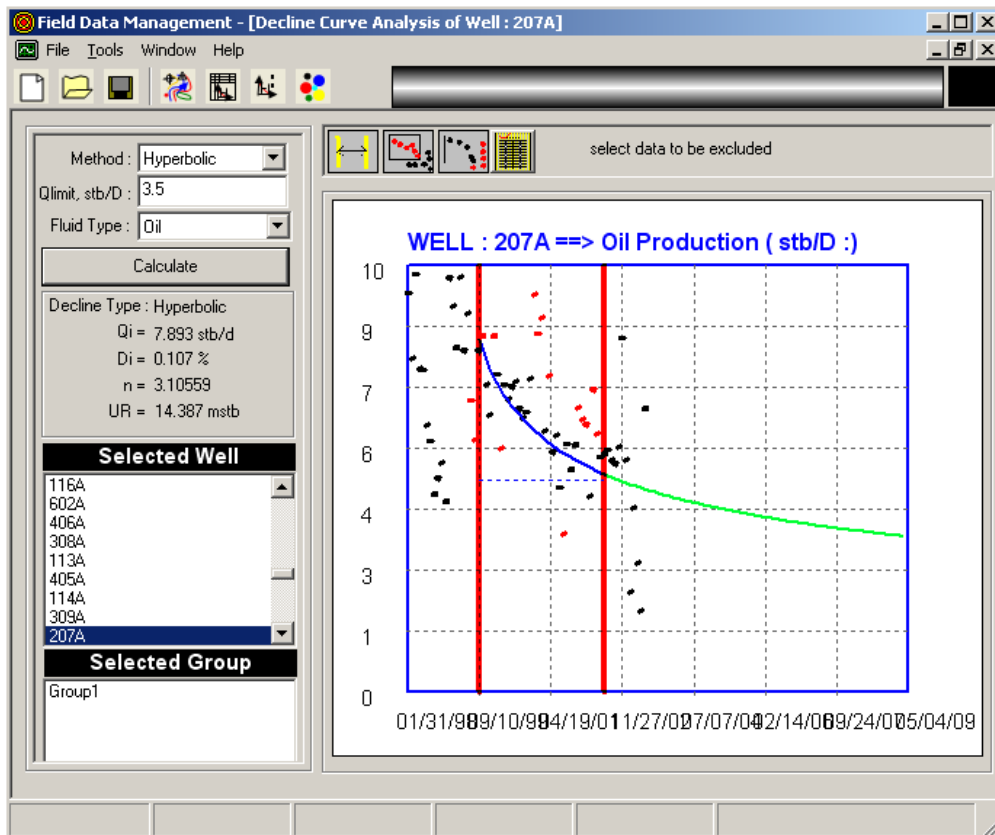


Fig. 3.7—Hyperbolic Decline Curve of Well 207A

3.2 References

1. Schechter *et al.*: “Preferred Waterflood Management Practices for the Spraberry Trend Area,” Semi-Annual Report (DOE Contract No.: DE-FC26-01BC15274), March – Sept 2002.
2. Spivey, J.P.: “A New Algorithm for Hyperbolic Decline Curve Fitting,” paper SPE 15293 presented at the Symposium on Petroleum Industry Application of Microcomputers, June 18-20, 1986.

APPENDIX-A FIELD DATA MANAGEMENT SOFTWARE

FEATURES

- FIELD MAP VIEWER**
 - DATA AND GRAPH VIEWER**
 - BUBBLE MAP /PIE CHARTS**
 - ISOBARIC MAPS**
 - GAS MATERIAL BALANCE**
-

TUTORIAL

Problem description

The example illustrates how to handle reservoir data (regular or sporadic) such as fluids production, injection data, the status of wells etc. The example will also familiarize you on how to create bubble maps, pie charts and production charts for single well or a group of wells.

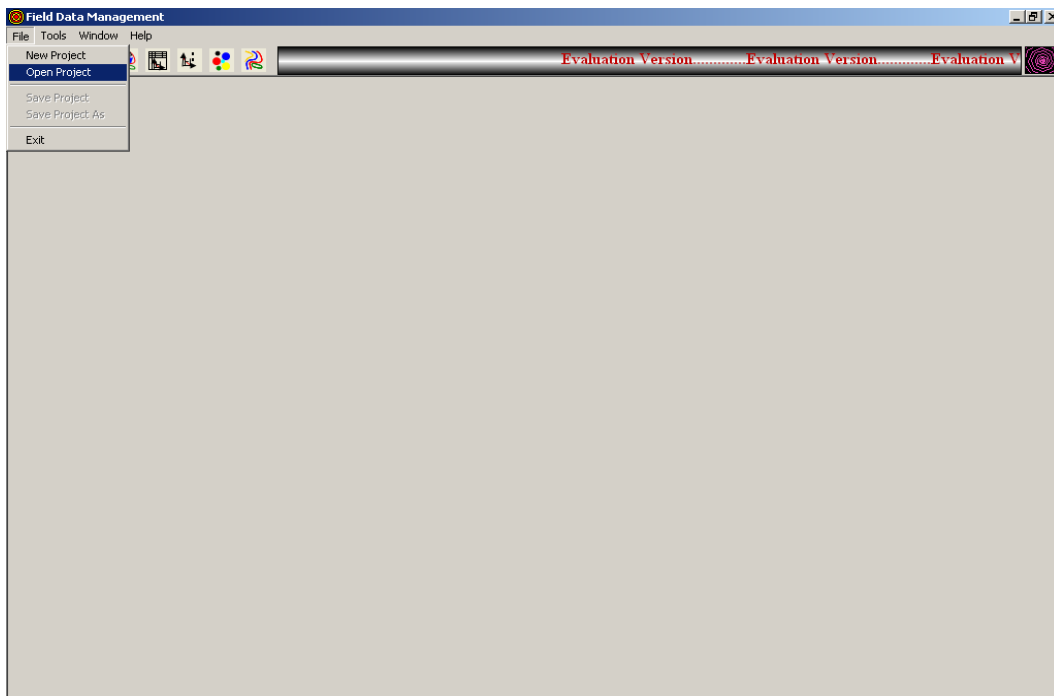
Data preparation

- Create a working directory in a convenient place.
 - Copy all data-files from the Tutorial directory, normally residing on /DSS/tutorials/example, to the current working directory.
 - The data files for this software have an extension “.prj”
-

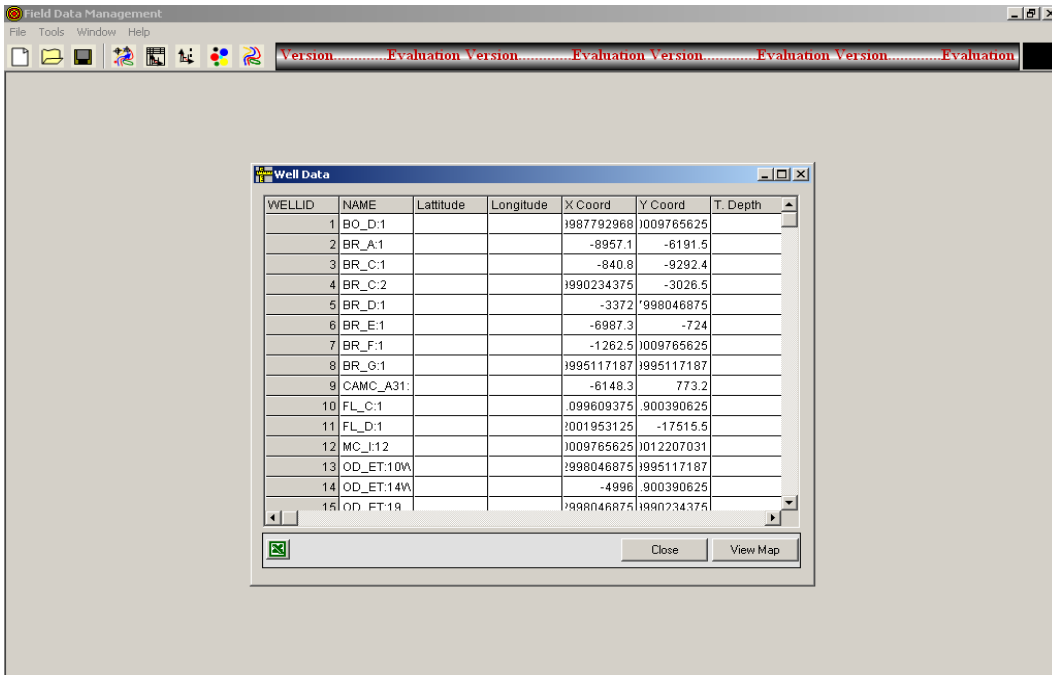
Open new project

To begin, start **DSS FDM**. You will need to double-click on the **DSSFieldDM2.exe** icon.

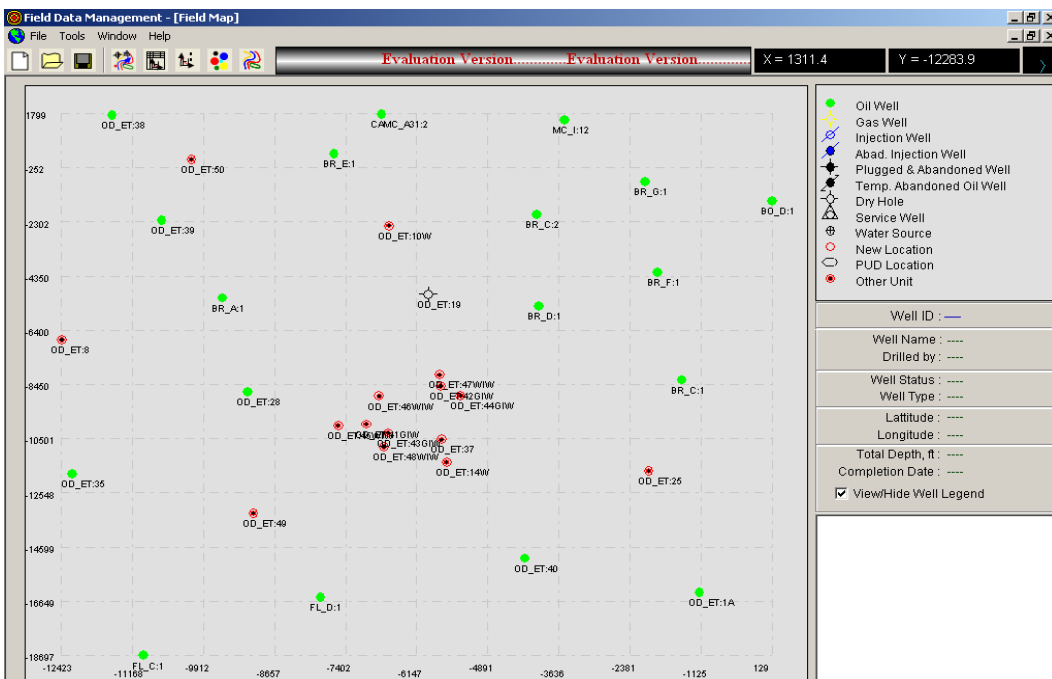
Select **File | Open Project**. The screen will look like the one shown below.



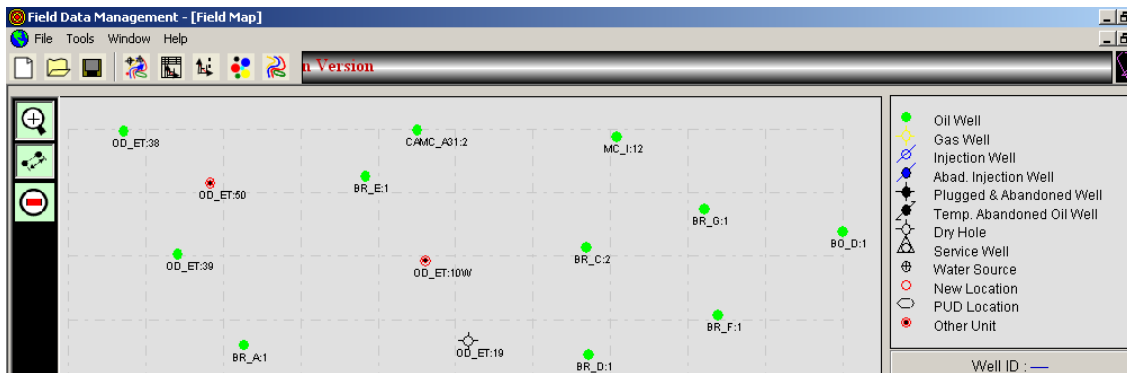
Call the project **Example1**. A screen will open up confirming that a correct data set has been entered. If an incorrect dataset is loaded an error message will prop up.




Click on **View Map** to view the map of this field. The legend on the right hand side describes the type of well and also gives the history of the well on moving the cursor to that particular well.




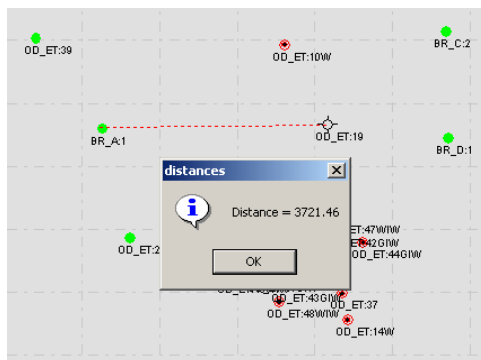
Since we have seen how to view the field map. Lets us explore the options available in the View field map mode.




On moving the cursor to the far left side of the screen, three more icons show up.

 Clicking this icon enables the zoom option.

 This option calculates the distance between any two points in the map.



 Clicking this icon resets the map.

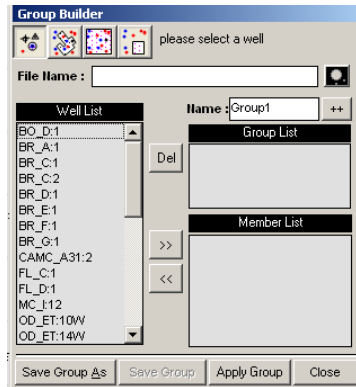
GROUPING WELLS

Grouping selected wells is the very important in order to study a particular field or region. The following example helps you to understand how to create and load groups.

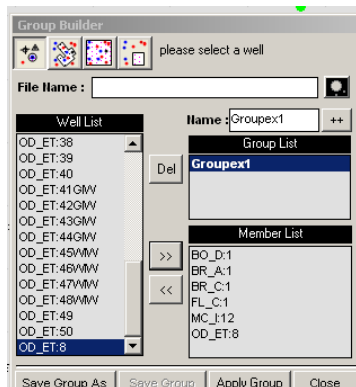
Suppose we want to group the following wells under the group name “Groupex1”

- BO_D:1
- BR_A:1
- BR_C:1
- FL_C:1
- MC_I:12
- OD_ET:8

Select **Tools : Create Group** and a Group Builder window pops up.



Enter the name of the group “Groupex1” in the Name window and press on “++”. You would find the group name added under Group list. In order to select the wells under the member list you can either click on the well name in the field map or chose the well from the well list and transfer to the Member list through “>>” button. You can choose more than one well by pressing CTRL key. Similarly you can remove a well from the Member list through the “<<” button. Once the wells has been added the screen should be as shown in Figure below.



Click on **Save Group** as to save the new group under a different name. The saved group will have a file extension “.grp”. This would help in future when you need to upload the group.

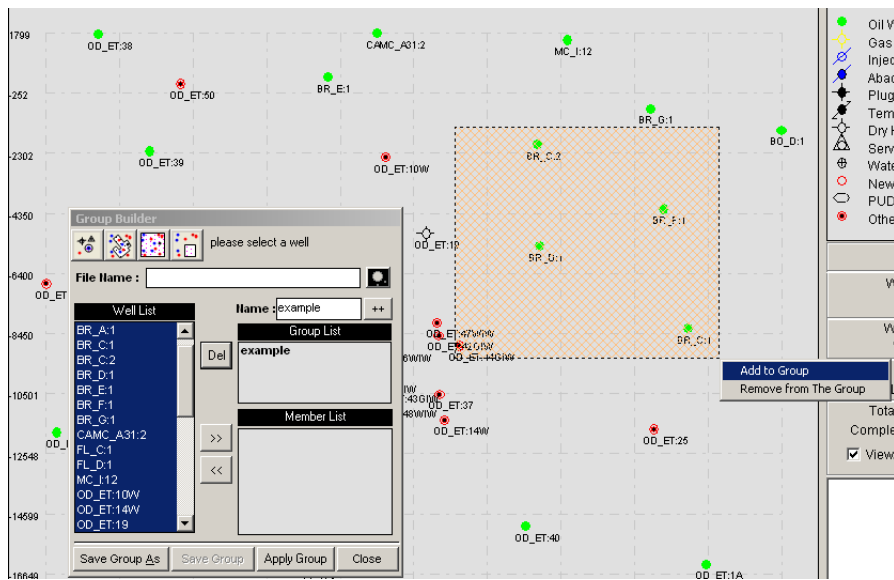
Group Builder icons:



Select one well at a time. Once the well is chosen, a thumb sign indicates the location of the well on the field map.



Select wells through a window. Click on the map and select the region which contain the wells by dragging the cursor, keeping the mouse clicked. Once the region is selected, release the mouse. Two options show up, whether to add the wells to the group or to remove the wells from the group.

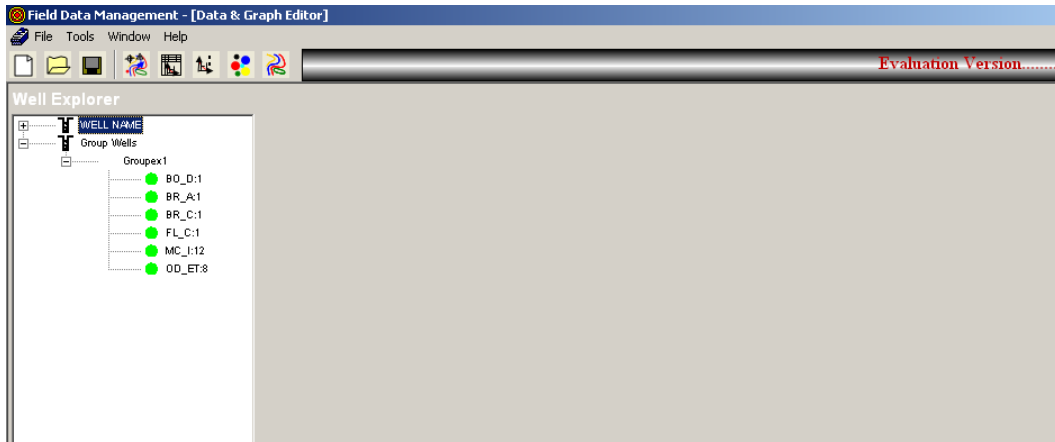


Selects all the wells from the list. Once selected move all the wells to the Member list through “>>” button.



Deselect All/ Remove the group.

Once having created the group click on Apply Group in order to activate the new group. This would activate the Data Viewer mode as shown in figure below. You can see from the figure that the group that was created is now active.



Now you can choose to view the production and pressure plots of each well. This procedure will be described in subsequent pages.

ICON DESCRIPTION

This software is very useful in handling data and generating the required outputs. The following describes the purpose of each icon.



creates a new project



opens a new project



saves the project



on clicking displays the field map



display data in a table format and has options to display production maps, pressure maps and also to update data.



perform decline curve analysis on production data




view the bubble map of the given production data.



view the isobaric contour (pressure map).

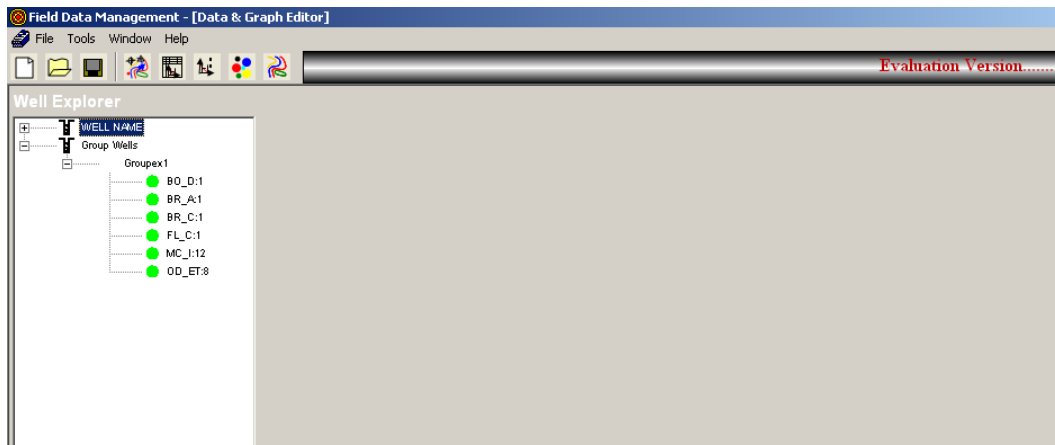
DATA AND CHART VIEWER

Let us now explore how to display and handle data in a table format and create production and pressure maps.

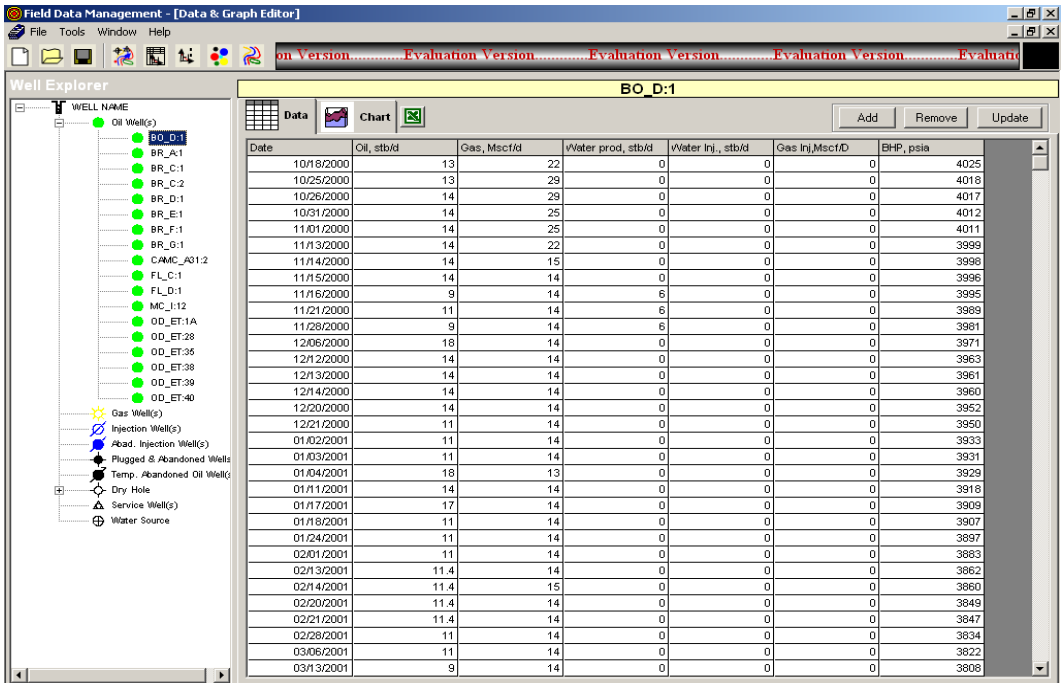
On clicking , the data view mode is activated. You will be shown the screen shown below. The left-hand side of the screen describes the type and status of well. The type of well is specified as an integral part of the input data. on the left-hand side window two categories would be shown


- WELL NAME
- Group wells

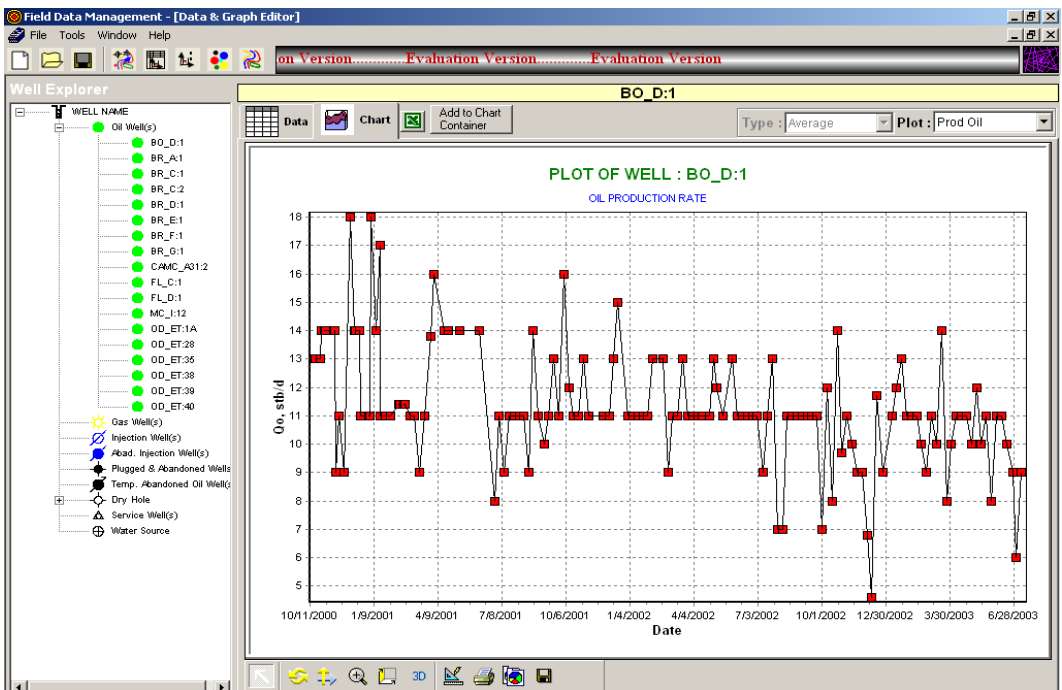
“Group wells” option is available because we have created the group “Groupex1” earlier. We can also load another group that we have created already. The group can also be created as a part of the input data set. The procedure will be addressed later.



On expanding **WELL NAME**, the information about the type and status of the wells are shown. Figure below shows the type and names of wells present in the input data. The right-hand window shows the data in a table form. In this example, the production data for well BO_D:1 is shown.



Click on  to view production plots of the selected well. The software gives you many options to plot. The two windows located on the right –hand gives the plot options.




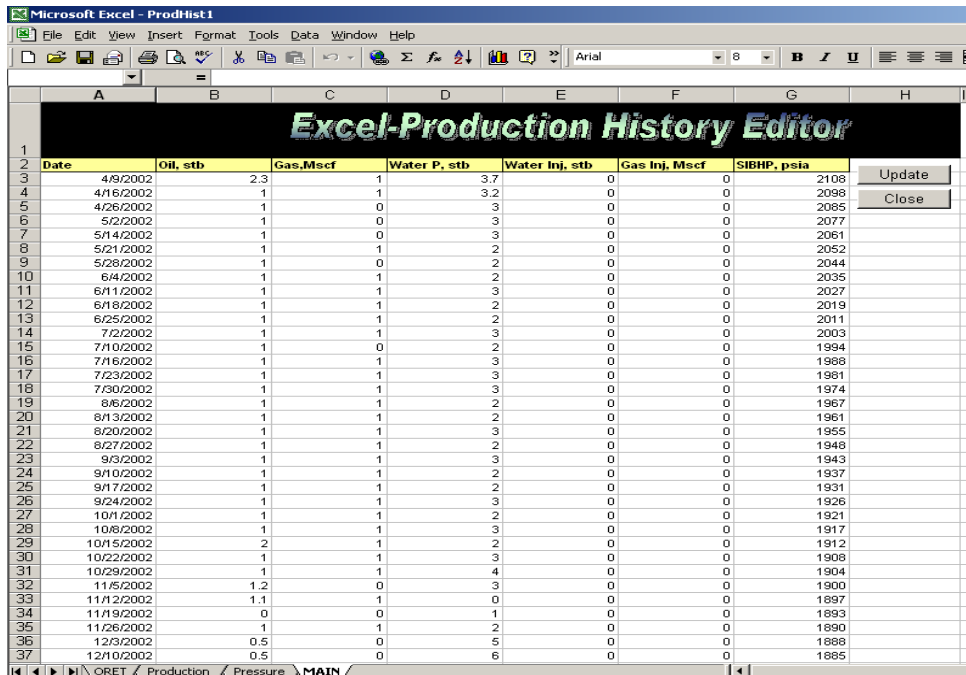
On scrolling down the **Plot** window the following plot options are available.

- Produced oil
- Produced gas
- Produced water
- Injected water
- Injected gas
- ALL- plot all the data available
- Cumulative oil
- Cumulative water
- Cumulative water injected
- Cumulative gas injected
- Water oil ratio
- Gas oil ratio
- Gas water ratio
- Bottom hole pressure

The **Type** window is turned inactive here because the data entered is the average daily production rate for wells. The **Type** window will become active and will have two options, when you click on Grouper1

- Average
- Summation

On clicking , the data is transferred to an excel spreadsheet, where data can be updated or changed.



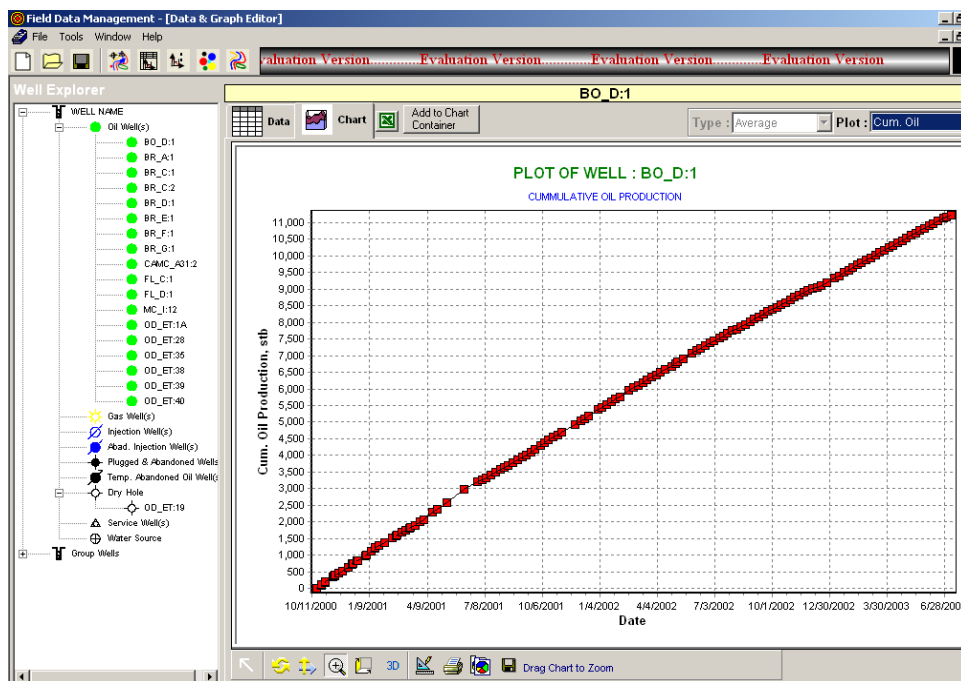
1	Excel-Production History Editor								
2	Date	Oil, stb	Gas, Mscf	Water P. stb	Water Inj. stb	Gas Inj. Mscf	SIBHP. psia		
3	4/8/2002	2.3	1	3.7	0	0	2108	Update	
4	4/16/2002	1	1	3.2	0	0	2098	Close	
5	4/26/2002	1	0	3	0	0	2085		
6	5/2/2002	1	0	3	0	0	2077		
7	5/14/2002	1	0	3	0	0	2061		
8	5/21/2002	1	1	2	0	0	2052		
9	5/28/2002	1	0	2	0	0	2044		
10	6/4/2002	1	1	2	0	0	2035		
11	6/11/2002	1	1	3	0	0	2027		
12	6/18/2002	1	1	2	0	0	2019		
13	6/25/2002	1	1	2	0	0	2011		
14	7/2/2002	1	1	3	0	0	2003		
15	7/10/2002	1	0	2	0	0	1994		
16	7/16/2002	1	1	3	0	0	1988		
17	7/23/2002	1	1	3	0	0	1981		
18	7/30/2002	1	1	3	0	0	1974		
19	8/6/2002	1	1	2	0	0	1967		
20	8/13/2002	1	1	2	0	0	1961		
21	8/20/2002	1	1	3	0	0	1955		
22	8/27/2002	1	1	2	0	0	1948		
23	9/3/2002	1	1	3	0	0	1943		
24	9/10/2002	1	1	2	0	0	1937		
25	9/17/2002	1	1	2	0	0	1931		
26	9/24/2002	1	1	3	0	0	1926		
27	10/1/2002	1	1	2	0	0	1921		
28	10/8/2002	1	1	3	0	0	1917		
29	10/15/2002	2	1	2	0	0	1912		
30	10/22/2002	1	1	3	0	0	1908		
31	10/29/2002	1	1	4	0	0	1904		
32	11/5/2002	1.2	0	3	0	0	1900		
33	11/12/2002	1.1	0	1	0	0	1897		
34	11/19/2002	0	0	1	0	0	1893		
35	11/26/2002	1	1	2	0	0	1890		
36	12/3/2002	0.5	0	5	0	0	1888		
37	12/10/2002	0.5	0	6	0	0	1885		

On addition/correction of data hit the **update** button to update the data. In order to view the updated data, refresh the data by clicking on the well name and then view the plot. Once the update is done, you can close the spreadsheet by hitting the **close** button.

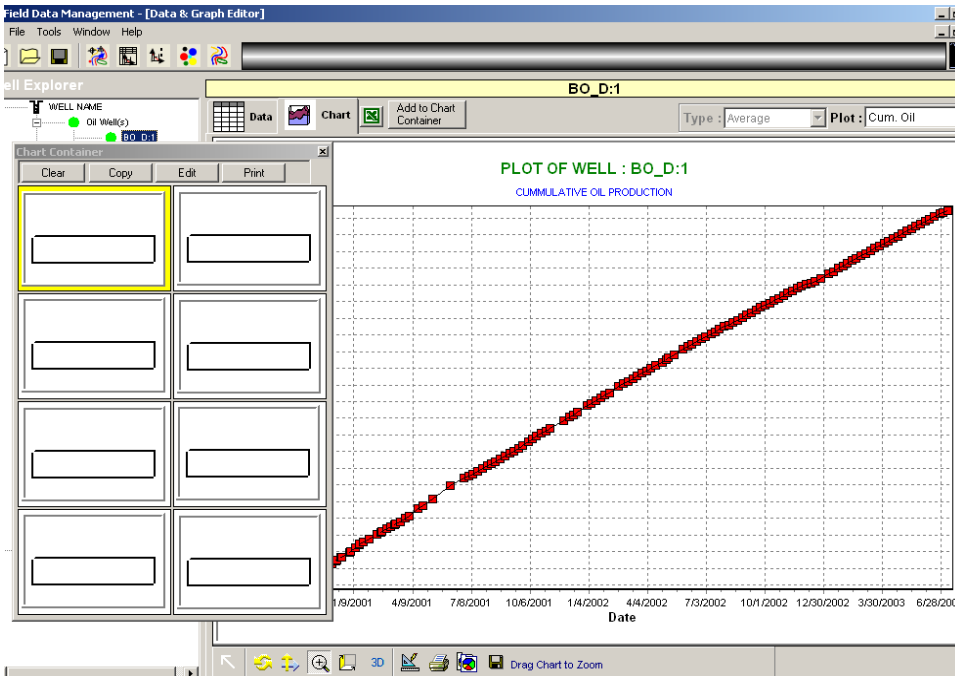
The software also has options to design your own plots. This is handled by the **Add to Chart Container** tab. The following exercise will help you familiarize with designing your own plots.

Suppose you want to create a plot of cumulative oil, BHP and produced gas vs. time for well BO_D:1.

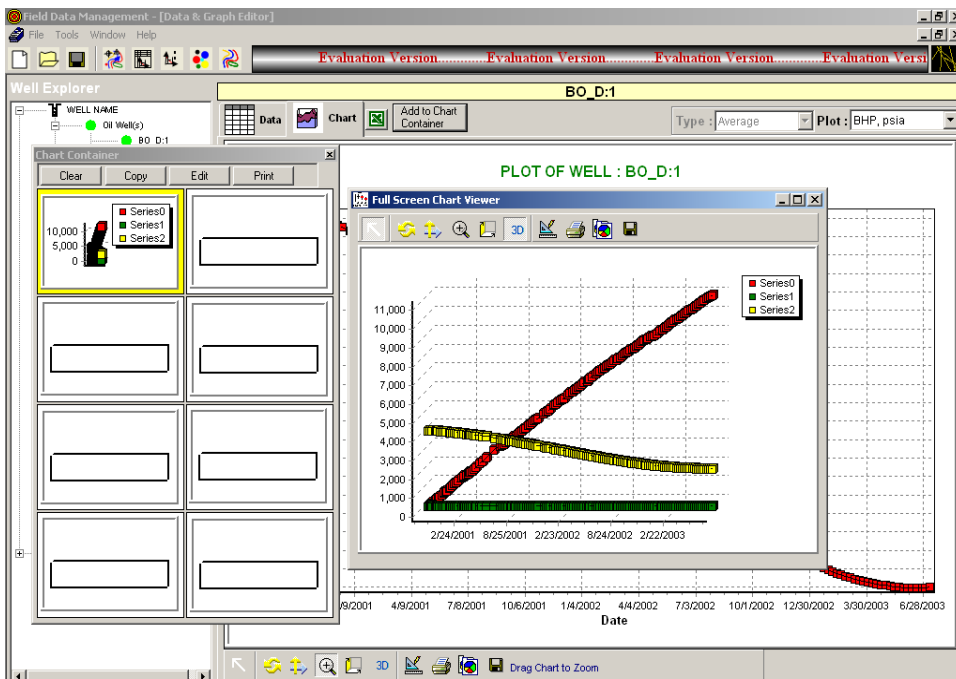
1. Choose **Cum. Oil** in the **Plot** window. You should now see the plot of cumulative oil vs. time.



2. Select **Tools:Add to Chart Container**. You should see the screen shown in following figure.



3. Click on **Add to Chart Container** tab. Now the plot is transferred to the chart container. Similarly choose **BHP** and **Prod. Gas** from the **Plot** window and click on **Add to Chart Container** tab. Now all the 3 plots are added to the chart. You can view the created chart by double clicking on the chart in the chart container.



The plots can be edited using the options available in the chart viewer.

CHART EDITOR

Chart display features are those, which affect the overall appearance of the Chart. They include those properties and methods that define the color of the Chart background, Titles and their position, margins, borders and bevels, background images, frame and axis visible, pen colors and widths, 3D, walls, etc.

The overall Chart appearance characteristics are a grouped into these categories:

[General](#)

[Axis](#)

[Titles](#)

[Legend](#)

[Panel](#)

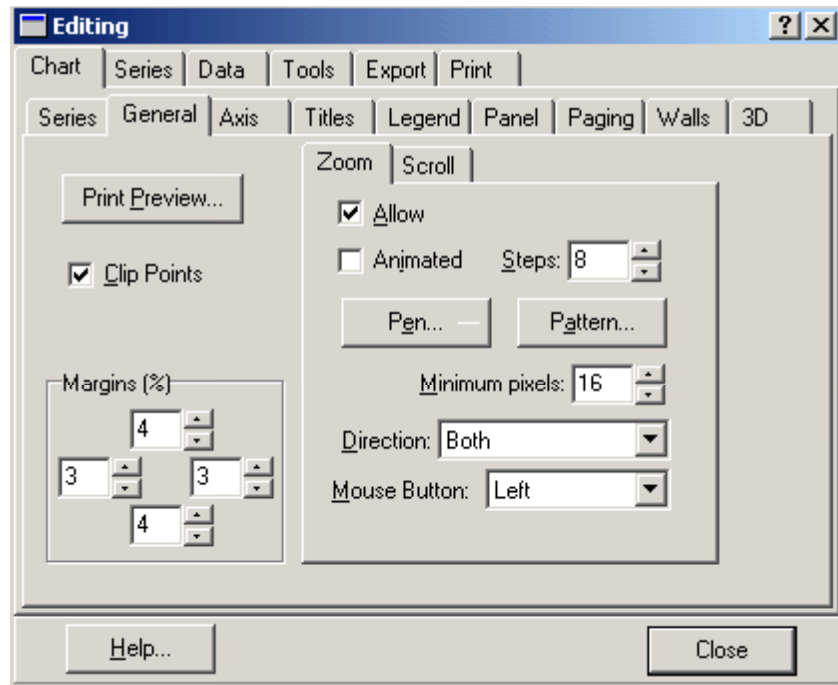
[Walls](#)

[3D](#)

These are the groupings you will find if you open the Chart Editor and browse the Chart pages. Other properties affect the 'look' of your Chart. These include Series colors and mark characteristics, individual Axis and Grid display properties and labeling.

Getting started with Chart display properties

General Chart properties

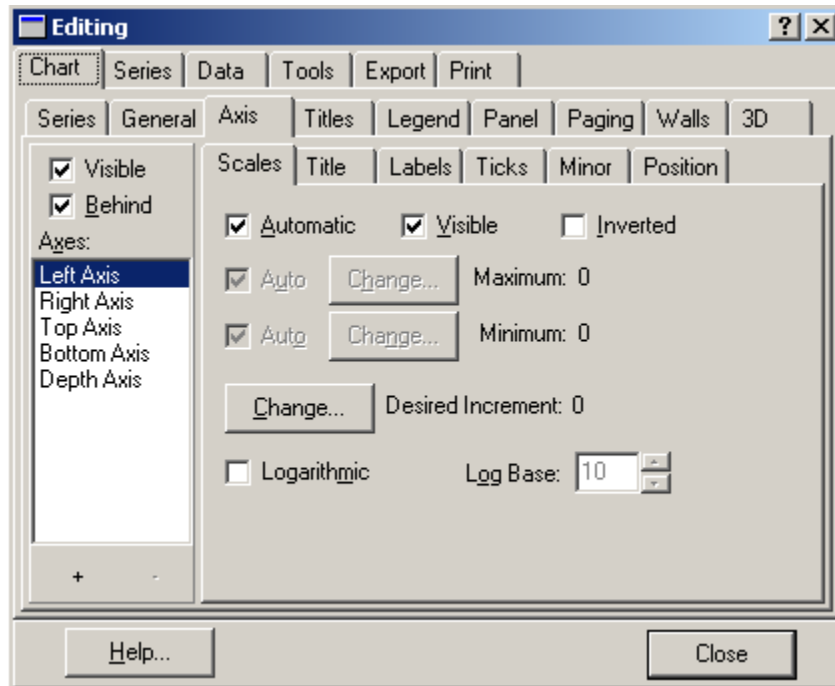


General options include Print Preview and Chart Export . This also has options to zoom the chart to the desired level.

Axis Properties

Control of the axes is quite a specialized area at its greatest level of intricacy. Here we will cover the fundamentals of Axis and Frame display.

The second Chart page holds the properties for defining axis and frame characteristics.



There are 5 axes in the Chart. Left, Top, Right, Bottom and Depth. The Chart Frame displays as a surround to the Chart's plottable area and has no data corresponding features (See BackWall). The Depth initializes by default as not Visible. All other Axes are visible from the moment that a Series is added to the Chart and associated with those Axes (Left and Bottom as default). Custom Axes may be added/removed by using the + and - keys on the dialogue. For a Custom Axis to be visible (as for any other Axis) a Series must be associated with the Axis.

The key properties to enable display of axes and frame are:

Visible

This checkbox enables or disables display of all axes. If the Back wall Frame is visible then the Chart surround is still visible when the axes are hidden. The result will be the appearance of a larger Chart as no area is reserved for the axis

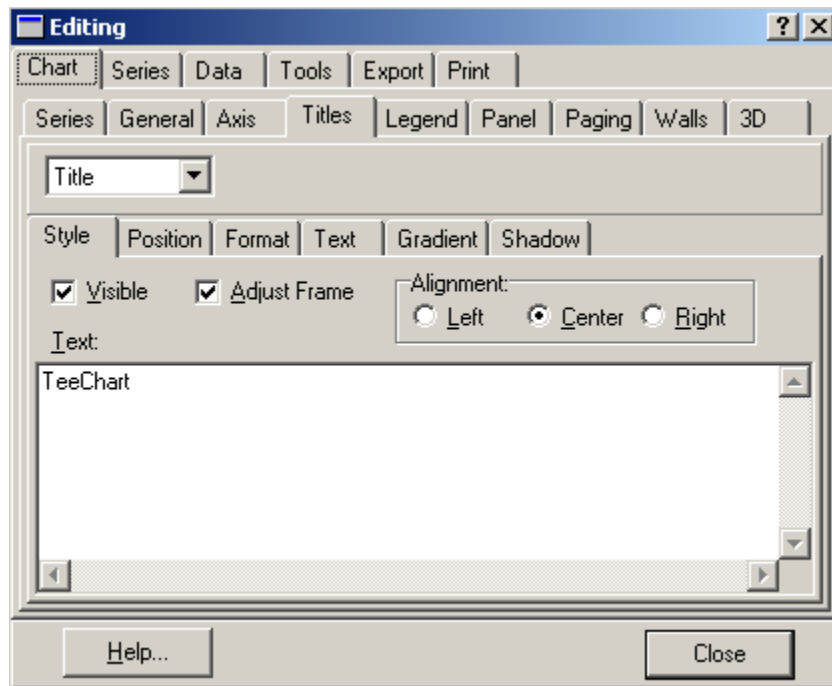
labels. The Visible property for each Axis (Scales tab) overrides the visible characteristic for each Axis. If you select the Depth Axis in the List then you will note that Depth Axis Scales. Visible is by default 'not visible'.

Axis: Left, Right, Top, Bottom and Depth Visible

Select the Axis that you wish to display or hide in the Listbox and toggle the Visible checkbox on the Scales tab to control the display for that specific axis.

Titles Properties

The Titles page of the Chart Editor controls the characteristics of the Chart Titles, Header and Footer.



Text

Use the dropdown Combobox to select either Title (Header), SubTitle, Foot or SubFoot. Enter the required text in the Textbox. You may type multiline titles.

Style Alignment

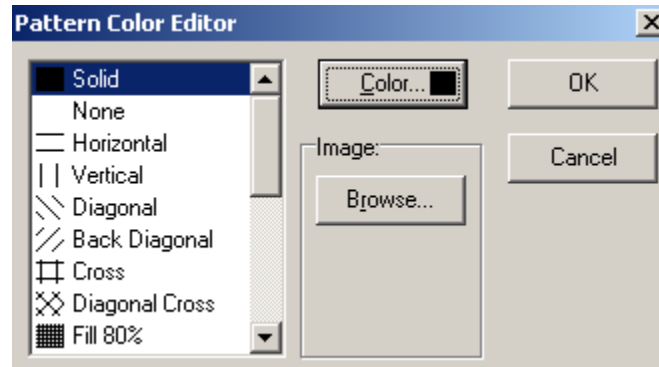
Alignment refers to the Header (or Footer) alignment with respect to the Chart area NOT the overall Chart Panel. The Chart area is the plottable area of the Chart plus Axis Labels and Legend.

Position

Use Position to override the Title or Footer default position and set a custom position (pixels relation to Chart Top, Left).

Format

Contains the settings for the Title box, e.g. Frame, Background color, etc.



Pattern refers to the background pattern of the Title or Footer box. The default is Clear. The selected Pattern will sit behind the Text.

Text

Contains the Title Text appearance formatting characteristics.

The Font button will grant access to the Font Dialog window, which allows selection of Windows Fonts and definition of style (italic, bold, etc.) and color.

Gradient

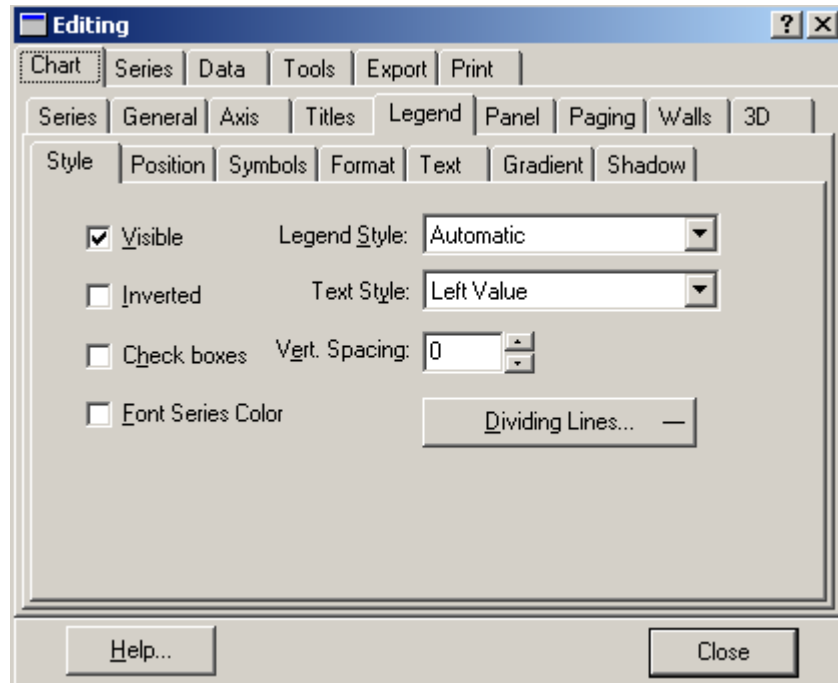
Enable/disable a Background Gradient in the Title box and select its direction and colors.

Shadow

Properties for display of the Header or Footer box Shadow. You may define color and size.

Legend Properties

Legend contents are a specialist subject that will be dealt with in a later tutorial. In the Legend page of the Chart Editor you may define appearance aspects of the Legend. Important initial steps are to control Legend alignment and visible properties, color, font, frame, shadow, etc..



Style

Toggle On/Off Legend display and set Legend display content characteristics (inclusion of Checkboxes, etc).

Position

Custom positioning of the Legend. If the Legend is set to the side (left or right) of the Chart the contents of the Legend, by default, sit as a list from top to bottom. If the Legend sits below or above the Chart then the Legend contents are placed side by side. The default behavior may be overridden by using the Resize Chart option and/or by using Custom positioning.

Symbols

Size and formatting of the Legend symbols.

Format

Contains the settings for the Legend box, e.g. Fill Color, Frame color, style and width, Pattern style, color and image, bevel style and size and checkboxes for Round Frame and Transparent.

Text

Text characteristics for the Legend text contents.

Gradient

Enable/disable a Background Gradient in the Legend box and select its direction and colors.

Shadow

Properties for display of the Legend box Shadow. You may define color and size.

Panel Properties

Border

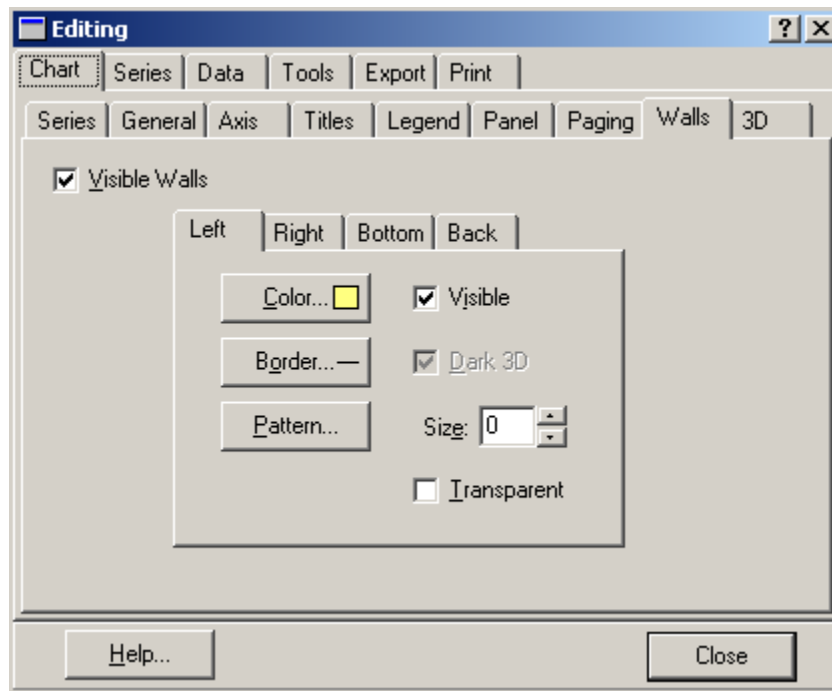
You may define Border independently or in conjunction with the Bevel properties. With Border set to Visible True you will obtain a 'sunken' border effect on the outside of the Chart Panel. Mixing Bevel and Border and manipulating Width give almost any combination of 3D effects.

Gradient

To define a Gradient you must select a StartColor and EndColor (plus, optionally MidColor) and enable as Visible the Gradient. The Gradient will cover the whole Chart panel. Gradient direction defines the direction of color change between Start, Mid and EndColor.

Walls Properties

This page in the Chart section of the Chart Editor applies properties to the Chart Walls. There are 4 Walls: Left, Right, Bottom and Back that may be represented in 2D or 3D.

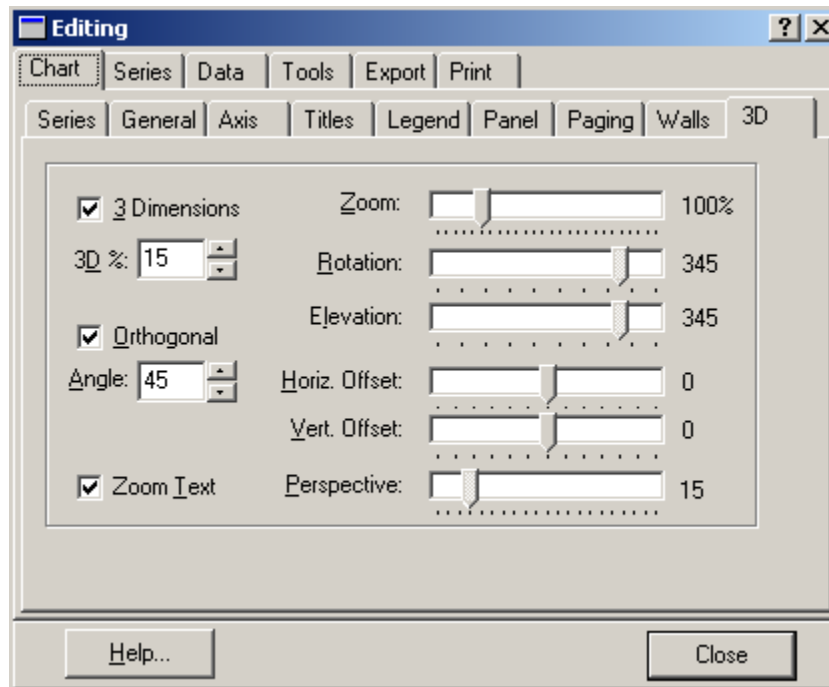


WallBorder

You can specify the thickness of the walls for the chart here.



3D VIEW



Editor options:

3 Dimensions

Selecting this property (toggling) will change the Chart from a 3D to a 2D Chart in design time and the setting will take effect for runtime.

The Orthogonal Option, when disabled, enables Windows Native 3D mode allowing you to Rotate, Elevate and offset the Chart. The Zoom option allows you to bring forward or move away the whole Chart. Zoom internally in the Chart on Data Series is still available at runtime.

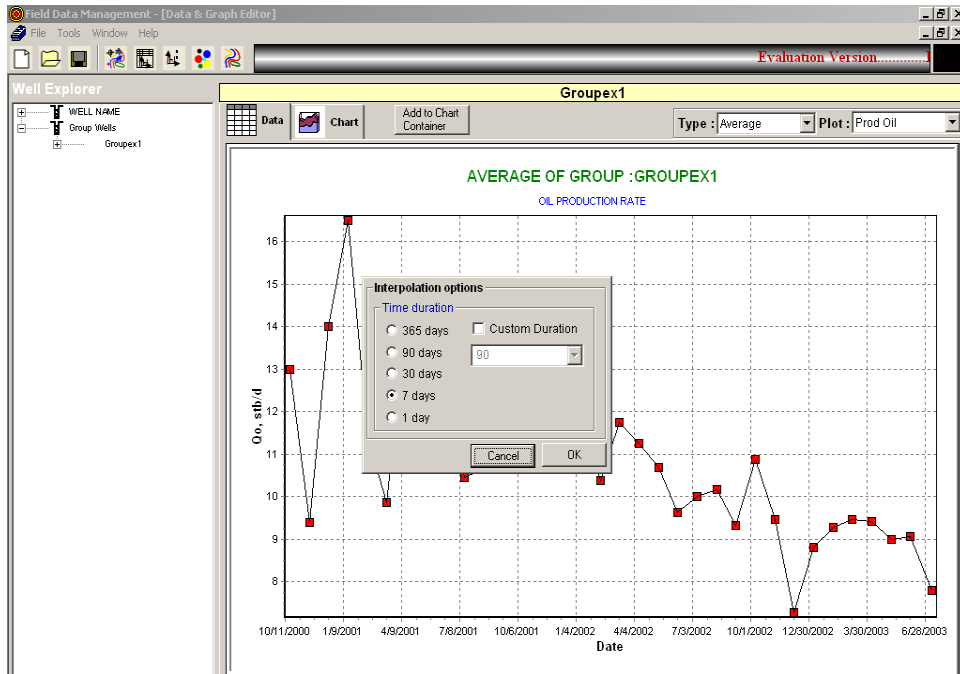
The **Perspective** property allows you to set a distance perspective as if looking into a room. **Perspective** offers a visual enhancement for Charts used for presentation purposes.

INTERPOLATION OPTIONS

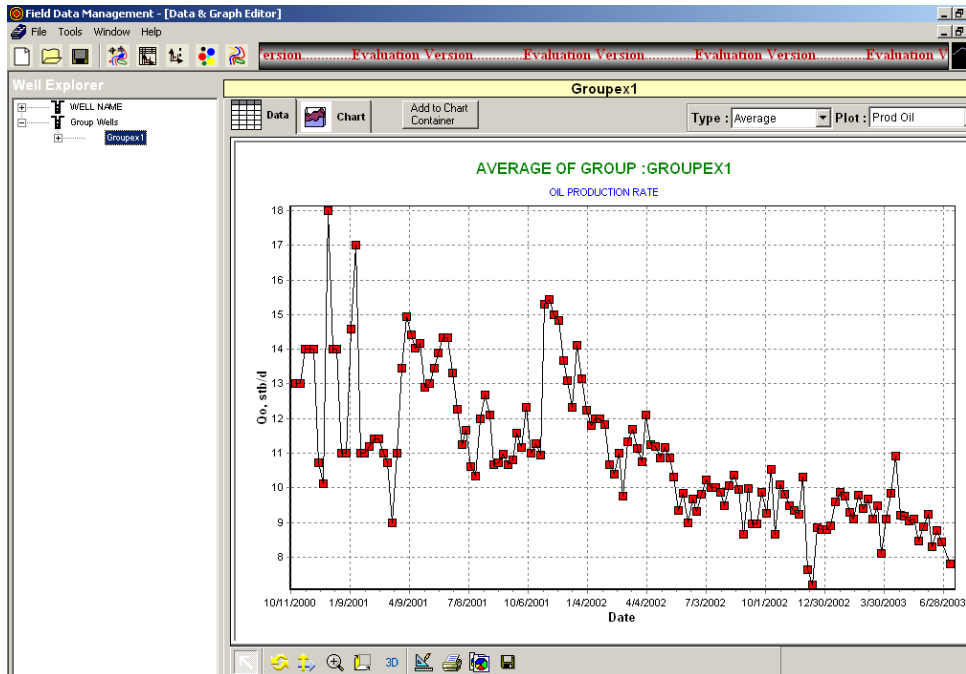
The software also has provisions to interpolate the given data in order to create more data. One of the main features of this software is that it can handle sporadic data. This would extremely be helpful when handling a group of wells, because the production dates of all the wells in a group may not be the same. The interpolation option helps to create a regular data set from a sporadic data set of the selected group.

Select Tools: Interpolation Options

The interpolation option window will pop up and give you options for the duration of interpolation.



Choose the time duration for interpolation from the window and press OK. For this example select 7 days. The software calculates the interpolated values and plots the result of interpolation. Figure shown below gives the interpolated (every 7 days) plot of oil produced for the group “Groupex1”.




Note: the “Type” window is now active and has the options

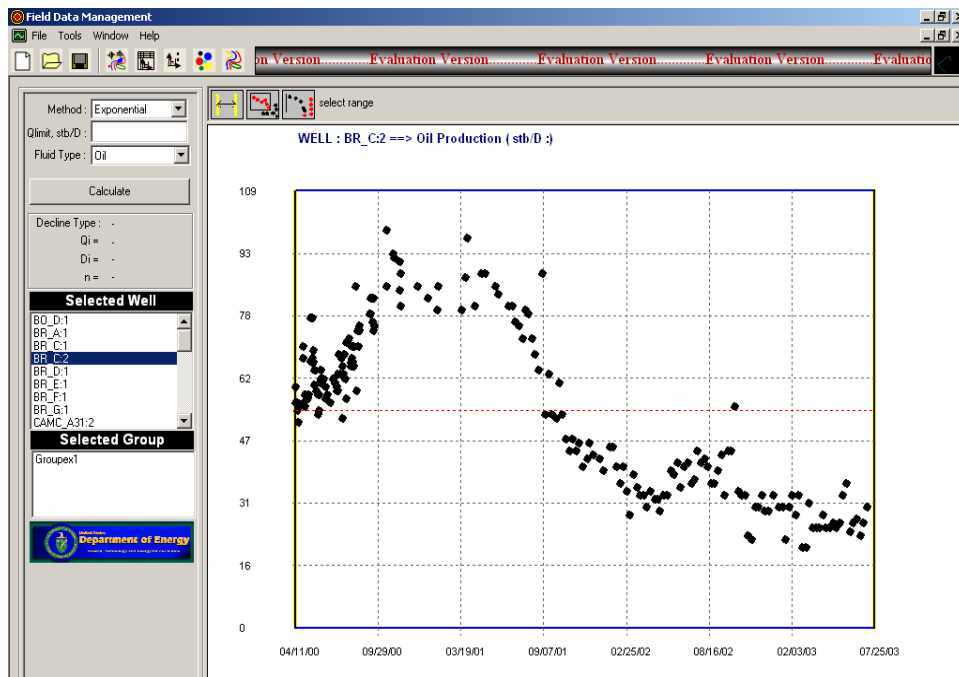
- Average
- Summation

This enables to plot the average of the group or the summation of the group.

DECLINE CURVE ANALYSIS

The software also performs decline curve analysis. In order to perform decline curve analysis click on .

On click the decline curve analysis mode is activated and the screen would look like the one shown in Figure below. In the figure well BR_C:2 has been highlighted to perform decline curve analysis. The yellow lines at the left and right end of the plot separated by a red-dashed line indicates the range of data to be included in the analysis.



The decline curve analysis has several options. The functions of icons are discussed below.



The range of data in the x-axis can be adjusted using this icon. Clicking the icon and moving the yellow lines to the required range achieve this.

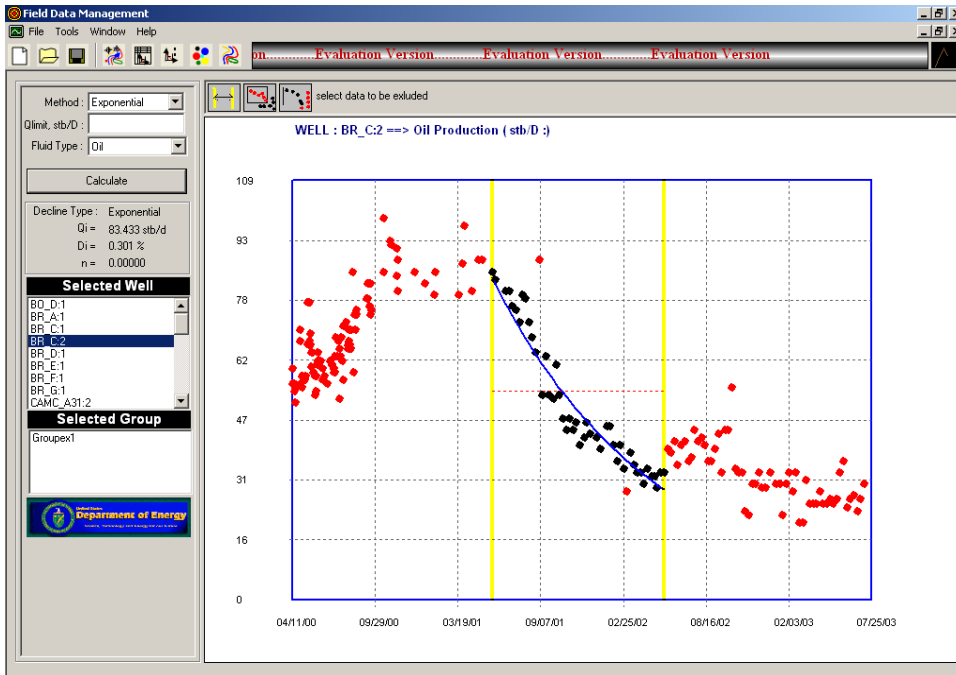


Bad data can be omitted using this option.



The data can be reset through a window range using this option.

Using the above options a decline curve analysis is performed on well BR_C:2 as shown below. The data points in red indicate neglected data.



The decline curve analysis in this software has provisions for the type of decline you choose to employ. The methods of decline available are

- Exponential
- Hyperbolic
- Harmonic

A **Best Fit** Option is also provided to let the software determine the best of the three methods used to analyze decline. You can also specify the **Qlimit** for decline in the window provided. Press **Calculate** to perform the decline.


On performing the decline the output is shown in the left-hand side window stating,

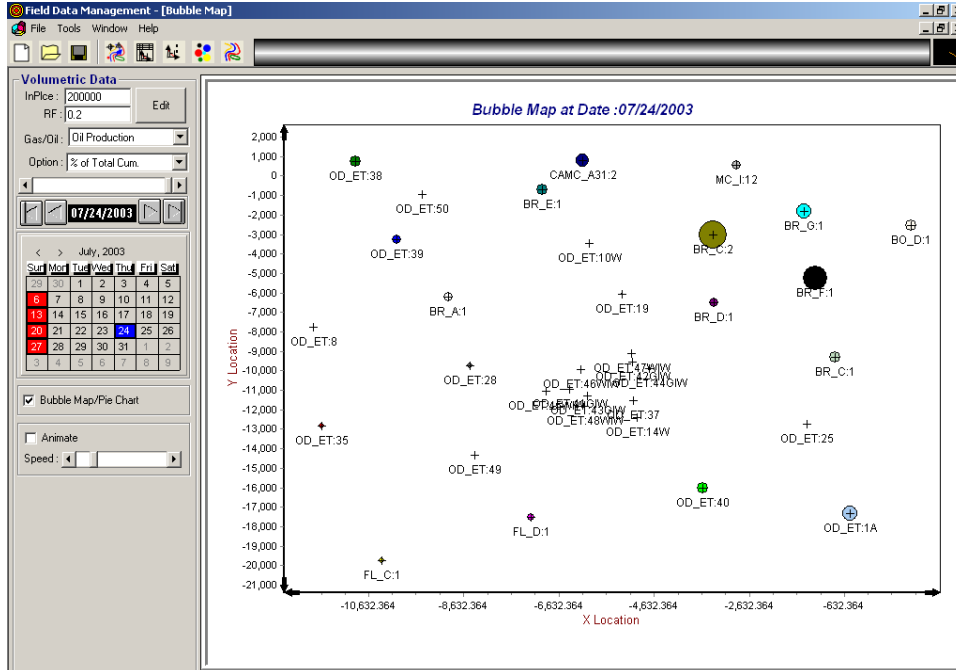
- Decline type
- Initial rate
- Decline rate
- Decline parameter

There are two windows on the left-hand side, **Selected well** and **Selected Group** which enables to analyze decline for one selected well or a group of wells, respectively.

BUBBLE MAP AND PIE CHARTS

Procedure for generating bubble map

Click on  to activate the Bubble map mode. You would see the a screen as shown below.



The volumetric data is given on the left-hand side of the window. The features in the volumetric window are,

1. Fluid in place
2. Recovery factor
3. Types

This would include

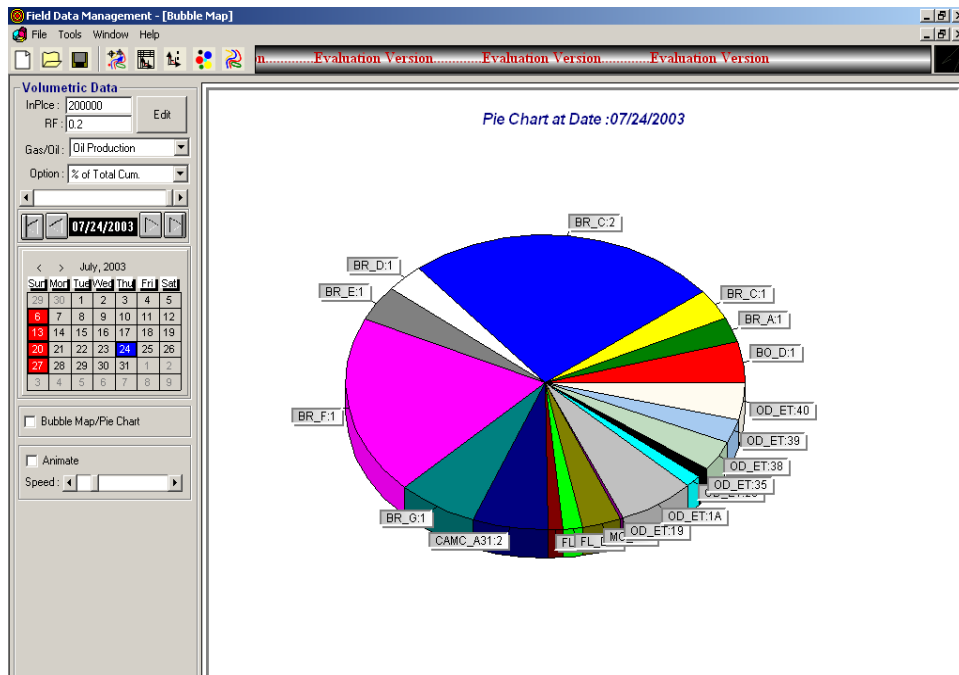
- Oil production
- Gas production
- Water production
- Water injection
- Gas injection

There are also options to plot the bubble map as

1. % of Total cumulative production
2. % of Recoverable reserves
3. % of Fluid in place

The bubble map can be plotted at any point in time by scrolling the time bar on the left-hand side of the window or even more specific by choosing the required date on the calendar.

The **Bubble Map/Pie chart** button can be toggled to view either the Bubble map or the Pie chart. By default the button is checked and the bubble map is visible. In order to view the Pie chart uncheck the button.




Animation sequence of the formation of bubble map over time could be realized by checking the **Animate** button. The speed of the animation could be adjusted using the **Speed** bar.

Note: when this button is checked all other options are disabled. In order to stop the animation, uncheck the **Animate** button. Also if the speed of animation is very high there could be problems in animation, keep the speed to optimum level.

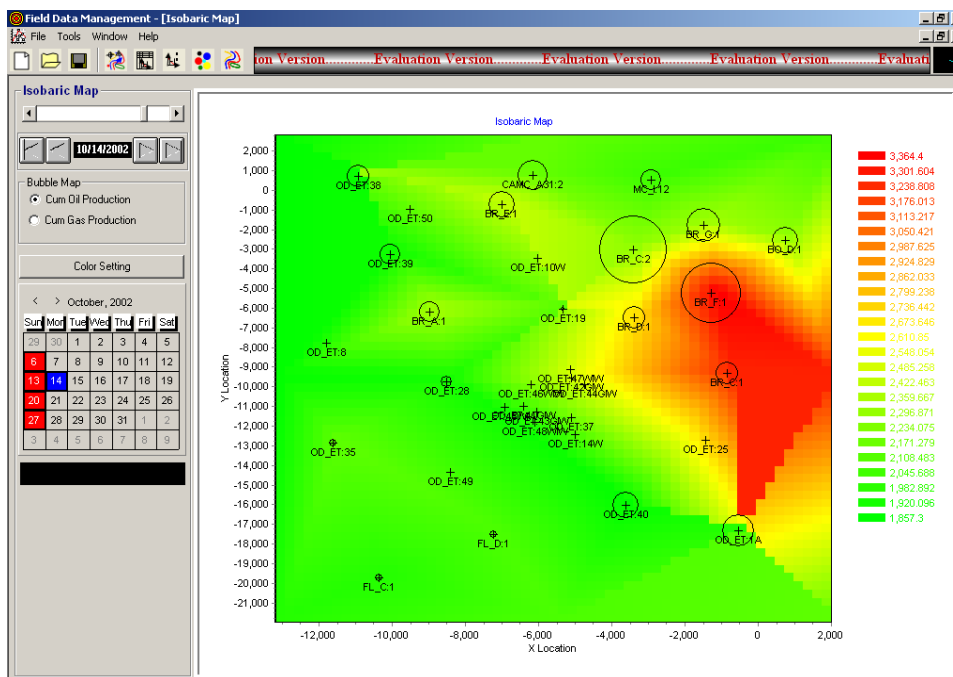
ISOBARIC MAPS

Procedure for generating bubble map

Click on  to activate the Isobaric map mode.

Note: As soon as the button is clicked, there would be an error message prompting that there is insufficient data to create a contour map. Press OK to the message. You would then see a field map without any contours. On moving the Time bar located on the left side of the window, the isobaric map becomes visible.

You would see the screen as shown below



The isobaric map mode also has provisions to include the bubble map along with the isobaric contours. The bubbles (with no color inside them) represent the production bubble maps. The types of bubble map options presented at the left side of the window are

1. Cumulative oil production
2. Cumulative gas production

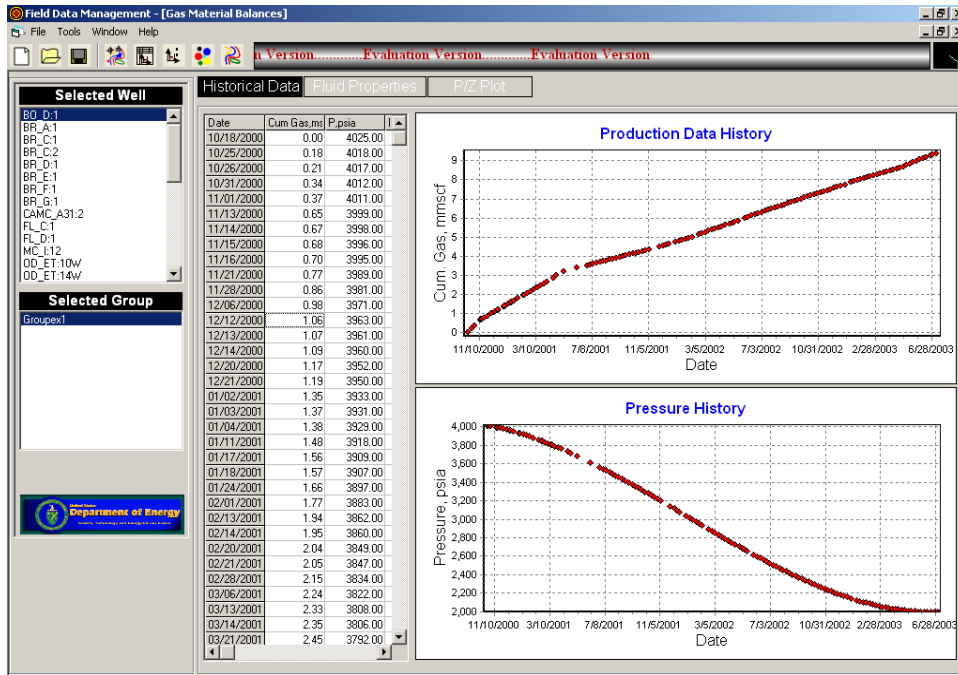
The **Color settings** button enables to change the basic colors of the map by editing the start, end and middle color.

GAS MATERIAL BALANCE

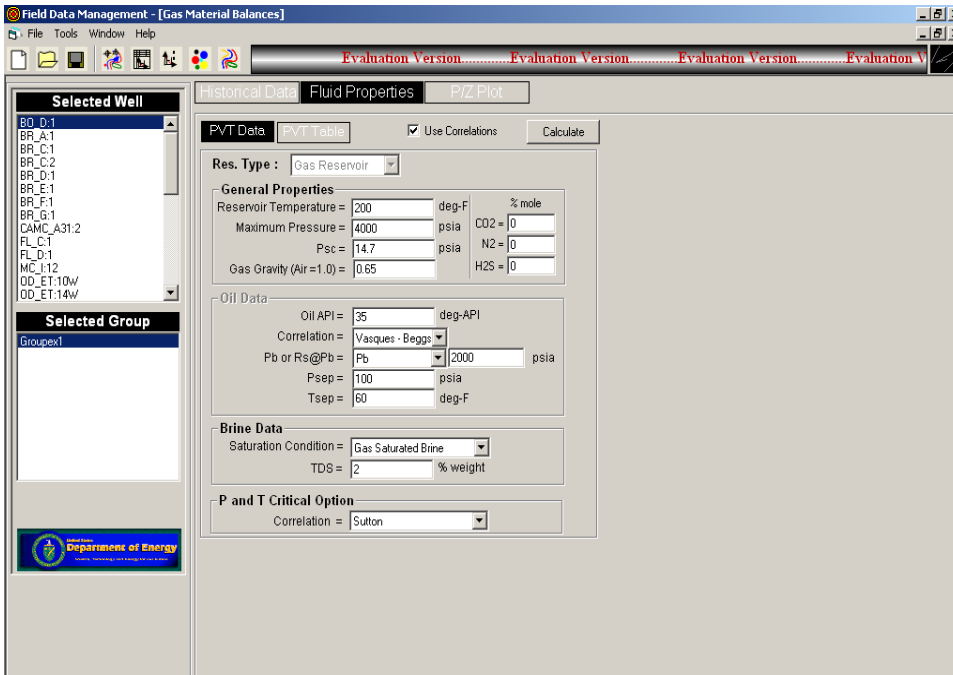
The procedure for performing gas material balance is as follows.

Select **Windows : Gas Material Balance**

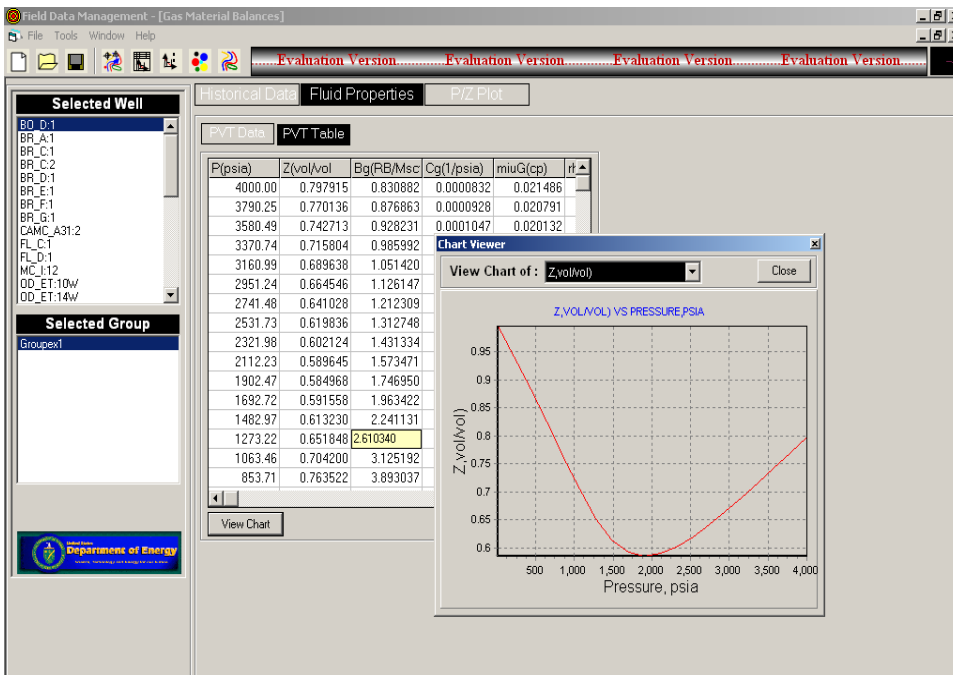
On selecting this option the gas material balance window is activated. You would see the screen shown below. In this example the well BO_D:1 is activated and the Historical Data tab is enabled. This tab plots the gas production history and pressure history of the well.



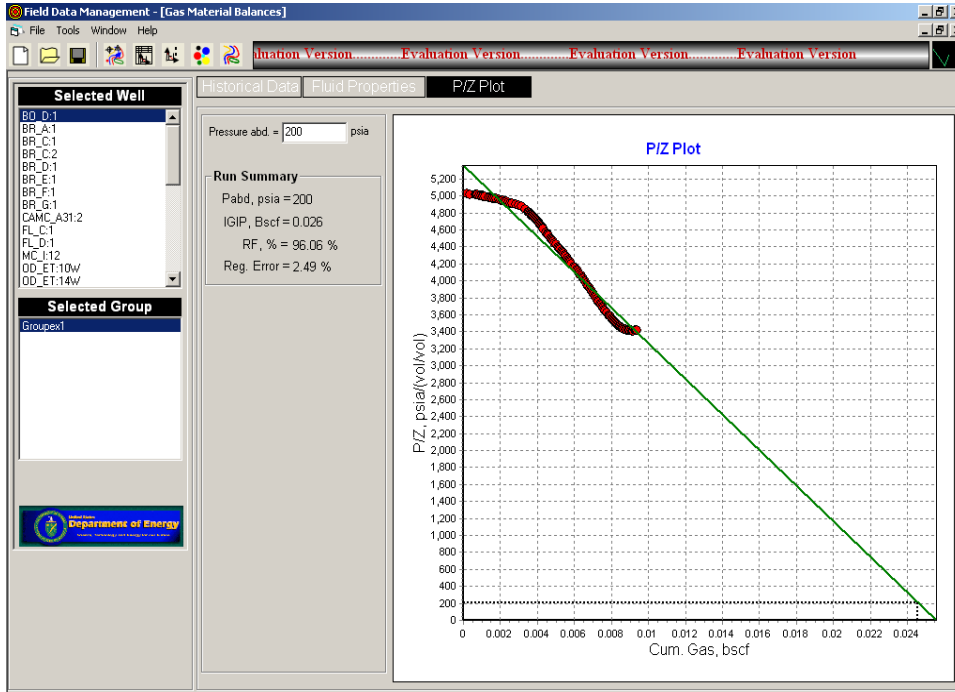
The fluid properties for the analysis could be viewed by pressing the Fluid Properties tab. The general properties of the reservoir can be entered here by enabling the PVT tab.



The PVT data table can be viewed by pressing the PVT table tab as shown below. In order to view the PVT properties click on View Chart to explore the chart options. You can either leave the data unchanged or input your own data.



In order to perform the P/Z plot click on P/Z Plot. on clicking the P/Z Plot mode is active . you can enter a value for abandonment pressure (say 200 psi) and press Enter. On hitting the Enter button you would see the run summary, which indicates the Original Gas in place along with the error estimates.



APPENDIX-B: PROJECT FACT SHEET

CONTRACT TITLE: Preferred Waterflood Management Practices for the Spraberry Trend Area – PUMP Breakout

ID NUMBER: DE-FC26-01BC15274 B&R CODE: AC1005000	CONTRACTOR: Texas Engineering Experiment Station ADDR: 322 Wisenbaker Engineering Research Center College Station, TX 77843		
DOE PROJECT MANAGER: NAME: Daniel J. Ferguson LOCATION: NPTO PHONE: 918/ 699-2047 E-MAIL: dan.ferguson@npto.doe.gov	CONTRACT PROJECT MANAGER: NAME: David Schechter PHONE: 979/ 845-2275 FAX: 979/845-1307 E-MAIL: schech@spindletop.tamu.edu		
PROJECT SITE CITY: College Station STATE: TX CITY: STATE: CITY: STATE:	CONTRACT PERFORMANCE PERIOD: 9/1/2001 to 8/31/2003 PROGRAM: Reservoir Life Extension RESEARCH AREA: PUMP PRODUCT LINE: RLE		
CO-PARTICIPANTS:			
PERFORMER: Pioneer Natural Resources	CITY: Irving	STATE: TX	CD:
PERFORMER:	CITY:	STATE:	CD:
PERFORMER:	CITY:	STATE:	CD:
PERFORMER:	CITY:	STATE:	CD:

FUNDING (1000'S)	DOE	CONTRACTOR	TOTAL
PRIOR FISCAL YRS	0	0	0
FY 2001 CURRENT OBLIGATIONS	500	1567	2067
FUTURE FUNDS	5	0	5
TOTAL EST'D FUNDS	505	1567	2072

OBJECTIVE: The objective of this project is to design and test different waterflood techniques that have never been utilized in the Spraberry Trend Area. The new waterfloods will align injection wells along the fracture trend with production wells. New injection wells will be drilled that will not be artificially fractured to test whether specific zonal isolation is the primary key. Existing producers with massive hydraulic fracture treatments will be converted to injectors to test whether the hydraulic fractures hinder or aid sweep efficiency. An injection pattern, which is adjacent to, and on-trend with a section containing a majority of plugged wells will be dedicated to investigating whether there is still mobile oil in the vicinity of old, abandoned wells and whether this oil can be swept and captured in current producing wells. A comprehensive economic analysis will be provided to identify the preferred management practices and to transfer the information to all Spraberry operators so that other operators can initiate water injection based on the results of the Spraberry Shackelford Unit Field Demonstration.

PROJECT SUMMARY

Background:

Regions with greatest potential – the naturally fractured Spraberry Trend Area is one of the largest reservoirs in the domestic U.S. and is the largest reservoir in area extent in the world. Production from Spraberry sands is found over a 2,500 sq. mile area and Spraberry reservoirs can be found in an eight county area in west Texas. Over 150 operators produce 65,000 barrels of oil per day (bopd) from the Spraberry Trend Area from more than 9,000 production wells. Recovery is poor, on the order of 7 – 10% due to the profoundly complicated nature of the reservoir, yet billions of barrels of hydrocarbons remain. We estimate over 15% of remaining reserves in domestic Class III reservoirs are in Spraberry Trend Area reservoirs. This tremendous domestic asset is a prime example of an endangered hydrocarbon resource in need of immediate technological advancements before thousands of wells are permanently abandoned.

Integrate solutions to technological, regulatory and data constraints – the technological and data constraints have resulted in a general lack of confidence for water injection in the Spraberry Trend. Regional variations in geology combined with highly permeable, stress-sensitive fractures and very low matrix permeability create intensely difficult technical challenges. The fact that several waterflood projects over the course of 40 years have failed to provide an adequate and definitive answer regarding the technical and economic feasibility of waterflooding is a testament to technological and data constraints. Simply by the magnitude of the number of wells, management practices are of paramount importance when optimizing water injection in the Spraberry Trend Area. Many companies operate wells outside the Spraberry Units and several zones are typically commingled. Regulatory and data acquisition constraints are a serious issue and pose a great challenge for waterflood operations in Spraberry reservoirs. Proper reservoir engineering in a reservoir that is so large and communicates, via the fractures, over great distances poses a complicated technological and data management constraint. Reservoir engineering, by definition, requires precise injection, production and pressure data. Acquisition and control of this data has always been a constraint to providing the optimum method for water injection. The result is large volumes of oil that could have been recovered via water injection that remain untapped. We believe we have reached a fundamental understanding of Spraberry reservoirs. Individual Spraberry wells will never produce large volumes of oil, however, if past constraints, barriers to production and a general lack of confidence in waterflooding can be overcome, even modest improvements in well productivity multiplied over such a vast area would result in rapid increase in production.

Field demonstration – a low risk, high potential demonstration of technological innovations will be completed within two years. A waterflood demonstration is proposed by the Harold Vance Department of Petroleum Engineering in the Spraberry Shackelford Unit with Pioneer Natural Resources as the operator and Exxon/Mobil as supporting owner. This field demonstration will be carefully monitored and may result in a rapid increase in Spraberry production.

ACCOMPLISHMENTS:

Task 1.0 Shackelford and Germania Unit Historical Review

- Reconstruction of Shackelford and Germania Injection/Production Data
- Development of production and database using Oil Field Manager (OFM)
- Development of field management software (FMS)
- Review well bore status in Shackelford Unit

Task 2.0 Review Midkiff Pilot

- Review of Upper and Lower Pilots in the Spraberry Area

Task 3.0 Develop production and database using OFM and Field Data Management software

Task 4.0 Development of optimum injection well patterns based on simulation

- Improving Waterflood and CO₂ Pilot Performance in the Naturally Fractured Spraberry Trend Area, West Texas

Task 5 Refine sub-surface maps for 1U and 5U oil saturated intervals

- Germania Unit Characterization using an Analog Field and Old Cased Hole Neutron

Task 6 Field demonstration

Modify strategy based on response and development of expansion plans

- Germania Unit rate forecasting based on other waterflood pilots in the Spraberry Area
- Evaluation of E.T O'Daniel Pilot

Task 7 History match and verification of simulation results

- Improving Waterflood Performance in the Naturally Fractured Spraberry Trend Area

SCHEDULED MILESTONES:

	Time (months)				
	0	6	12	18	24
Task 1. Shackelford and Germania Unit Historical Review	■				
Task 2. Review Midkiff Pilot	■				
Task 3. Develop production and database using OFM and Field Data Management software*	■				
Task 4. Development of optimum injection well patterns based on simulation	■				
Task 5. Refine sub-surface maps for 1U and 5U oil saturated interval	■				
Task 6. Field demonstration	■				
Task 7. History match and verification of simulation results	□				
Task 8. Technology Transfer	■				

* Software developed during this project

- Accomplished Milestones
- Proposed Milestones

REPORTS:

1. Putra, E. and Schechter, D.S.: “Review of Upper and Lower Pilots in The Spraberry Area,” report included in “Preferred Waterflood Management Practices for the Spraberry Trend Area – PUMP” Semi-Annual Report (DOE Contract No.: DE-FC26-01BC15274), Sept 1, 2001- March 1, 2002.
2. Putra, E., and Schechter, D.S.: “Germania Unit Rate Forecasting Based on Other Waterflood Pilots,” report included in “Preferred Waterflood Management Practices for the Spraberry Trend Area - PUMP” First Annual Report (DOE Contract No.: DE-FC26-01BC15274), April 1- Sept 31, 2002.
3. Lakshman, G., Putra, E., and Schechter, D.S.: “Evaluation of Current E.T O’Daniel CO2 Pilot,” report included in “Preferred Waterflood Management Practices for the Spraberry Trend Area - PUMP” First Annual Report (DOE Contract No.: DE-FC26-01BC15274), April 1- Sept 31, 2002.

4. Olumide, B.A.: “Germania Unit Characterization using an Analog Field and Old Cased Hole Neutron,” report included in “Preferred Waterflood Management Practices for the Spraberry Trend Area – PUMP” Semi-Annual Report (DOE Contract No.: DE-FC26-01BC15274), April 1 – Sept 31, 2003.

TECHNOLOGY TRANSFER ACTIVITIES:

Presentations

On October 6, 2003, we (Galaviz, J.) presented “Low-Rate Water Injection Enhances Recovery In The Naturally Fractured Spraberry Trend Area” at the international student paper contest at 2003 SPE Annual Technical Conference, CO. Mr. Galaviz won the first price.

On September 18, 2003, we presented the talk “Waterflood and CO₂ performance in the Naturally Fractured Spraberry Trend Area,” at the Statoil Research Summit 2003, Trondheim, Norway.

On June 2003, we presented the Short Course for Saudi Aramco in Al Khobar, Saudi Arabia – “Reservoir Characterization, Engineering and Enhanced Oil Recovery in Naturally Fractured Reservoirs.”

On March 2003, we presented the Short Course for UNAM/PEMEX in Mexico City, Mexico – “Reservoir Characterization and Engineering in Naturally Fractured Gas and Oil Reservoirs – Part II.”

On October 2001, we presented the Short Course for UNAM/PEMEX (National Petroleum Company of Mexico) in Mexico City, Mexico – “Reservoir Characterization and Engineering in Naturally Fractured Gas and Oil Reservoirs - Part I.”

On February 2001, we presented the Short Course for UNAM/PEMEX in Mexico City, Mexico – “Reservoir Characterization and Engineering in Naturally Fractured Gas and Oil Reservoirs – Part I.”

On June 13, 2002, we presented the "Imbibition and its Relevance to Waterflood Performance in the Naturally Fractured Spraberry Trend Area," at the Rice University and University of Houston invited lecture for Society of Petroleum Engineering Chapter, Duncan Hall, Rice University.

Papers and Publications

1. Schechter, D.S., Putra, E., Baker, R.O., Knight, W.H., McDonald, W.P., Leonard, P., and Rounding, C.: “CO₂ Pilot Design and Water Injection Performance in the Naturally Fractured Spraberry Trend Area, West Texas,” paper SPE 71605 presented at the 2001 Annual Technical Conference and Exhibition, New Orleans, LA, September 30–October 3.
2. Baker, R.O., Bora, R., Schechter, D.S., McDonald, P., Knight, W.H., Leonard, P., and Rounding, C.: “Development of a Fracture Model for Spraberry Field, Texas USA,” paper SPE 71635 presented at the 2001 Annual Technical Conference and Exhibition, New Orleans, LA, September 30–October 3.
3. Schechter, D.S., Putra, E., Knight, W.H., Leonard, P., and Baker, R.O.: “Improving Waterflood and CO₂ Pilot Performance in the Naturally Fractured Spraberry Trend Area, West Texas,” paper presented at the 2002 Conference on Naturally Fractured Reservoirs, Oklahoma, June 3-4.
4. Chowdhury, T., Dabiri, G., Putra, E., and Schechter, D.S.: “Improving Waterflood Performance in the Naturally Fractured Spraberry Trend Area,” paper presented at the 2002 Conference on Naturally Fractured Reservoirs, Oklahoma, June 3-4.
5. Alfred, D., Putra, E., and Schechter, D.S.: “Transcending Conventional Log Interpretation – A More Effective Approach for Spraberry Reservoir,” paper presented at the 2002 Conference on Naturally Fractured Reservoirs, Oklahoma, June 3-4.

Internet Postings on the Project and Software to Download

A description of our research group can be found at the following Petroleum Engineering Texas A&M Website: <http://pumpjack.tamu.edu/faculty/schechter/baervan/homepage.html>. The site lists the publications of our group and allows downloads of several papers, reports, and presentations.

CONTACT INFORMATION:

NAME: David Schechter

PHONE: 979/ 845-2275

FAX: 979/845-1307

E-MAIL: schech@spindletop.tamu.edu

DIGITAL PICTURES: