Recognizing Bell Canyon and Cherry Canyon "Behind Pipe" Pay Sands Reeves and Culberson Counties, Texas

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ABSTRACT

The difficulties in recognizing pay versus non-pay zones in the Permian Bell Canyon and Cherry Canyon sands in Reeves and Culberson counties are the result of: 1.) the presence of residual oil, 2.) the very fine grain size (Mz = 0.05 to 0.10mm), 3.) the high Rw values (Rw = 0.15 to 0.25 ohm-m) and 4.) the presence of authigenic chlorite and mixed-layered illite-smectite clays. The fine grain size and the authigenic clays result in high irreducible water saturations. These high irreducible water saturations together with the presence of residual oil in both pay and non-pay sands and high Rw values result in low resistivity contrast between pay and non-pay sands. In order to overcome these difficulties, a series of crossplots and core analysis were used to determine pay from non-pay zones in two wells.

Using net pay cut-offs of Vcl < 15% (dispersed clay), effective porosity (øe > 15% for 1.0 md) and Archie water saturation (Swa) < 60%, three "behind pipe" pay zones were identified in the two wells. These three zones have a combined hydrocarbon pore-meter thickness of 1.5 (5.0 pore-feet which calculates into 1.55 million barrels of oil in place assuming 40-acre drainage.

INTRODUCTION

The Permian (Guadalupian) Delaware Mountain Group in Texas and New Mexico is subdivided into the Bell Canyon, Cherry Canyon and Brushy Canyon formations. The Delaware Mountain Group is composed of multiple siltstones and very fine-grained sandstones interbedded with limestones and organic-rich shaly siltstones. These formations were deposited in the deep waters of the Delaware basin.

The siltstone (Mz = 0.05 to 0.06 mm) and sandstone (Mz = 0.08 to 0.10 mm) facies are composed of angular to subangular quartz and K-feldspar grains with minor dolomite and anhydrite cement. Authigenic chlorite and mixed-layered illite-smectite are present as pore lining (reservoir) or pore filling (non-reservoir) clays. Clays are also present in some of the siltstones as part of the detrital component in organic-rich microlaminae. However, in this study only the non-microlaminated "massive" zones were considered as reservoir rocks. Because the clays in these reservoir rocks are dispersed, a volume of clay (Vcl) cutoff of 15% was used in the net pay calculations as suggested by Dewan (1983).

The Delaware Mountain Group in the area of the Screwbean and Geraldine fields of Reeves and Culberson counties (Figure 1) has been oil productive since 1948. Most of the production is from the Bell Canyon (Ramsay sand) with lessor production from the Cherry Canyon and Brushy Canyon sands. However, many of the wells in this area do not penetrate below the upper Bell Canyon; therefore the true productive potential of the Cherry Canyon and Brushy Canyon sands is unknown.

PETROPHYSICS

General

The formation evaluation of the Delaware Mountain Group in the Screwbean and Geradine fields is often made difficult for the following reasons: 1.) lack of resistivity logs, 2.) "Delaware Effect" on older laterologs (Laterolog-3), 3.) very fine grain size, 4.) presence of authigenic clays, 5.) residual oil saturations, and 6.) elevated Rw values. This study is not concerned with the first two problems because both wells have modern resistivity logs.

The combination of very fine grain size (Mz = 0.05 to 0.10 mm) and authigenic clays result in low permeabilities even at high porosities. The fine grain size and the authigenic clays are also responsible for high irreducible water saturations (Sw irr). These high irreducible water saturation (Sw irr) values, together with the presence of residual oil in many of the water productive sands, result in a low resistivity contrast between oil and water productive zones. The elevated Rw values (Rw = 0.15 to 0.25 ohm-m) are the result of fresh water influx from outcrops to the west. These high Rw values also contribute to the low resistivity contrast between pay and non-pay sands.

A combination of core and log analysis was used to differentiate pay from non-pay sands in two example wells. The core analysis was used to determine the cementation exponent (m) and to determine a porosity/permeability cutoff. The log analysis consists of a series of crossplots to differentiate permeable from non-permeable zones, oil productive versus water productive zones and net pay. These crossplots include: 1.) q-Plot, 2.) Resistivity derived porosity (ør) versus total porosity (øt), 3.) Pickett plots, 4.) Archie water saturation (Swa) versus ratio water saturation (Swr) and 5.) Rxo/Rmf versus Rt/Rw (Dew Plot). The software for the log analysis was Shaly Sand Advisor (SSA; Brown and Walsh, 1992).

Core Analysis

Figure 2 is a crossplot of 46 core derived porosity versus permeability measurements measured on 3.8 centimeter (1.5 inch) core plugs. These core analyses were performed at the Center for Applied Petrophysical Studies (CAPS) at Texas Tech University. Note in Figure

2 that in order to have a permeability of 1.0 md, the porosity must be greater than 15%.

A cross plot of formation resistivity factor (Fr) versus core porosity has a slope of 1.80 (Figure 3), indicating an average cementation exponent (m) of 1.80. All these m measurements were made at CAPS on 3.8 centimeter (1.5 inch) core plugs under confining stress. The core derived cementation exponent (m) of 1.80 was then used to calculate Archie water saturations for the net pay determinations.

Log Analysis

Well #1

The first example well was drilled with fresh water mud (Rmf = 0.76 ohm-m @ 27°C) and was logged with the following log suite: Dual Induction-Laterolog-8 with self potential plus a gamma ray sonic log. In this well the Bell Canyon (Ramsay) sand was drill stem tested and 23 meters (75 feet) of slightly oil and gas cut mud plus 18 meters (60 feet) of mud cut salt water was recovered. Subsequently the Ramsay was perforated and 74 meters (243 feet) of salt water was recovered. Presently this well is plugged and abandoned.

Because only water was recovered from the Ramsay sand, apparent formation water resistivity (Rwa) was calculated (Rwa = 0.1 ohm-m). In addition, Rw was also determined from the SP log (Rw SP = 0.2 ohm-m). The Rwa and Rw SP values were then averaged (Rw = 0.15 ohm-m) and this value was used in our log analysis. It was assumed that Rw was constant because the magnitude of the self potential (SP) deflection is constant through the Bell Canyon and Cherry Canyon intervals. Laboratory measured values of produced water from two nearby wells ranged from 0.16 to 0.17 ohm-m at 23°C thus substantiating the log derived Rw values.

Using an Rw of 0.15 ohm-m, several sands in both the Bell Canyon and Cherry Canyon formations were analyzed. However, only one zone in the Bell Canyon, from 1077 meters (3532 feet) to 1094 meters (3590 feet), appeared to be productive. The upper 5 meters (16 feet) of this zone was drill stem tested and 110 meters (360 feet) of mud was recovered.

The first step in our analysis was to calculate the volume of clay (Vcl) using the gamma ray log (Figure 4). Even though the Bell Canyon and Cherry Canyon sands contain K-feldspars the adjacent organic-rich shaly siltstones contain similar amounts of K-feldspar. Therefore, when the gamma ray index (IGR) is calculated, the effects of K-feldspar are eliminated. Thomerson (1992) noted a similar relationship in his study of the Brushy Canyon sands in the Hat Mesa Delaware field in Lea County, New Mexico. Using the volume of clay (Vcl), the total porosity (øt) calculated from the sonic log was corrected to effective porosity (øe) and the amount of porosity filled with clay (q) was determined (q = [øt-øe]/øt). Using effective porosity (øe) and q, a shaly sand producibility plot (q-Plot; Altas Wireline, 1985) was constructed (Figure 4). Note on the q plot (Figure 4) that almost all of the data from this Bell Canyon sand cluster in the producible region. It is important to remember that the q-plot only indicates if there is reservoir quality rock. It does not indicate whether or not the zone in question will produce water or oil.

Figure 5 is a crossplot of resistivity derived porosity (ør) using the laterolog-8 (LL8) versus total porosity (øt) from the sonic log. Because there was not an Rxo log run, Rz (mixed water resistivity; Atlas Wireline, 1985) was used, instead of Rmf, to calculate resistivity porosity (ør). Note in Figure 5 that much of the Bell Canyon data cluster below line where resistivity porosity (ør) equals total porosity (øt) indicating residual hydrocarbons in the invaded zone. The resistivity log detects the presence of hydrocarbons as a loss in resistivity porosity because hydrocarbons are insulators. The highest amount of residual oil (i.e., data outside the dotted pattern) is present in the top 6 meters (20 feet) of the Bell Canyon zone (Figure 5). Figures 6 through 9 are all crossplots that are designed to determine if the Bell Canyon sand from 1077 meters to 1094 meters (3532 feet to 3590 feet) is hydrocarbon or water productive. On each of the crossplots (Figures 6 through 9) when the Bell Canyon data cluster in the wet regions of the crossplot the concomitant depths are indicated on the log by a dotted pattern. Figure 6 is a crossplot of resistivity derived porosity (ør) using deep resistivity (Rt) versus total porosity (øt). The data from the porous sand (Figure 6) cluster below the line (ør = øt; Sw = 100%) indicating the zone should be productive (Figure 6).

The Pickett plot (figure 7) from our Bell Canyon sand indicates that, at some of the depths, water saturations are less than 60%. Therefore, some of the zone should be productive. Note that none of the data cluster along the wet resistivity (Ro) line (Sw = 100%) which suggests hydrocarbons are present throughout the zone (Figure 7). Figure 8 is a crossplot of Archie water saturation (Swa) versus Ratio water saturation (Swr). On this crossplot note that the top 5 meters (16 feet) of the Bell Canyon sand plot outside the wet area of the plot (i.e. Swa and Swr < 60%; Fig. 8). The last crossplot is a Dew plot (Rs/Rz versus Rt/Rw). The Rs represents the resistivity measured by the laterolog-8. On the Dew plot (Figure 9), all the data cluster in the wet region indicating only minor movement of hydrocarbons. The lack of hydrocarbon movement is a result of the low permeability of these reservoirs due to the fine grain size and the authigenic clays.

Figures 10A and 10B are crossplot summaries of the wet Ramsay sand (Figure 10A) and the Bell Canyon sand from 1077 meters to 1094 meters (3532 feet to 3590 feet). Note in Figure 10A that the Ramsay sand from 783 meters to 792 meters (2570 feet to 2600 feet) has wet indications on all the hydrocarbon versus water crossplots (columns 3 through 6). Conversely, data from the Bell Canyon sand (Figure 10B) indicates the sand is productive in columns 3 and 4. In addition the upper 5 meters (16 feet) of the Bell Canyon sands appears productive in column 5 (figure 10B). We can conclude therefore that the upper part of Bell Canyon sand is productive. Figure 11A is a net pay summary for the Bell Canyon (Ramsay) sand using the following cutoffs: Vcl < 15%, øe > 15% and Swa < 60%. Using these net pay cutoffs, the Ramsay sand from 783 meters to 792 meters (2572 feet to 2600 feet) has no net pay. Conversely the Bell Canyon sand from 1077 meters to 1094 meters (3532 feet to 3590 feet) has 4 meters (13 feet) of net pay and 0.43 hydrocarbon pore-meters (1.4 pore-feet; Figure 11B).

Well #2

Well #2 was drilled with salt water mud (Rmf = 0.16 ohm-m @ 23°C) and was logged with the following log suite: dual laterolog (DLL) with micro-spherically focused log (MSFL) and a gamma ray neutron-density log. At the present time this well is producing from a Cherry Canyon sand. We will examine two additional zones in this well that may be productive. Other zones were examined in Well #2 but they appeared to be wet. The two potential zones include a Bell Canyon sand (Ramsey) and a Cherry Canyon sand 15 meters (50 feet) above the Cherry Canyon producing zone. An Rw of 0.15 ohm-m was used in the Ramsay sand same as in the previous well (i.e., Well #1). However, Rwa calculations from wet zones in the Cherry Canyon indicated a higher Rwa (Rw = 0.25 ohm-m).

Figures 12A and 12B are crossplot summaries of the two potential zones in the second well. Note in the Ramsay sand (Figure 12A) that columns 3 and 4 indicate productive, and column 5 indicates productive for most of the zone. The Cherry Canyon zone (Figure 12B) appears to be productive in all the columns (columns 3 through 6). Therefore, in Well #2 there are two potentially productive zones. Net pay summaries (Figures 13A and 13B) of the two potential zones using net pay cutoffs of Vcl < 15%, øe > 15%, and Swa < 60% reveal 5.5 meters (18 feet) of net pay in the Ramsay (Figure 13A) and 5.2 meters (17 feet) of net pay in the Cherry Canyon (Figure 13B). The hydrocarbon pore-meter thickness in the two zones are 0.55 (1.8 pore-feet) and 0.55 (1.8 pore-feet; Figures 13A and 13B).

SUMMARY

By combining core analysis with a series of logging crossplots three potentially productive "behind pipe" Bell Canyon and Cherry Canyon oil zones have been identified. These three potential zones are in two wells, one of which is a dry hole and the other is presently producing from the Cherry Canyon. It is important to point out to the reader that two of the logging crossplots that were used to differentiate pay from non-pay zones require a value for Rmf. Therefore, reliable values for Rmf are vital to the correct log interpretation.

Using net pay cutoffs of Vcl < 15% (dispersed clay), øe > 15% for 1.0md, and Swa < 60%, a total of 14.6 meters (48 feet) of net pay was identified in the three zones. This 14.6 meters (48 feet) of net pay has a total hydrocarbon pore-meter thickness of 1.5 (5.0 pore-feet). Assuming 40-acre drainage, these three zones could have a total original oil in place of 1.55 million barrels. Using a recovery factor of 17%, these three zones may have recoverable reserves of 263,000 barrels of oil (Table 1). However, using standard values for cementation exponent (m) results in a 9% to 13% decrease in volumetric oil reserves (Table 1).

The Delaware Mountain Group has been producing oil in the Screwbean and Geraldine fields since 1948. However, 44 years later it is still possible using petrophysics to identify potentially productive "behind pipe" zones with substantial oil reserves.

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ACKNOWLEDGEMENTS

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Table 1

Oil Reserve Changes with Changes in Cementation Exponent(m) for the Three Bell Canyon and Cherry Canyon Behind Pipe Pay Sands Reeves and Culberson Counties, Texas

Method	OOIP(40 ac.)	Recoverable Reserves(17% R.F.)
F=1/ø^1.80	1.55 million	263,000
F=0.62/ø^2.15	1.42 million	241,000
F=0.81/ø^2.0	1.37 million	233,000

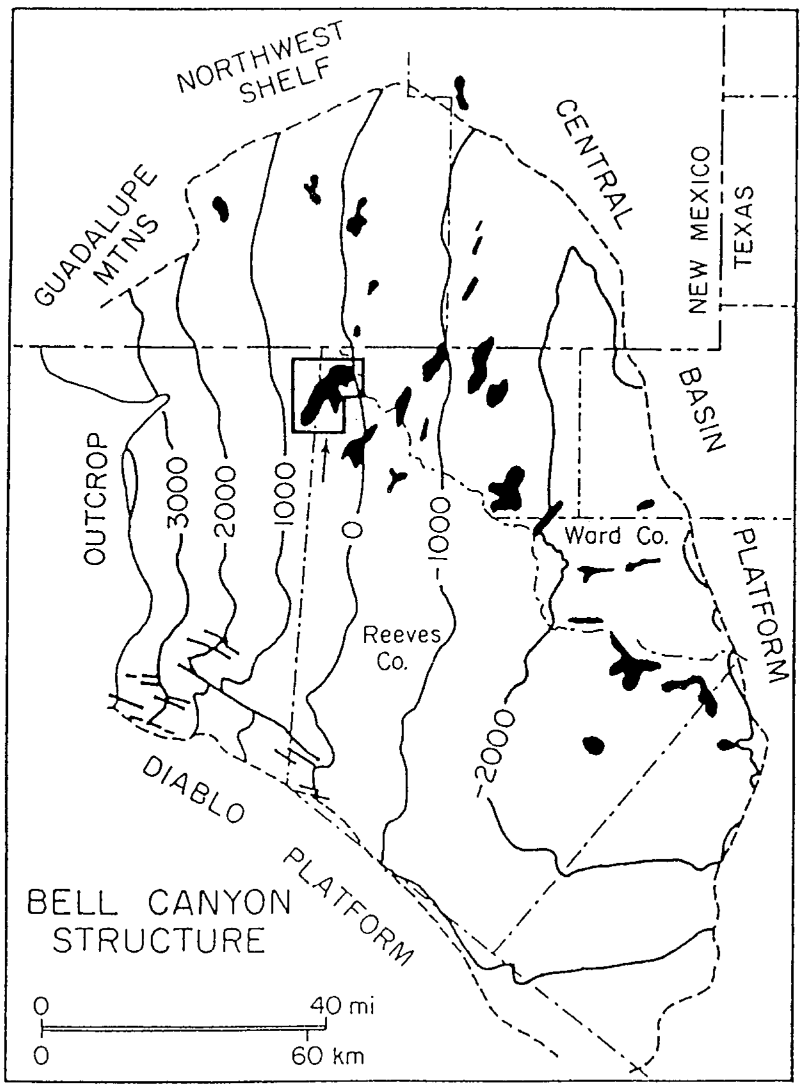

Figure 1 - Index map of the study area in Reeves and Culberson counties, Texas, in the area of the Screwbean and Geraldine fields.

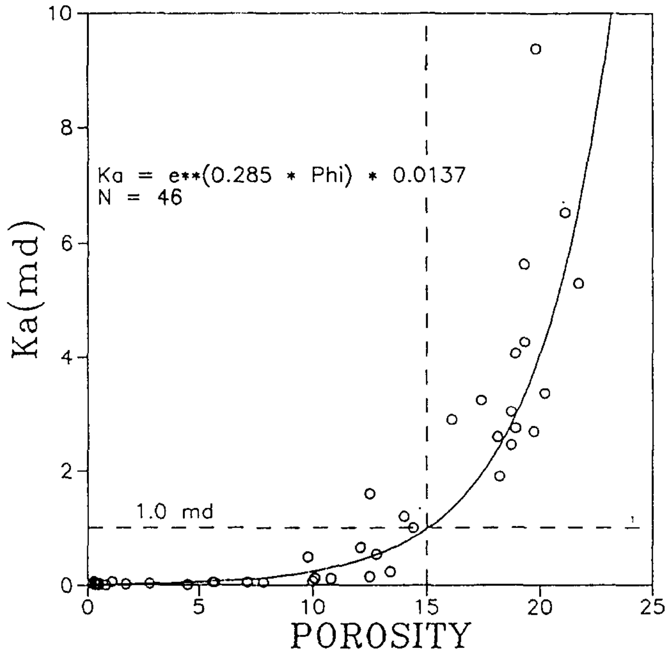

Figure 2 - Crossplot of core derived porosity versus permeability for the Bell Canyon and Cherry Canyon sands in Reeves and Culberson counties, Texas. Note that a porosity of 15% corresponds to a permeability of 1.0 md.

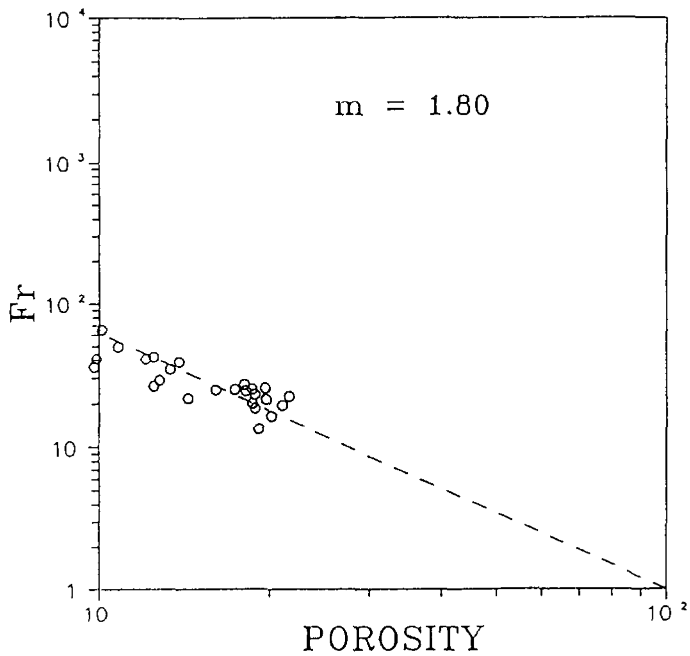

Figure 3 - Crossplot of formation resistivity factor (Fr) versus core porosity for the Bell Canyon and Cherry Canyon sands in Reeves and Culberson counties, Texas. The slope of the best fit line (slope = 1.80) *represents the average cementation exponent (m)* for the Bell Canyon and Cherry Canyon sands.

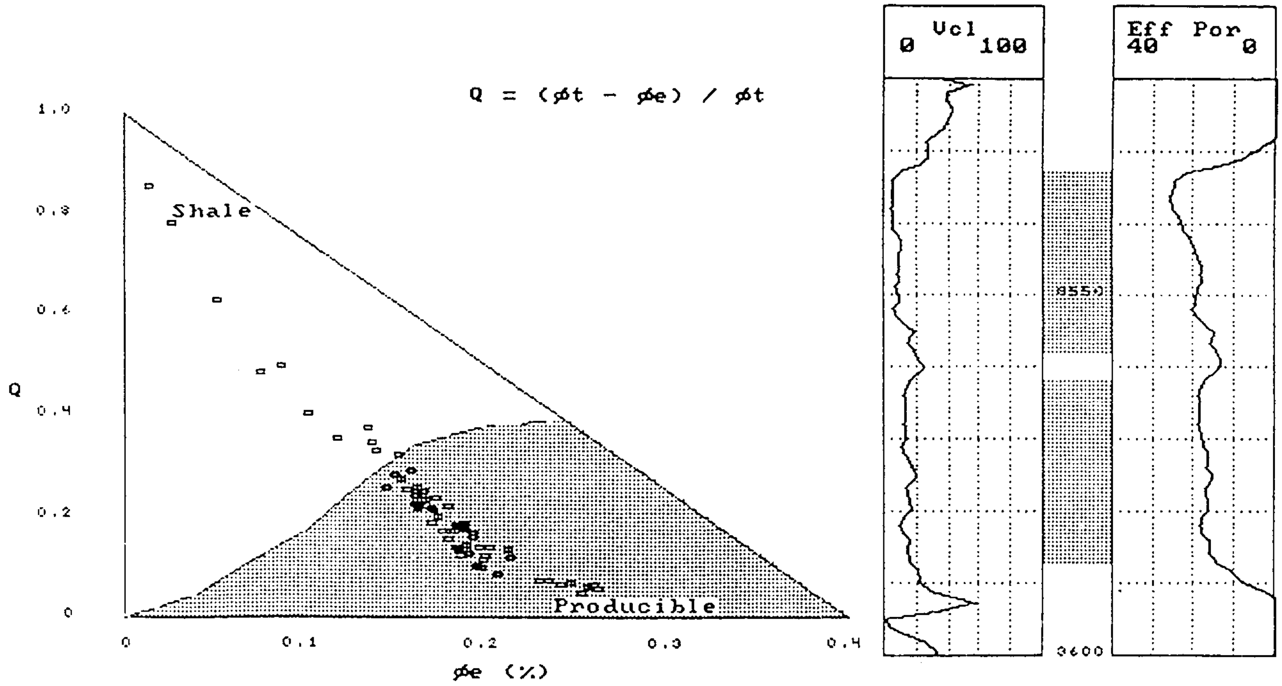

Figure 4 - Shaly Sand Producibility Plot (q-Plot) with volume of clay (Vcl) calculated from the gamma ray log for the Bell Canyon sand. Note that the majority of the data cluster in the producible region of the plot.

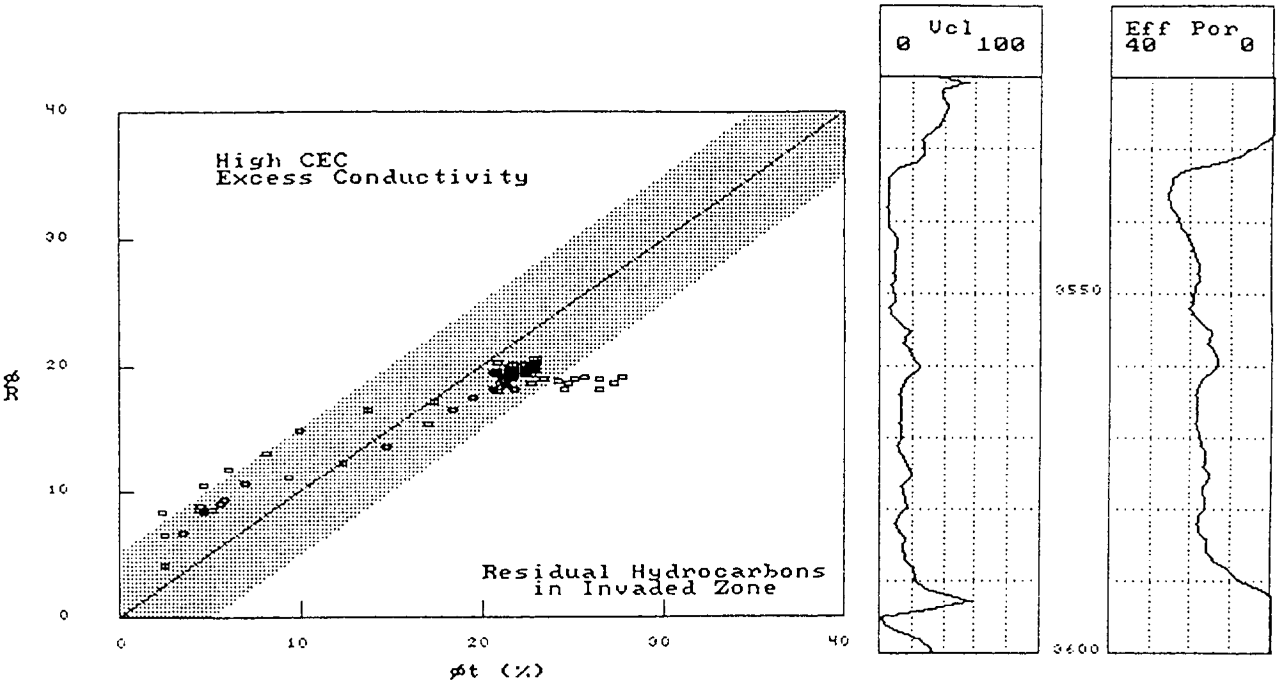

Figure 5 - Crossplot of shallow resistivity porosity (ør) versus total porosity (øt) for the Bell Canyon sand. The data that plot below the 45 degree line (ør = øt; Sw = 100%) represent residual oil in the invaded zone. The data that plot below and outside the dotted pattern represent the higher amounts of residual oil present in the top 6.1 meters (20 feet) of the zone.

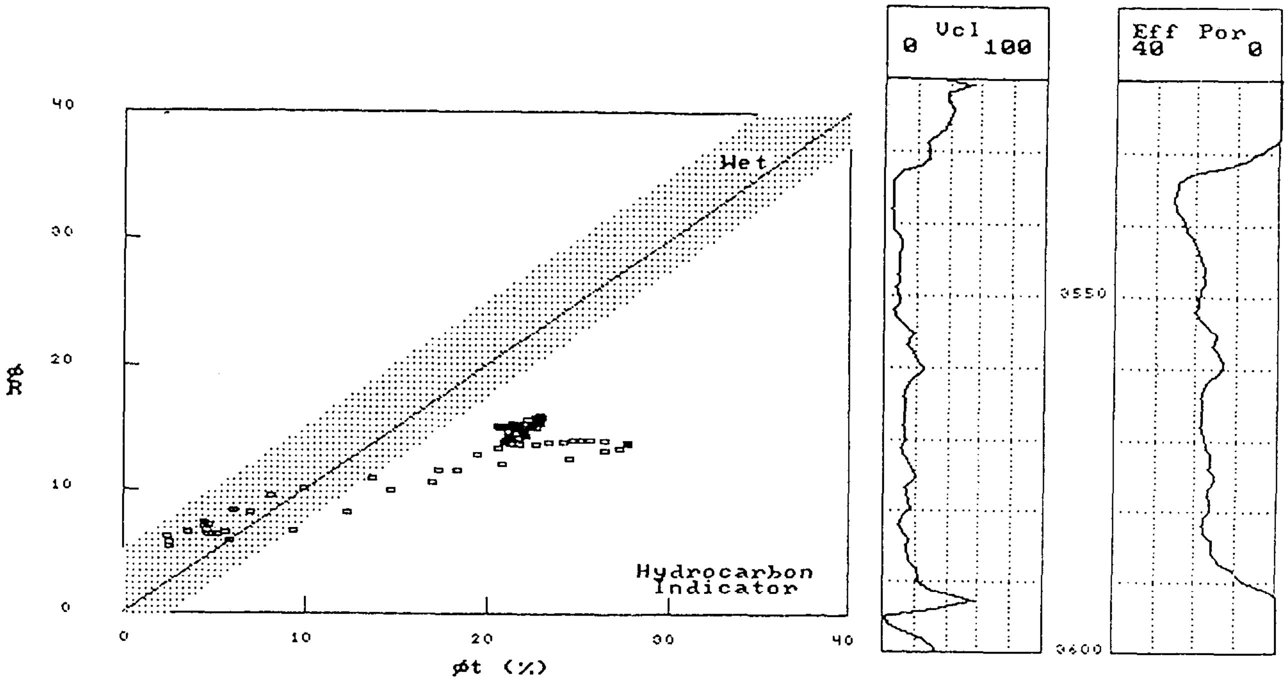

Figure 6 - Crossplot of invasion corrected deep resistivity (Rt) Porosity (ør) versus total porosity (øt) for the Bell Canyon sand. The data that plot below the dotted pattern are from the porous sand from 1080 meters (3542 feet) to 1094 meters (3590 feet) and indicate the presence of hydrocarbons in the uninvaded zone. The zone should therefore be productive.

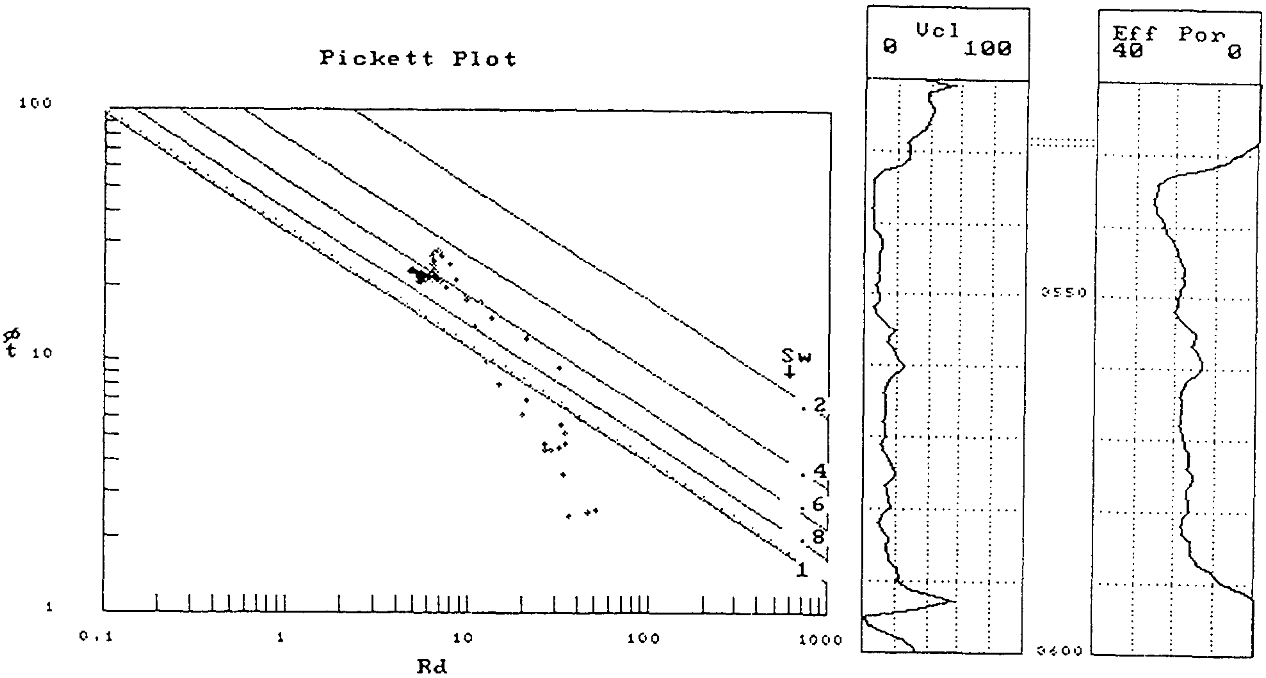

Figure 7 - Pickett Plot for the Bell Canyon sand. Note that a portion of the data plot above the Sw = 60% line (i.e. Sw < 60%) and that none of the data plot on the Ro line (i.e. Sw = 100%). The data that plot well below the Ro line are the result of wash-out.

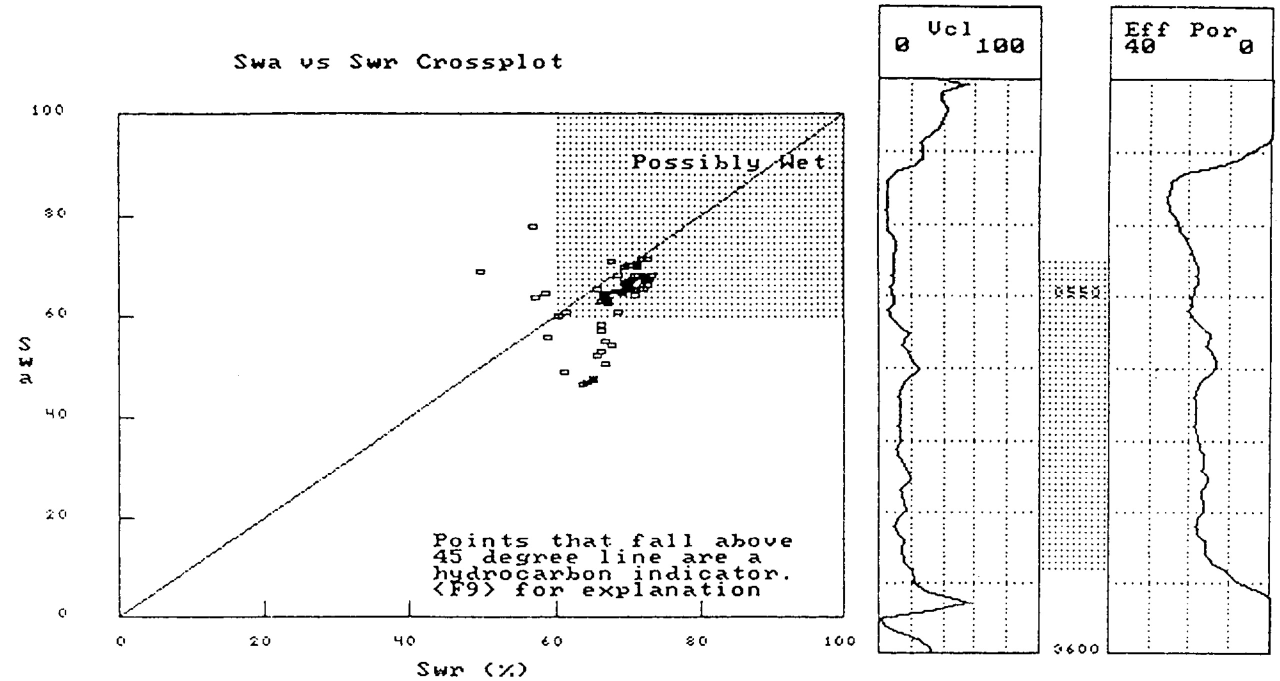

Figure 8 - Crossplot of Archie Water Saturation (Swa) versus Ratio Water Saturation (Swr) for the Bell Canyon sand. Note that below a depth of 1081 meters (3546 feet) to the bottom of the sand 1094 meters (3590 feet) the data cluster in the wet region. Conversely the top 5 meters (16 feet) of the sand from 1076 to 1081 meters (3530 to 3546 feet) appears productive.

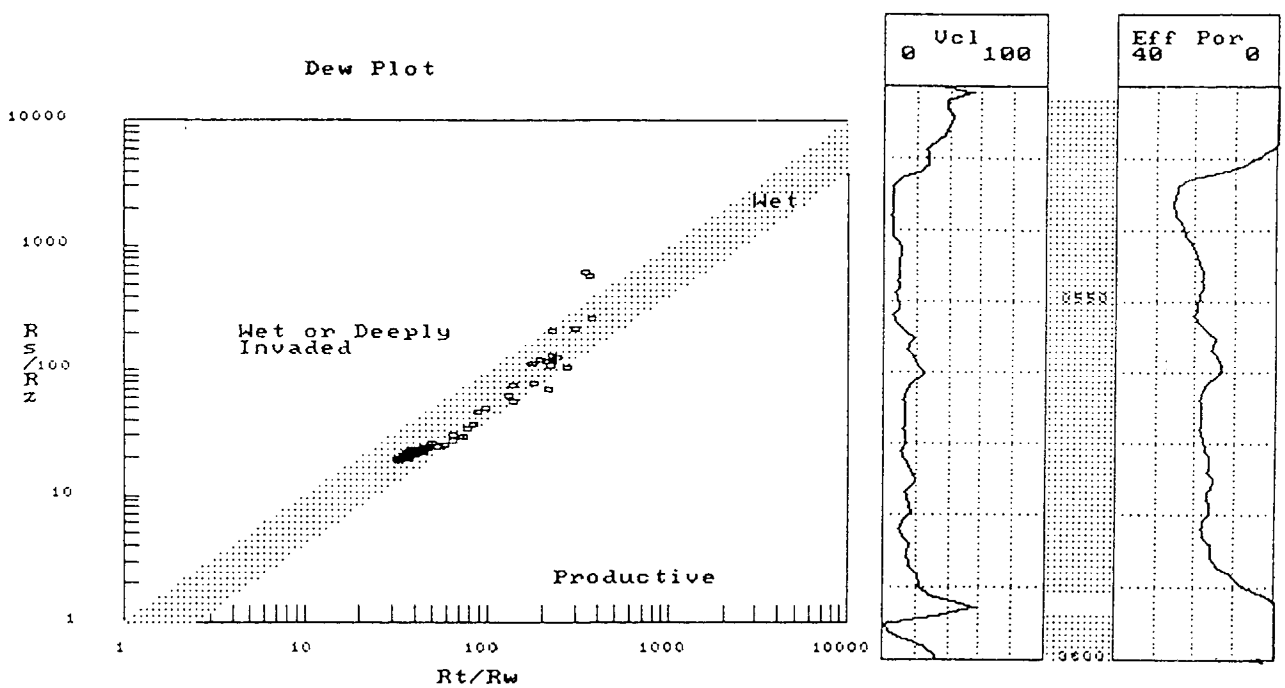

Figure 9 - Dew Plot (Rs/Rz versus Rt/Rw) for the Bell Canyon sand. Note that all of the data cluster above the productive line (Sw/Sxo > 0.7) indicating a lack of moved hydrocarbons. This lack of moved hydrocarbons is the result of the low permeability (i.e. high residual hydrocarbons see: Figure 5).

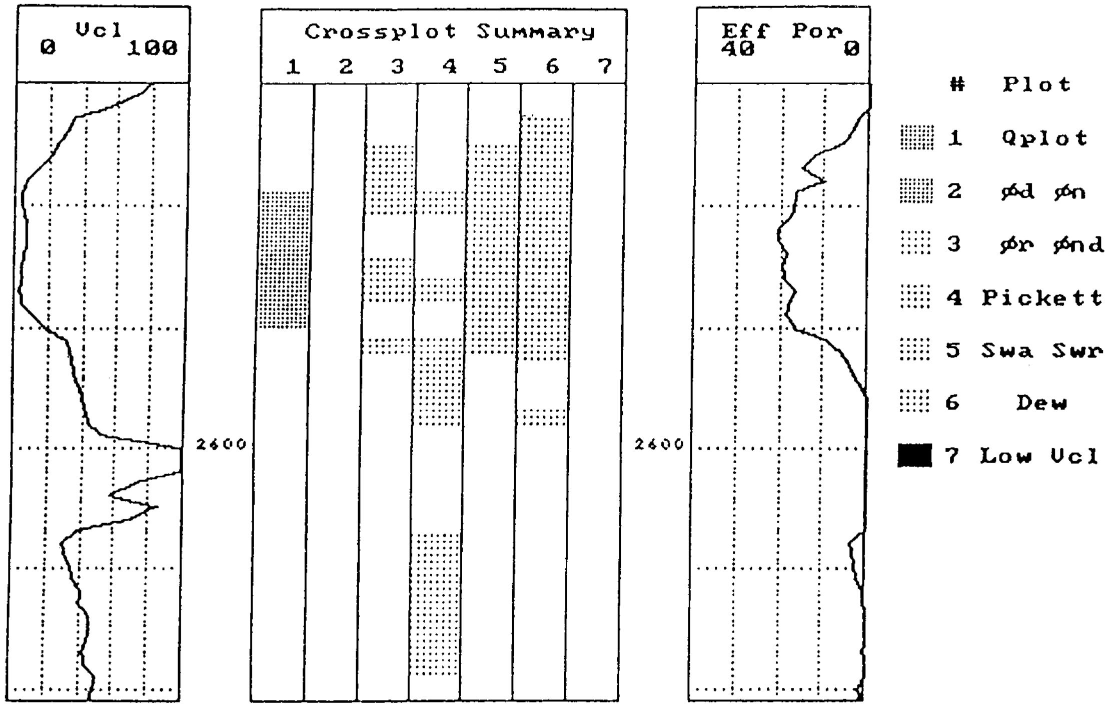

Figure 10a - Crossplot Summary for the water productive Bell Canyon (Ramsay) sand from 783 to 792 meters 2570 to 2600 feet). Note that on all the hydrocarbon versus water crossplots (columns 3 - 6), the Ramsay is indicated to be wet.

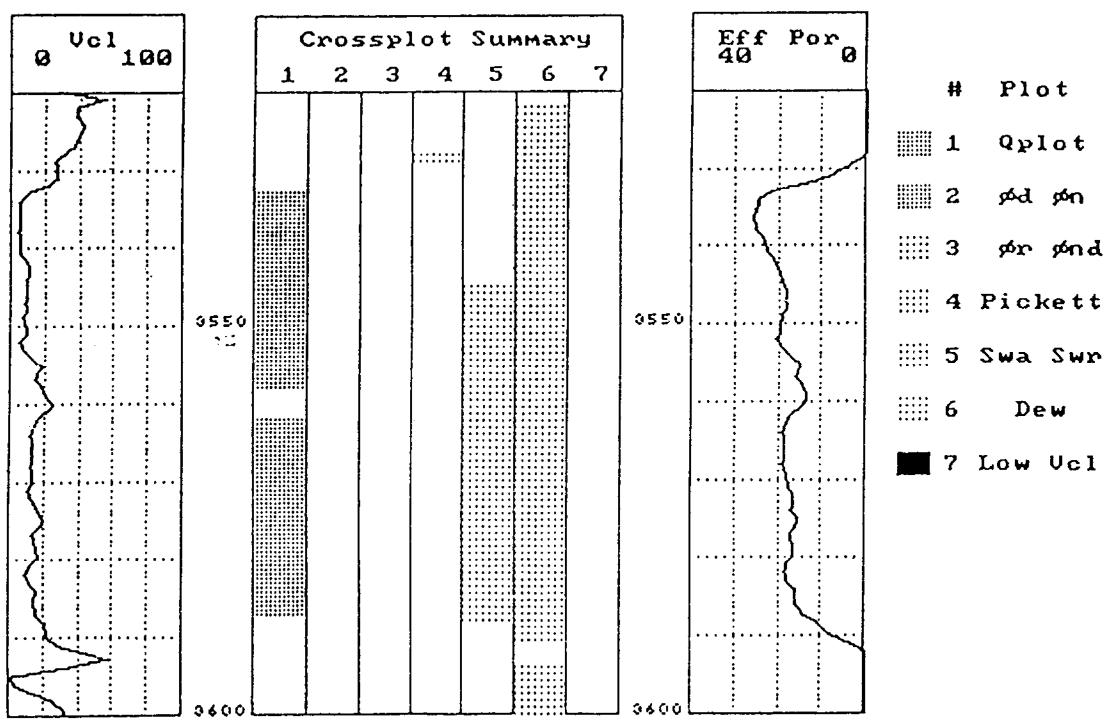

Figure 10b - Crossplot Summary for the potentially productive Bell Canyon sand from 1077 to 1094 meters (3532 to 3590 feet). Note that columns 3 and 4 (hydrocarbon versus water crossplots) indicate productive and column 5 indicates productive in the top 5 meters (16 feet). Only column 6 (Dew Plot) indicates water.

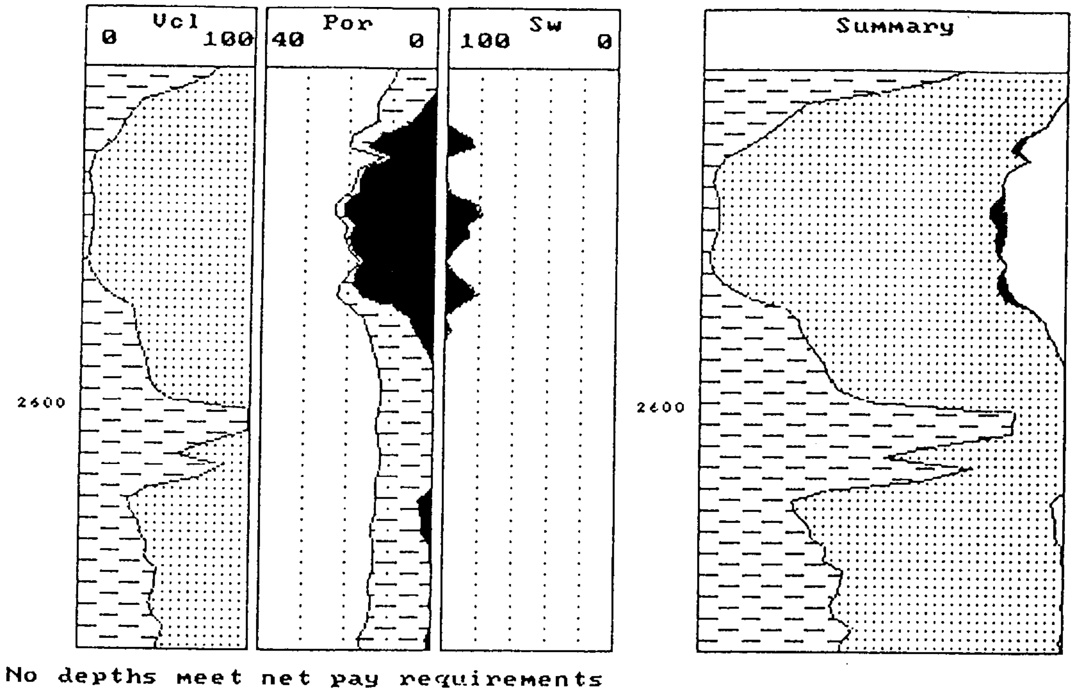

Figure 11a - Net Pay Summary for the water productive Bell Canyon (Ramsay) sand 783 to 792 meters (2570 to 2600 feet). Note that no net pay is indicated using the following cutoffs: Vcl <15%, øe > 15%, and Sw < 60%.

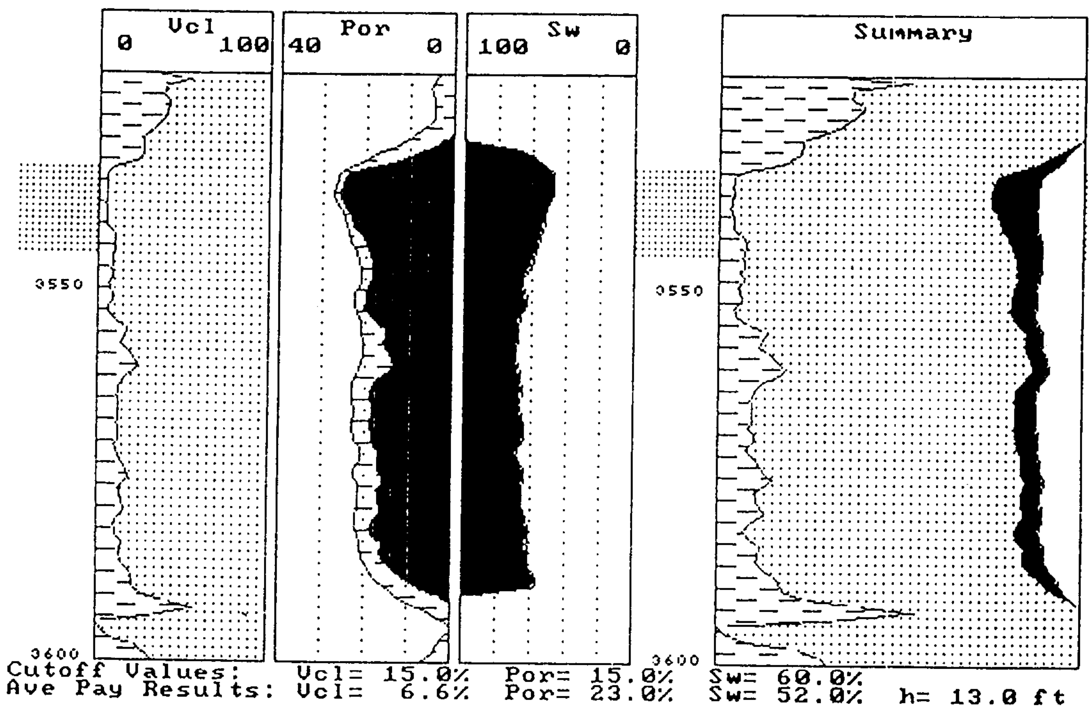

Figure 11b - Net Pay Summary for the potentially productive Bell Canyon sand 1077 to 1094 meters (3532 to 3590 feet). Note that there is 4 meters (13 feet) of net pay indicates with a concomitant hydrocarbon pore-meter thickness of 0.43 (1.4 pore-feet) using the following net pay cutoffs: Vcl < 15%, øe > 15%, and Sw < 60%.

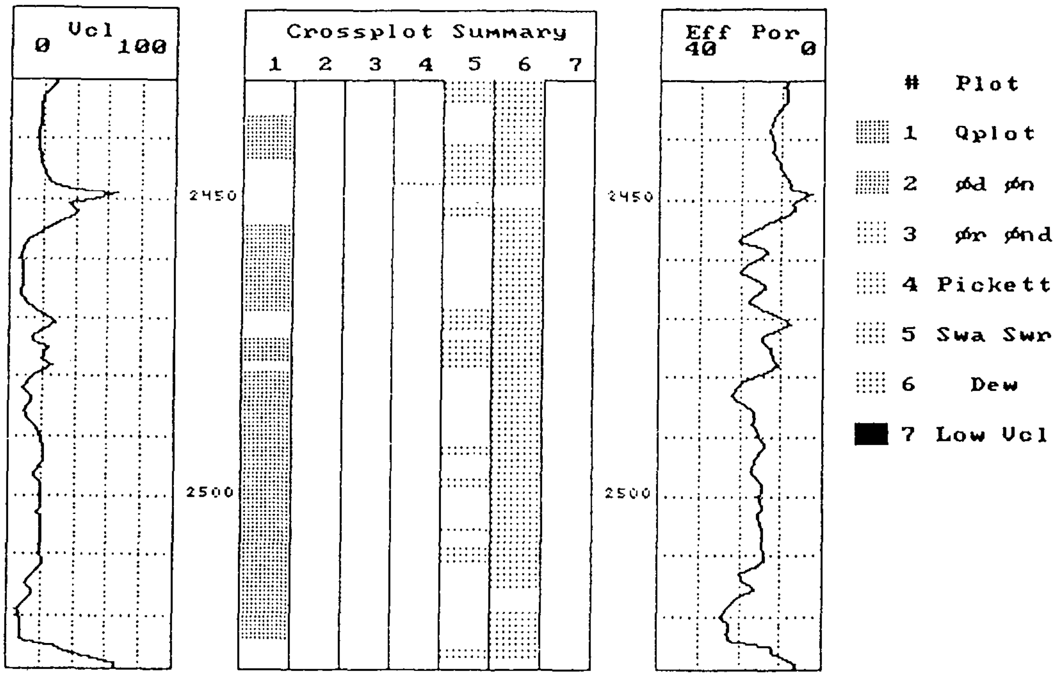

Figure 12a - Crossplot Summary for the potentially productive Bell Canyon (Ramsay) sand 741 to 770 meters (2430 to 2526 feet). Note that the permeable zones shown on column 1 are indicated to be productive on columns 3, 4 and most of column 5. Only column 6 (Dew Plot) indicates water.

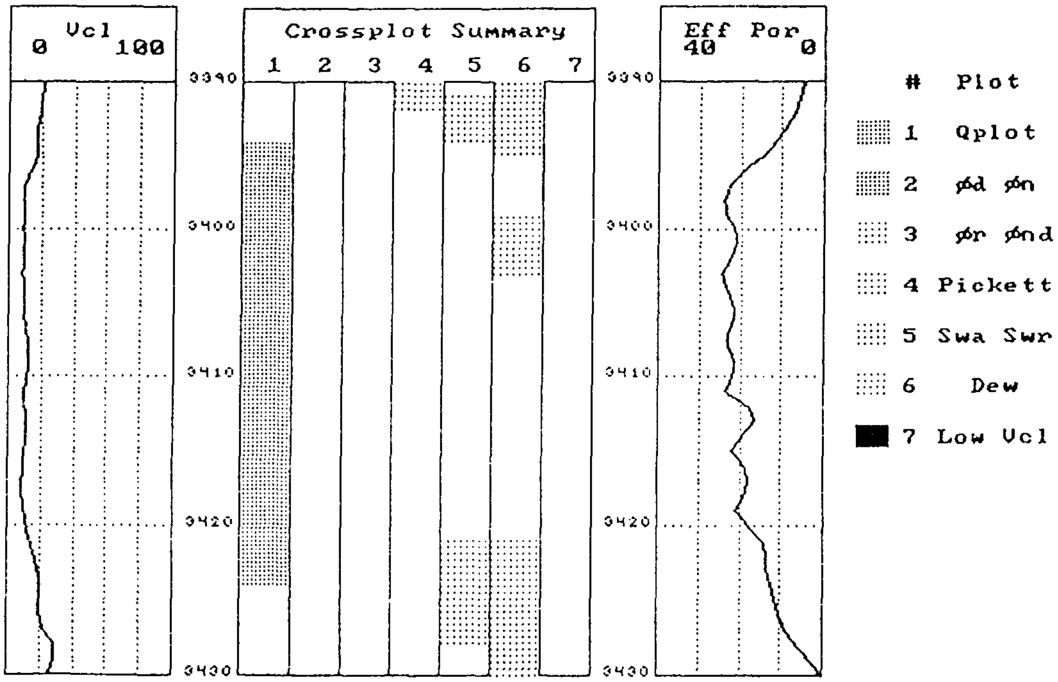

Figure 12b - Crossplot Summary for the potentially productive Cherry Canyon sand 1035 to 1044 meters (3396 feet to 3424 feet). Note that in columns 3 - 5 (hydrocarbon versus water crossplots) the zone appears productive over the permeable interval shown in column 1.

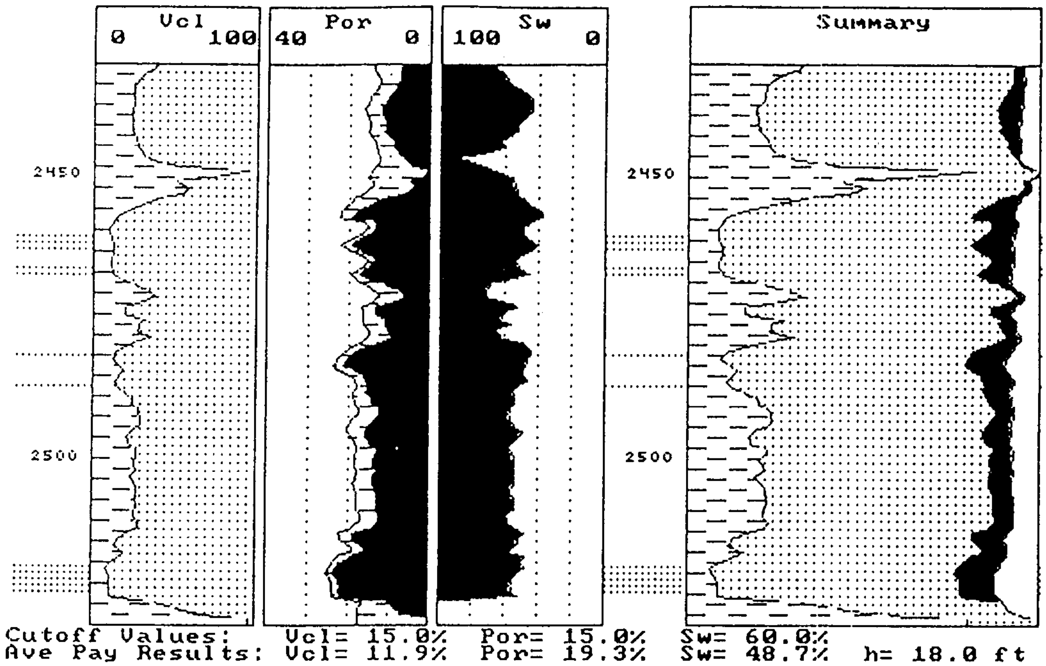

Figure 13a - Net Pay Summary for the potentially productive Bell Canyon (Ramsay) sand 741 to 770 meters (2430 to 2526 feet). Note that 5.5 meters (18 feet) of net pay is indicated with a concomitant hydrocarbon pore-meter thickness of 0.55 (1.8 pore-feet) using the following cutoffs: Vcl < 15%, øe > 15%, and Sw < 60%.

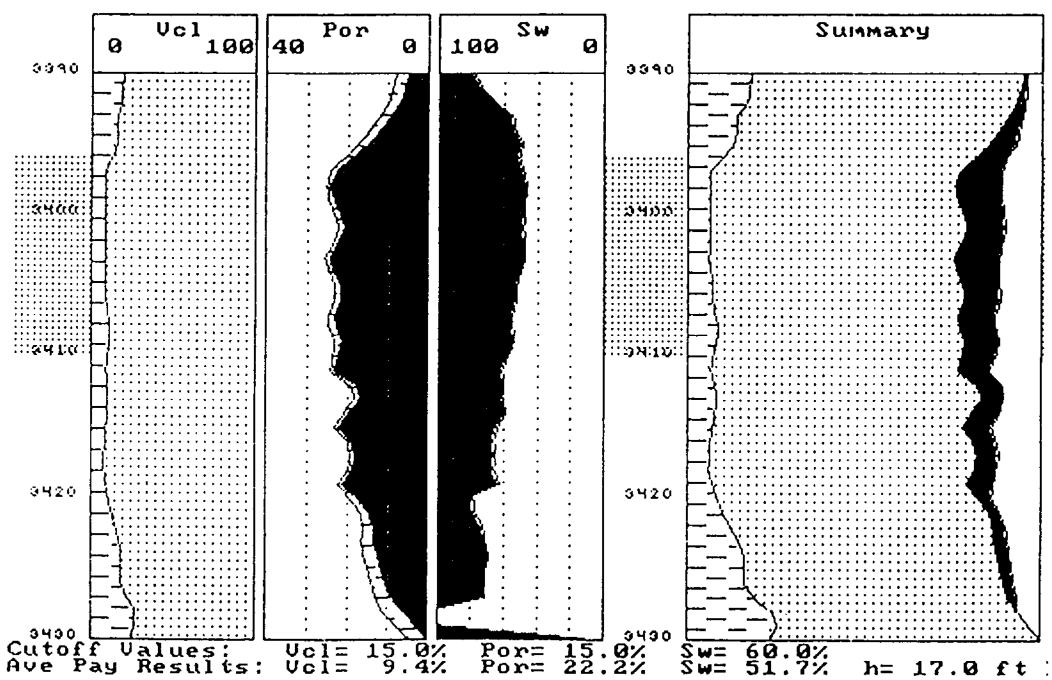

Figure 13b - Net Pay Summary for the potentially productive Cherry Canyon sand 1035 to 1044 meters (33996 to 3424 feet). Note that 5.1 meters (17 feet) of net pay is indicated with a concomitant hydrocarbon pore-meter thickness of 0.55 (1.8 pore-feet) using the following cutoffs: Vcl < 15%, øe > 15%, and Sw < 60%.