STUDY OF
MODELING OF WATER SATURATION
IN ARCHIE AND NON-ARCHIE POROUS MEDIA

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Approval of the Graduate School of Natural and Applied Sciences

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ABSTRACT

STUDY OF
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The aim of this thesis is to study water saturation models available in the literature and to apply a proper one to a real field case.

Archie equation is the most well-known water saturation model. However, it is formulated on some assumptions and is applicable to only clean sands. Archie equation cannot be used for shaly formation. There are many shaly water saturation models that account for shale effect for water saturation estimation.

In this study, 3 wells, namely Well-01, Well-02 and Well-03 are studied. These wells lie in a fractured carbonate reservoir located in Southeastern part of Turkey. From well log recordings, the production formation is seen almost clean. In other words, the shale amount of the formation is so small that it can be neglected. Thus, to calculate the water saturation in those wells, the well-known Archie water saturation equation is used. Since the formation is fractured carbonate, the cementation factor (m) and saturation exponent (n) of conventional value of "2" each cannot be used for the water saturation calculation. Instead, these parameters are obtained from generalized crossplot of log-derived porosity and resistivity technique.

Finally, each well is divided into zones using porosity data. Zonation is conducted based on statistical method, ANOVA (analysis of variance). Well-01 and Well-02 are both divided into two zones. On the other hand, the statistical method was initially divided Well-03 into three zones. However, Well-03 is better described as a whole zone, depending on the geological analysis and engineering judgment. After the zonation, the zones are correlated from well to well. The water saturations in significantly correlated zones are examined. Also, using the same statistical method, the water saturation zones are identified. However, these zones do not coincide with the porosity zones. This difference is attributed to pore size distribution and wettability which affect saturation distribution.

Keywords: *water saturation, Archie equation*, *statistical zonation, cementation factor and saturation exponent.*

ÖZ

ARCHIE VE ARCHIE OLMAYAN GÖZENEK ORTAMDAKI
SU SATURASYON MODELLEMENIN CALISMASI

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Yüksek Lisans, Petrol ve Doğal Gaz Mühendisliği
Tez danışmanı: Prof. Dr. Ender Okandan

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Bu tezin amacı literatürdeki su doymuşluk modellerini inceleyip uygun birinin gerçek sahada kullanılmasıdır.

Archie denklemi en çok bilinen su doymuşluk modelidir. Ancak, bu denklem bazı varsayım üzerine kurulmuştur ve sadece temiz kum tabakalarında uygulanabilir. Archie denklemi şeylli tabakalarda kullanılamaz.

Bu araştırmada 3 kuyu, Kuyu-01, Kuyu-02 ve Kuyu -03 incelenmiştir. Kuyular Türkiye'de Güney AnaDoludaki çatlaklı kalker bir reservuardan üretmektedir. Kuyu loglarından, üretim formasyon tamamen temiz görünmektir, bir başka deyişle, üretim formasyondaki şeyl miktarı ihmal edilebilecek kadar az bulunmaktadır. Bu yüzden, Archie denklem su doymuşluk miktarının hesaplanmasında kullanılmıştır. Fakat bu hesaplamada, formasyon çatlaklı kalker olduğundan, çimento faktör ve su doymuşluk katsayısı, geleneksel değer olan "2" olarak alınmamıştır. Bunun yerine, bu parametrelerin değerleri log resistivite ve gözeneklik krosplot teknik kullanılarak çıkartılmıştır.

Son olarak, her kuyu kendi gözeneklik değerlerini kullanılarak katmanlara bölünmüştür. Katmanlama, istatistik metot olan ANOVA ile gerçekleştirilmiştir. Kuyu-01 ve Kuyu-02 ikişer katmanlara ayrılmıştır. Diğer taraftan, istatistik metot

Kuyu-03'u üç katmana ayırmıştır. Ancak jeolojik analiz ve mühendislik kararı altında, Kuyu-03 tek bir katman olarak alınmıştır. Daha sonra, katmanların kuyudan kuyuya bağlantısı belirlenmiştir. Su doymuşluğunun bağlantılı olan katmanlar boyunca benzerliğine bakılmıştır. Ayrıca aynı istatisik metot kullanılarak su doymuşluk katmanları belirlenmiştir. Ancak bu katmanlar gözeneklik katmanlarıyla uyumlu bulunmamıştır.

Anahtar kelime: *su doymuşluğu, Archie denklemi*, *istatistik zonlama, çimento faktörü ve su doymuşluğu katsayısı* .

To my mother & in memory of my father

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a = a tortousity factor

B = the equivalent conductance of sodium clay exchange cations

B =the variance between zones

C =bulk volume fraction of water

C_t = formation true conductivity

C_w = formation water conductivity

F = formation factor

F^* = the intrinsic formation factor for a shaly sand

i = the summation index for the number of zones

j = the summation index for the number of data within the zone

L = the number of zones

m = the cementation factor

m_i = the number of data in the i th zone

N = the total number of data

n =the saturation exponent

n_h and n_i = the number of data in the h th and i th zones

Q_v = the cation exchange capacity per unit volume

R =the zonation index

R_o = the resistivity of a 100% water (brine)-saturated sandstone

R_t = the true resistivity of the rock saturated with both formation water and hydrocarbons

R_w = the water (brine) resistivity

s =the standard deviation of all the porosity data from the reservoir

S_w = water saturation

S_{wi}=irreducible water saturation

v and p = used to identify z -values

W = the pooled variance within zones

X =Non-Archie term or excess conductivity to due the presence of clay

X_i = the mean of the porosity data in the i th zone

x_{ij} = the porosity data

Y_h = the arithmetic average of the porosity data of the h th zone in one well

Y_i = the arithmetic average of the porosity data of the i th zone in an adjacent well

z = a constant tabulated as a function of the number of data, the number of zones and probability level

μ = the overall mean of the data in the well

CHAPTER 1

INTRODUCTION

In order to calculate the hydrocarbon reserve in a formation, one needs to know the water saturation amount. Improper calculation of water saturation leads to great errors in reserve estimation.

The Archie equation is well known for determining water saturation of a reservoir rock and therefore, initial hydrocarbon reserve estimation of the reservoir. Archie introduced an equation, which relates resistivity index (RI) and formation resistivity factor (F) in order to calculate water saturation. Using this equation, water saturation is computed (Archie G.E, 1942). The formation resistivity factor, F is related to porosity, and the resistivity index, RI, is related to the water saturation. Archie's equation requires the values of cementation exponent, m, saturation exponent, n and the rock consolidation factor, a. The equation was not a precise one, as he pointed out, and was only an approximate relationship. The conventional procedure to determine m and n parameters is by the crossplot techniques. Plotting formation resistivity factor, FR, versus core or log porosity on the log-log paper is used to find a and m values. The value of m is the slope and a is the intercept. S_w is plotted against resistivity index, RI, to find the value of n.

However, Archie equation is valid for Archie reservoir rock or clean sands (Worthington P.F, 1985). If a reservoir rock, which is electrochemically clean, in other words, conduction takes place only through the free ions within the formation water, and then reservoir rock is called an Archie reservoir rock or Archie porous media. However, all reservoirs are not clean sand. They contain shale. This condition is called non-Archie condition and thus, a porous media containing shale or clay is named as non-Archie porous medium. The Archie equation can not be applied for the S_w for shaly section of the reservoir. There are water saturation models addresing the clay effect.

1.1. LITERATURE SURVEY ON WATER SATURATION MODELS

1.1.1. ARCHIE EQUATION

In 1942, Archie derived two emprical relationships, namely, resistivity index and formation factor. His first equation introduces a relationship between the resistivity index (RI) and water saruration (S_w) which is given in Eq. 1.1

$$RI = \frac{R_t}{R_o} \tag{1.1}$$

where,

R_t is the true resistivity of the rock saturated with both formation water and hydrocarbons;

R_o is the resistivity of a 100% water (brine)-saturated sandstone; and

n is the saturation exponent

Archie's second equation gives the correlation between the formation factor (F) and porosity (Φ), given in Eq. 1.2

$$F = \frac{R_o}{R_w} = \frac{a}{\Phi^m} \tag{1.2}$$

where,

R_w is the water (brine) resistivity; and

m is the cementation factor.

a is a tortousity factor.

The difference between R_o and R_w is due to the presence of the matrix.

Combining Eqs. 1.1 and 1.2 gives Archie's well known equation for water saturation.

$$S_w = \left(\frac{1}{RI}\right)^{\frac{1}{n}} = \left(\frac{F * R_w}{R_t}\right)^{\frac{1}{n}} \rightarrow$$

$$S_w^n = \frac{aR_w}{\Phi^m R_t} \quad (1.3)$$

As mentioned before, Archie derived Eq. 1.1 on three implicit assumptions:

1- The saturation and resistivity relationship is unique so only one resistivity is measured at a given saturation,
2- The saturation exponent *n* is a constant for a given porous medium and
3- Solely, the brine in reservoir rock is electrically conductive.

These assumptions are valid if and only if the reservoir rock is strongly water wet. Moreover, Archie equation does not address the presence of clays and clay minerals.

1.1. 2. SHALY (NON-ARCHIE) WATER SATURATION MODELS

Clay acts as an electrolytic conductor in the matrix and also adds another path of conduction for the ions in parallel to the formation water. Because a clay mineral when wetted with water dissociates into conducting positive ions and a non-conducting negatively charged mineral framework. Due to the attraction force between negative and positive ions, the positive ions can not go very far from their stationary negative framework. However, these positive ions can move freely as long as they are adjacent to the solid mineral framework.
The extent to which clay affects the resistivity of the rock depends on the quantity and the chemical structure.

In terms of conductivity, the Archie equation is

$$C_t = \frac{C_w}{F} S_w^n \quad (1.4)$$

where,

C_t - formation true conductivity

C_w - formation water conductivity

F - formation factor

S_w - water saturation

n - saturation exponent

The general form of a shaly water saturation model is

$$C_t = \frac{C_w}{F} S_w^n + X \qquad (1.5)$$

where,

X - Non-Archie term or excess conductivity to due the presence of clay.

Since 1950, the shaly-sand problem has been fully recognized and addressed. The shaly-sand models introduced ever since that, have been divided into two main groups (Worthington P.F, 1985):

i) Concepts based on the shale volume fraction, V_{sh}. These models have the disadvantage of being scientifically inexact with the result that they are open to misunderstanding and misuse. On the other hand they are at least notionally applicable to logging data without the encumbrance of a core sample calibration of the shale related parameter.

ii) Concepts based on the ionic double-layer phenomenon. These models have a more attractive scientific pedigree. If strictly applied, they require core-sample calibration of the shale related parameter against log derivable petrophysical quantity. Otherwise their field application might involve approximations, which effectively reduce the shale term to 1 in V_{sh}.

1. 1. 2. 1. V_{sh} MODELS

The quantity, V_{sh}, is defined as the volume of wetted shale per unit volume of reservoir rock. This definition takes account of chemically bound waters; in this respect, it is analogous to that of total porosity.

V_{sh} Models are tabulated as below.

Table 2.1 V_{sh} Models for hydrocarbon zone

$C_t = \frac{C_w}{F} S_w^n + V_{sh}^2 C_{sh}$	Hossin (1960)
$C_t = \frac{C_w}{F} S_w^n + V_{sh} C_{sh}$	Simandoux (1963)
$C_t = \frac{C_w}{F} S_w^n + V_{sh} C_{sh} S_w^n$	Bardon & Pied (1969)
$\sqrt{C_t} = \sqrt{\frac{C_w}{F}} S_w^{n/2} + V_{sh} \sqrt{C_{sh}}$	Worthington (1985)
$\sqrt{C_t} = \sqrt{\frac{C_w}{F}} S_w^{n/2} + V_{sh}^{1-\frac{V_{sh}}{2}} \sqrt{C_{sh}} S_w^{n/2}$	Poupon and Leveaux (1971)

The field application of V_{sh} models usually requires that V_{sh} should be estimated at each designated level using one or more shale indicators. A shale indicator is simply a conventional log or log combination whose response equations can incorporate a shale fraction terms. V_{sh} approach has retained an important role in formation evaluation because of the fact that V_{sh} is at least notionally log derivable.

Apart from the unavailability of a "universal" V_{sh} equation there is one other major disadvantage of V_{sh} models; the V_{sh} parameter does not take account of the mode of distribution or the composition of constituent shales. Since variations in these factors can give rise to markedly different shale effects for the same numerical shale fraction, improved models were sought which did take account of the geometry and electrochemistry of mineral-electrolyte interfaces.

1.1. 2. 2 DOUBLE-LAYER MODELS

Double-layer models are tabulated as below.

Table 2.2 Double-Layer Models for hydrocarbon zone

$C_t = \frac{C_w}{F} S_w^n + \frac{BQ_v}{F^*} S_w^{n-1}$	Waxman & Smith (1968)
$C_t = \frac{C_w}{F} S_w^n + \frac{(C_{bw} - C_w) v_Q Q_v}{F_0} S_w^{n-1}$	Dual-water model: Clavier et al. (1977)

Waxman and Smiths (1968) explained the physical significance of the quantity X in terms of the composite term BQ_v/F^*, where Q_v is the cation exchange capacity per unit volume, B is the equivalent conductance of sodium clay exchange cations (expressed as a function of C_w at 25°C) and F^* is the intrinsic formation factor for a shaly sand.

Clavier et al. (1977,1984) sought to modify the Waxman-Smiths equation to take account of experimental evidence for the exclusion of anions from the double layer. This was done in terms of a "dual water" model of free (formation water) and bound (clay) water. It was argued that a shaly formation behaves as though it were clean, but with an electrolyte of conductivity that is a mixture of these two constituents.

The double-layer models do offer physical interpretations of X (non-archie term) that are electrically compatible, at least in theory. However, there are no established techniques for the direct down hole measurement of X as interpreted in these models. Nevertheless, because these models represent X through electrochemical and geometrical parameters that can be measured in the laboratory, they would appear to afford a means of calibrating a log-derivable petrophysical parameter in terms of appropriate shale related quantity. Indeed, the field application of the double-layer models has followed this very philosophy of indirectness. For instance, Lavers et al. correlated Q_v with porosity for North Sea reservoirs. Johnson and Linke correlated cation exchange capacity with gamma ray response (Worthington, 1985).

While it is recognized that both V_{sh} and the double layer models suffer from deficiencies as regards field application, both approaches are also seriously affected by problems concerning laboratory measurement. A determination of X in the laboratory can be accomplished in two ways; by direct measurement of the constituent parameters, or by the multiple-salinity indirect approach, whereby values of C_o recorded at several different values of C_w are used to determine F, and hence by calculation X. The direct laboratory determination of V_{sh} is theoretically possible, but even if it were meaningful there remains the problem of C_{sh}. The indirect approach will provide a quantitative estimation of some function of V_{sh} and C_{sh}, but it will not separately resolve these quantities. The direct measurement of Q_v is feasible, but it is well known that different techniques furnish different results. A decision is required as to which measurement is likely to be the most meaningful in the light of the intended application.

CHAPTER 2

THEORY

2.1. THEORY ON WATER SATURATION

To calculate water saturation of a well, one needs to know the true formation resisitivity, formation water resistivity and porosity value. Apart from these, the important parameters needed for the calculation of water saturation are

- cementation factor, *m*
- saturation exponent, *n*
- tortousity factor, *a*

Cementation factor, *m,* shows the degree of the cementation . Cementation factor varies for different rock types. Its value ranges from the 1.3 to 2.8. However, it is usually assumed to have a value of 2.

Saturation exponent, *n,* is an essential parameter in petrophysics, since it determines a quantitative relationship between the electrical properties of a reservoir rock and its formation water saturation. In literature, the saturation exponent is reported between less than 2 (for strongly water-wet rocks) and above 25 (strongly oil-wet rocks) (Ara T.S et al, 2001). Like cementation factor, it is conventionally equal to 2. Tortousity factor, *a* is usually assumed to be equal to the value of unity.

Obviously, incorrect assumptions of the values of these parameters lead to errors in estimated water saturation, and consequently in reserve estimates. Ideally, these parameters should be obtained from laboratory measurements on reservoir rock samples and fluids obtained from the zone, the well, or the reservoir under study. This is rarely conducted because these experiments are time consuming and it is difficult to obtain representative core samples from a zone.

Therefore, it is a convention to assume the cementaion factor and saturation exponent are both equal to a value of “2”.

However, if the well log data is available, the use of log-derived resistivity and porosity crossplots technique can be employed to determine these parameters (Sanyal S.K and Ellithorpe J.E ,1978).

2.1.1. THE GENERALIZED CROSSPLOT METHOD

One means of obtaining the value of *m*, *n* and *a* without recourse to core analysis is the generalized crossplot of log derived resistivity-porosity approach as explained below.

Archie Equation is:

$$S_w^n = \frac{aR_w}{\Phi^m R_t} \tag{2.1}$$

Taking logarithms of both side of the Equation (2.1) gives:

$$n \log S_w = \log(aR_w) - m \log(\Phi) - \log(R_t) \tag{2.2}$$

Rearranging it, the following form is obtained:

$$\log R_t = -m \log(\Phi) + \log(aR_w) - n \log(S_w) \tag{2.3}$$

For a well section or a reservoir, the petrophysical properties and formation water resistivity remain essentially constant. Hence, m, a and R_w in the Equation (2.3) may be assumed constant for a well section.

If one considers only the water-saturated zone (S_w=100% or 1.0), the above equation reduces to:

$$\log R_t = -m\log(\Phi) + \log(aR_w) \qquad (2.4)$$

Hence a plot of log R_t versus log F for the fully water-saturated zones in the well section should define a linear trend with a slope of - m and an intercept (corresponding to Φ=1) of log (aR_w). An estimate of m can be obtained by fitting a line through the trend. Its slope gives the m value. The intercept is the product of (aR_w). If R_w is known (from logs or from fluid samples), a can be obtained. If a is known or assumed to be unity, an estimate of R_w is obtained. This crossplot does not yield a value for *n*.

It is a well-known observation that zones at irreducible water saturation (S_{wi}) in a formation display a constant bulk volume fraction of water, i.e.,

$$S_{wi} * \Phi = C \qquad (2.5)$$

where,

C is a constant.

As Φ increases S_{wi} decreases, so that their product remains constant through the irreducible water zone in a well or a reservoir. Log analysts often use a computer-plotted trace of the bulk volume water fraction as a diagnostic tool in assessing the productivity of a formation. Ransom has extended the concept of C in resistivity log interpretation.

For zones at irreducible water saturation, we can rewrite Equation (2.3):

$$\log R_t = -m\log(\Phi) + \log(aR_w) - n\log(S_w)$$

as,

$$\log R_t = -m\log(\Phi) + \log(aR_w) - n\log(S_{wi}) \qquad (2.6)$$

In this equation we can substitute for S_{wi} from Equation (2.5). Then,

$$\log R_t = -m\log(\Phi) + \log(aR_w) - n\log(\frac{C}{\Phi}) \quad (2.7)$$

and,

$$\log R_t = -m\log(\Phi) + \log(aR_w) - n\log(C) + n\log(\Phi) \quad (2.8)$$

Rearranging, we get:

$$\log R_t = (n-m)\log(\Phi) + \log(\frac{aR_w}{C^n}) \quad (2.9)$$

For a well section or a reservoir, the petrophysical properties such as m, a, C and R_w are expected to remain essentially constant. Hence the above equation shows that on an R_t vs. Φ crossplot on log-log paper, the points corresponding to the zones at irreducible water saturation should define a linear trend of slope $(n-m)$ and with an intercept (corresponding to Φ=1) of $\frac{aR_w}{C^n}$

As shown in Figure 2.1, the AC line is irreducible water saturation line and its slope gives $(n-m)$ and AB line is the 100% water saturated line and its slope is equal to -(m).

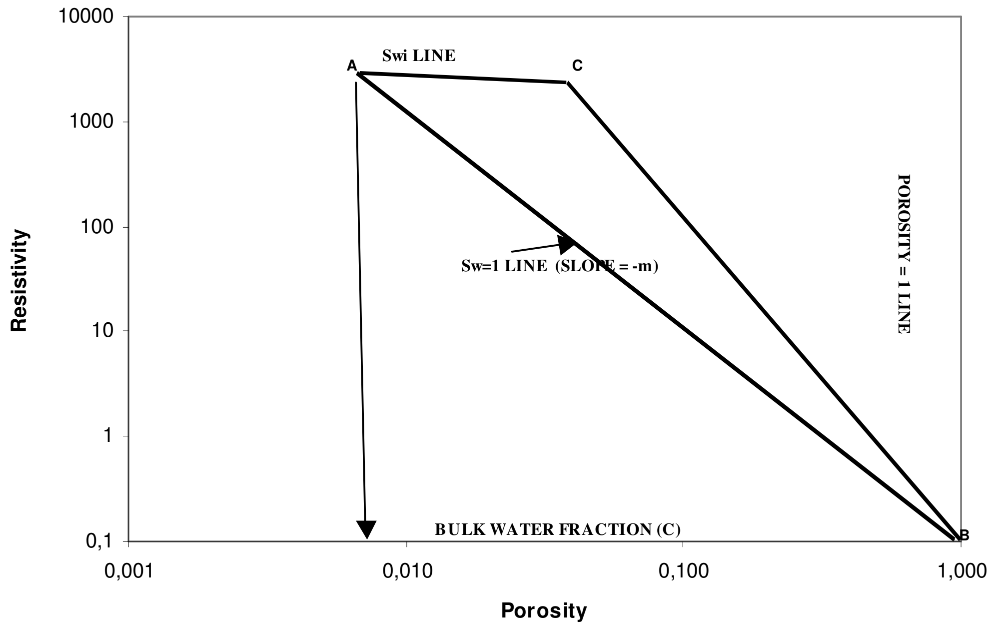


Figure 2.1 Crossplot of log derived resistivity and porosity.

2. 1.2. PROCEDURE FOR DETERMINATION OF *m* and *n*

To determine m and n parameters, the following steps are convenient to follow.

1- Plot R_t vs. Φ on log-log paper.

2- Assuming a =1, find the point on Φ=1.0 axis that has $R_t = R_w$. This is B point.

3- Draw a line through the mean point of cluster of 100% saturated zone and B point.

4- Find the point (A) on this line whose Φ is numerically equal to C (bulk volume of water fraction)

5- Draw a line through the mean point of cluster of irreducible water saturated zone and A point. This is AC line.

6- Negative slope of AB line gives the cementation factor (m)

7- The slope of AC line gives (n-m) value.

8- The saturation exponent (n) can be found from step 6 and 7.

2.2. THEORY ON STATISTICAL ZONATION AND CORRELATION

The statistical reservoir zonation is a two-step operation:

1) Dividing a single well into zones
2) Correlating the zones from well to well.

Initially, the porosity data of each individual wells are divided into zones using ANOVA (analysis of variance) statistical method. In dividing the well into physically meaningful naturally occurring zones, the criterion is that the variation within the zones is minimized and the variation between the zones is maximized.

The statistical equations that are used to find different zones where porosity data is the variable:

$$B = \frac{1}{L-1}\left[\sum_{i=1}^{L} m_i (X_i - \mu)^2\right] \tag{2.10}$$

$$W = \frac{1}{N-L}\left[\sum_{i=1}^{L}\sum_{j=1}^{m_i} (x_{ij} - X_i)^2\right] \tag{2.11}$$

For more convenience, Testerman (Testerman J.D, 1962) put the above equations into following forms:

$$B = \frac{1}{L-1}\left[\sum_{i=1}^{L} m_i (X_i - \mu)^2\right] =$$

$$= \frac{1}{L-1}\left[\sum_{i=1}^{L} \frac{(\sum_{j=1}^{m_i} x_{ij})^2}{m_i} - \frac{(\sum_{i=1}^{L}\sum_{j=1}^{m_i} x_{ij})^2}{N}\right] \tag{2.12}$$

$$W = \frac{1}{N-L}\left[\sum_{i=1}^{L}\sum_{j=1}^{m_i} (x_{ij} - X_i)^2\right] =$$

$$= \frac{1}{N-L}\left[\sum_{i=1}^{L}\sum_{j=1}^{m_i} x_{ij}^2 - \sum_{i=1}^{L} \frac{(\sum_{j=1}^{m_i} x_{ij})^2}{m_i}\right] \tag{2.13}$$

where,

B - the variance between zones,

L - the number of zones,

i - the summation index for the number of zones,

j - the summation index for the number of data within the zone,

m_i - the number of data in the i th zone,

X_i - the mean of the porosity data in the i th zone,

μ - the overall mean of the data in the well,

W - the pooled variance within zones,

N - the total number of data,

x_{ij} - the porosity data.

The effectiveness of any proposed zonation in minimizing (W) and maximizing (B) can be evaluated by computing a zonation index:

$$R = \frac{B - W}{B} \tag{2.14}$$

where,

R is the zonation index.

For a homogeneous set of data, B=0 and R=undefined, whereas for an optimal zonation, W=0 and R=1. Moreover, any proposed zonation, which does not yield B>W should be regarded as arbitrary and not reflecting real zones. When R falls below 0, then it is replaced by 0. Therefore R ranges from 0.0 to 1.0, and its magnitude provides a measure of the suitability of any chosen reference point for constituting a boundary between zones. The closer the index to 1.0, the more homogenous the zone is.

Second section correlates the zones from well to well throughout the reservoir to aid the engineer in determining continuity of the zone. This correlation is based on a statistical comparison of the difference of means of two zones in adjacent wells with the difference that could be expected from variation of measurements within the zones.

The statistical equation used in this section is:

$$(Y_h - Y_i) \geq \sqrt{\frac{1}{2}(\frac{1}{n_h} + \frac{1}{n_i})} * sz_{(v,p)} \tag{2.15}$$

where,

Y_h - the arithmetic average of the porosity data of the h th zone in one well,

Y_i - the arithmetic average of the porosity data of the i th zone in an adjacent well,

n_h and n_i - the number of data in the h th and i th zones,

s - the standard deviation of all the porosity data from the reservoir,

z - a constant tabulated as a function of the number of data, the number of zones and a probability level,

v and p - are used to identify z -values.

2.2.1 PROCEDURE FOR ZONATION

The complete zonation of well log can be done through the following steps.

Step 1: To divide the porosity data, in their original order of depth, into all possible combination of *two zones.*

Step 2: B, W and R are calculated for each of these possible *two-zone* combinations.

R, the zonation index, is the criterion used to describe the best division. This index, which ranges from 0 to 1.0, indicates how closely the division corresponds to homogeneous zones. The maximum R yields the best division into *two zones.*

Step 3: To divide the porosity data into three zones using all possible *three zone* combination. Dividing the existing 2 zones into 2 subzones does this. B ,W and R are again computed for each of these two subdivision and the best division is defined by the largest zonation index, R, comparing the respective zonation indices.

Step 4: To divide the porosity data into four zones using all possible *four zone* combinations.

The previous points of division are again retained as two of the (three) points of division into *four zones*.

In this manner, the set of porosity data can be divided into number of zones up to the number of the given data. At each extension of the number of zones in a well, the new index is compared with the previous index. The division into additional zones continues until the new index falls below the previous index.

In other words, the termination criterion for the additional zones is:

$$R_i < R_p$$

where,

R_i - new index and

R_p - previous index.

2. 2.2. PROCEDURE FOR CORRELATION

To apply the above equation 2.15, it is a convenient and efficient manner to follow the following steps.

Step 1: Rank well zone means in order of decreasing magnitude.

Step 2: Calculate W using all water saturation data in the entire field.

Step 3: Calculate the standard deviation from Step 2.

$$s = \sqrt{W}$$

Step 4: Select z -values for a 95 per cent probability level from Table of Critical Values for Duncan's New Multiple Range Test. (Harter H.L, 1960).

Step 5: Obtain F'_p by multiplying z -values in Step 4 by the standard deviation in Step 3.

$$F'_p = sz_{v,p}$$

Step 6: Test for significant differences among well-zone means.

If the left side of the Equation (2.15) is larger than the right side, the zones represented by the two means are considered, on the basis of statistics, to be different. However, if the left side of the same equation is smaller than the right side, the zones correlate and can be considered to be continuous.

CHAPTER 3

STATEMENT OF PROBLEM

The objectives of this thesis are

- To estimate the water saturations from well logs at the wells studied using an appropriate water saturation model, the Archie equation. A generalized crossplot technique of log-derived resistivity and porosity is used to determine the Archie parameters, cementation factor, m and saturation exponent, n.
- To identify different porosity zones in the wells and correlate these zones from well to well using a statistical method.
- To examine the average water saturations in the correlated zones.
- To identify, also, water saturation zones in the wells and analyze if they are consistent with the porosity zones, using the same statistical method.

CHAPTER 4

STUDY AREA

In this thesis, 3 wells, namely Well-01, Well-02 and Well-03 are studied. The study wells are located in a fractured carbonate reservoir from Southeastern part of Turkey. The well log data of production formation of these three wells are available. (Appendix A). The core data of Well-02 and Well-03 are also available as shown Table 4.1

Table 4.1 Core data of Well-02 and Well-03

	Depth range (m)	Thick-ness (m)	Φ (%)	k_a (md)	k_L (md)	Grain Den-sity (g/cc)	Weight of core (g)	Core Reco-very (%)
Well-03	2640-45	0.05	7.44	0.43	0.28	2.85	162.480	90
Well-03	2640-45	0.9	5.93	0.58	0.38	2.84	149.070	90
Well-03	2640-45	0.45	5.38	0.34	0.22	2.85	164.400	90
Well-03	2640-45	0.70	3.83	0.20	0.12	2.82	186.180	90
Well-02	2597-04	0.40	2.59	0.13	0.08	2.76	112.180	46
Well-02	2597-04	0.40	3.85	60.16	52.31	2.73	170.050	46
Well-02	2597-04	0.80	8.21	2.45	1.76	2.83	152.550	46

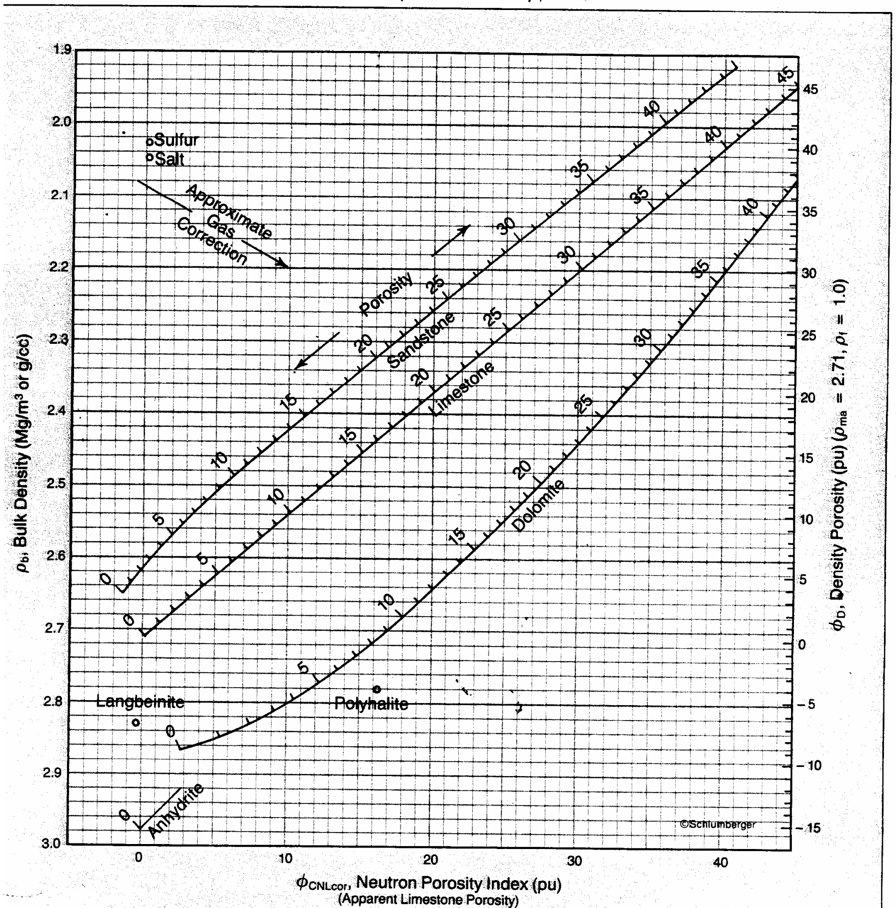
The petrophysical properties of the study wells are listed in Table 4.2 The porosity values are corrected for lithology from neutron and density cross plot (Schlumberger, 1984). (Figure 4.1)

Porosity correction for each well is given in Appendix B.

OSSPLOTS FOR POROSITY AND LITHOLOGY

Porosity and Lithology Determination from Formation Density Log and CNL* Compensated Neutron Log

Fresh Water, Liquid-Filled Holes ρ_f = 1.0



EXAMPLE: ρ_b = 2.43 g/cc (or Mg/m³)
ϕ_{CNL} = 23 pu (apparent limestone porosity)
ρ_f = 1.0 g/cc (or Mg/m³)

Plotting on Chart CP-1 indicates the rock to be a limestone-dolomite mixture (approximately 50% limestone, 50% dolomite) or a cherty dolomite (approximately 35% quartz, 65% dolomite). In either case, porosity is about 20 pu.

*Mark of Schlumberger

CP-1c

Figure 4.1 Neutron and Density Crossplot (Schlumberger: Log Interpretation Chart,1984.)

Table 4.2 Petrophysical properties of the Study Wells.

	Top of production zone(BSL) (m)	Average Porosity (corrected) (fraction)	Thickness of production zone (m)	Formation Water Resistivity (ohm-m)	Kelly Bushing (m)
Well-01	-1725.75	0.05	99	0.1	850.25
Well-02	-1714.70	0.03	95	0.1	860.3
Well-03	-1802.70	0.05	25	0.1	817.3

Figure 4.2 and Figure 4.3 show the location and the vertical cross view of these three wells, respectively.

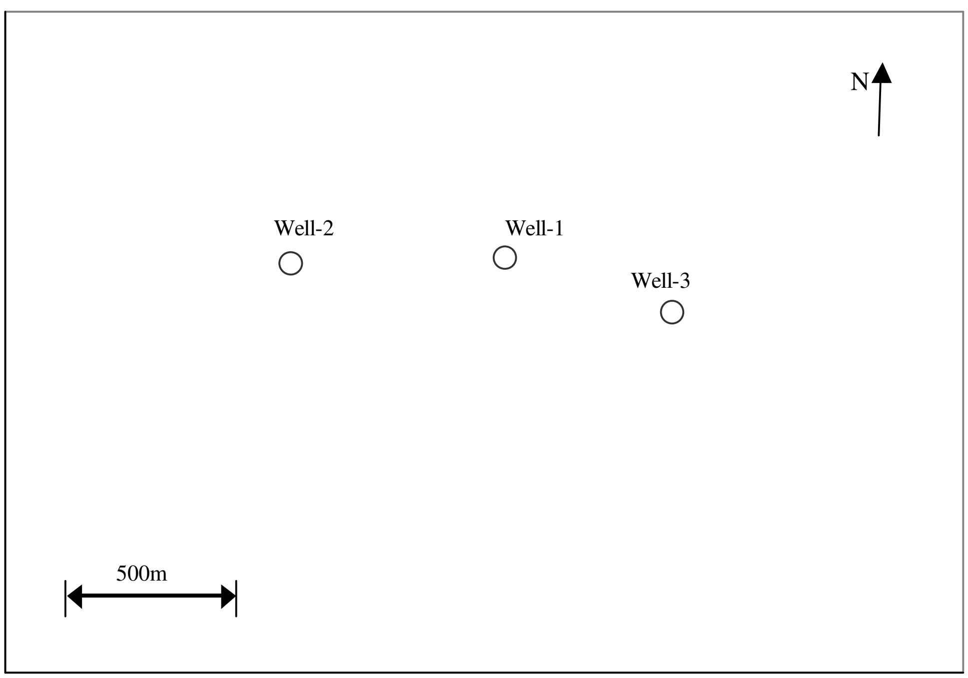


Figure 4.2 Location of Wells studied.

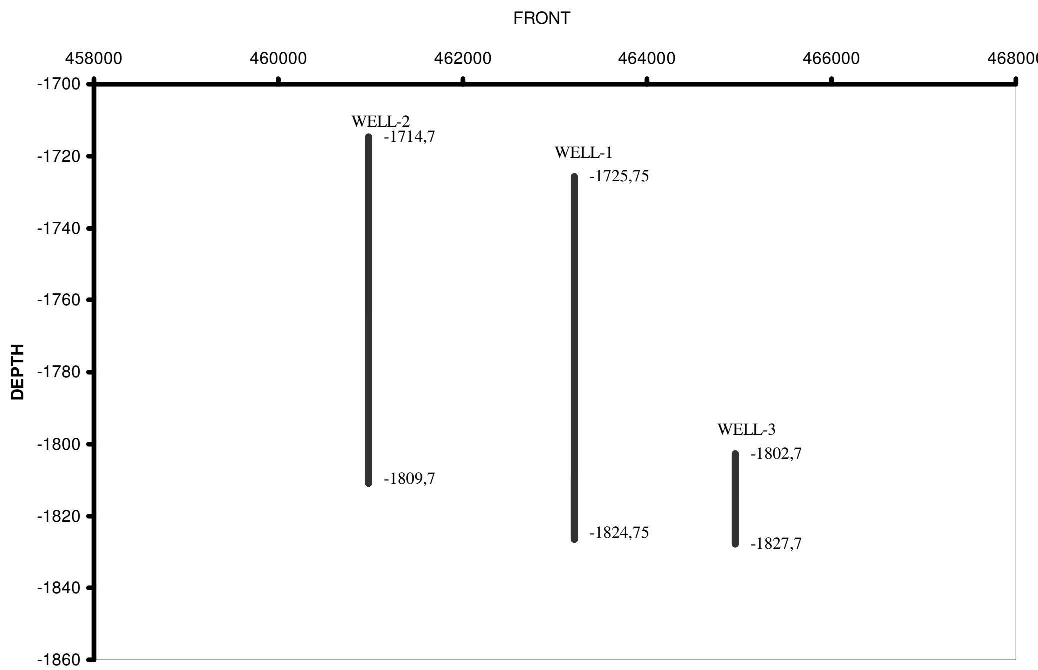


Figure 4.3 Vertical cross views of Wells studied.

Well log data was recorded at every ½ m yielding 150 data for Well-01 and 169 data for Well-02 and 35 data for Well-03. They are given in Appendix C.
These well log data provided by TPAO are from the production formation of the given wells as mentioned before.

CHAPTER 5

CALCULATION OF WATER SATURATION (S_w)

The shale amount in the wells studied in thesis was so small that could be neglected. Therefore, the Archie equation is a proper one for the water saturation calculation.

Using Archie equation, water saturations of 3 study wells are calculated, initially, following the conventional assumption of cementation factor, (m) and saturation exponent, (n) are equal to each other and numerically equal to a value of 2. The results of this calculation is given in Appendix A.

The average water saturation of each well is tabulated in the following Table 5.1. It is obtained by dividing the sum of the water saturations in the well by the number of its data. Here, the cementation factor and saturation exponent are assumed to be equal to a conventional value of 2.

Table 5.1 Average S_w of Study Wells.

	Average S_w (frac.)
Well-01	0.79
Well-02	0.94
Well-03	0.33

The water saturation amount is very high in Well-01 and Well-02. During the calculation process, well sections, whose water saturation is exceeding the value of 1, are found. These sections of each well are shown separately in Table 5.2 and Table 5.3

Table 5.2 Well section where water saturation amount higher than 1 in Well-01

Depth (m)	Depth (m) (BSL)	S_w (frac.)
2595	-1744.75	2.619
2597	-1746.75	6.567
2598	-1747.75	3.876
2599	-1748.75	3.214
2601	-1750.75	4.650
2602	-1751.75	3.381
2603	-1752.75	2.875
2604	-1753.75	3.214

Table 5.3 Well section where water saturation amount higher than 1 in Well-02

Depth (m)	Depth (m) (BSL)	S_w (frac.)
2656	-1795.7	2.268
2657	-1796.7	1.721
2658	-1797.7	1.849
2659	-1798.7	1.571
2660	-1799.7	1.491
2661	-1800.7	1.118
2662	-1801.7	1.643
2663	-1802.7	2.108

The highest water saturation fraction can be 1, which shows the 100% saturation. However, as seen in those tables , the saturations for the shown well sections are very much higher than 1. This obviously led the average water saturations of those wells to increase up to such numbers as 0.79 and 0.94. This error is probably due to fact the cementation factor and saturation exponent are conventionally assumed as 2 for the saturation estimation. In fact, the cementation factor and saturation exponent are functions of many parameters. Some of the affecting parameters are pore size and its distribution. Since the wells are from a fractured reservoir, it would be wrong to assume that the cementation factor and saturation exponent are just simply equal to 2. These parameters must be determined for proper and reasonable water saturation before calculating it. Since resistivity measurements of core samples cannot be carried out in a laboratory condition for this study, the crossplot method of log-derived resistivity and porosity is the only solution to determine *m* and *n* parameters. The theory and procedure of this crossplot are given in Chapter2.

5. 1. APPLICATION OF CROSSPLOT METHOD

In order to employ the crossplot method to determine the cementation factor and saturation exponent of a well, the well has to have an irreducible water zone and 100% water saturated zone. It is seen from well logs that Well-01 and Well-02 have these two zones. However, the Well-03 has no 100% water saturated zone. Thus, the crossplot method cannot be applied to Well-03.

The following Tables 5.4-5.7 give the 100% water saturated and the irreducible water zones of Well-01 and Well-02. The log data was read at 1 m interval.

Table 5.4 100% water saturated zone of Well-01

Depth (m) (BSL)	R_t (ohm-m)	Density	Neutron	Corrected Φ (frac.)
-1744.75	20	2.95	13	0.027
-1745.75	2	2.95	10	0.015
-1746.75	2	2.95	15	0.034
-1747.75	2.2	2.95	21	0.055
-1748.75	5	2.95	18	0.044

-1750.75	4	2.95	15	0.034
-1751.75	12	2.95	13	0.027
-1752.75	4	2.95	21	0.055
-1753.75	5	2.7	18	0.044

Table 5.5 Irreducible water zone of Well-01

Depth (m) (BSL)	R_t (ohm-m)	Density	Neutron	Corrected Φ (frac.)	S_{wi} (m=n=2	C= Φ* S_{wi}
-1784.75	1000	2.62	3.5	0.05	0.26	0.013
-1785.75	3000	2.62	4	0.05	0.14	0,007
-1786.75	2000	2.65	7	0.06	0.15	0,009
						0.01

Table 5.6 100% water saturated zone of Well-02

Depth (m) (BSL)	R_t (ohm-m)	Density	Neutron	Corrected Φ (frac.)
-1795.7	60	2.72	3	0.018
-1796.7	150	2.7	2	0.015
-1797.7	130	2.7	2	0.015
-1798.7	180	2.7	2	0.015
-1799.7	200	2.7	2	0.015
-1800.7	200	2.7	3	0.02
-1801.7	70	2.68	2.5	0.023
-1802.7	100	2.7	2	0.015
-1803.7	100	2.69	4	0.03
-1804.7	80	2.7	3	0.02
-1805.7	200	2.7	2.5	0.018
-1806.7	170	2.66	3	0.03

Table 5.7 Irreducible water zone of Well-02

Depth (m) (BSL)	R_t (ohm-m)	Density	Neutron	Corrected Φ (frac.)	S_{wi} (m=n=2	C= $\Phi^* S_{wi}$
-1770.7	1000	2.8	4.5	0.013	0.769	0.01
-1771.7	1400	2.75	4	0.018	0.470	0.008
-1772.7	2000	2.8	5	0.015	0.471	0.007
-1773.7	2500	2.8	5	0.015	0.422	0.006
-1774.7	3800	2.78	4	0.013	0.395	0.005
-1775.7	2800	2.8	3	0.006	0.996	0.006
-1776.7	3000	2.82	2	0.002	2.887	0.006
-1777.7	3000	2.8	3	0.006	0.962	0.006
-1778.7	4000	2.8	3.5	0.008	0.625	0.005
-1779.7	2000	2.8	4	0.01	0.707	0.007
-1780.7	1600	2.77	4.5	0.016	0.494	0.008
						0.007

Table 5.5 shows the irreducible water saturation zone of Well-01. This zone is obtained by looking at the interval where the resistivitey is highest, which means the water saturation is the lowest. However, this obtained interval is found below the 100% water saturated interval. Therfore, the crossplot is also conducted using another interval(Table 5.8) with low water saturation, which is located above the 100% water saturated interval.

Table 5.8 Irreducible water zone of Well-01(above 100% water saturated zone)

Depth (m) (BSL)	R_t (ohm-m)	Density	Neutron	Corrected Φ (frac.)	S_{wi} (m=n=2	C= Φ* S_{wi}
-1725.75	500	2.62	3	0.04	0.354	0.014
-1726.75	700	2.6	2	0.04	0.299	0.012
-1728.75	1000	2.6	2.5	0.045	0.222	0.010
-1729.75	300	2.6	2	0.04	0.456	0.018
-1730.75	300	2.6	4	0.054	0.338	0.018
-1731.75	230	2.6	4	0.054	0.386	0.021
-1732.75	350	2.65	2	0.028	0.604	0.017
-1736.75	400	2.61	3	0.045	0.351	0.016
-1737.75	800	2.65	6	0.05	0.224	0.011
-1738.75	500	2.62	4.5	0.044	0.321	0.014
-1739.75	200	2.67	7.5	0.052	0.430	0.022
-1740.75	600	2.6	10.5	0.087	0.148	0.013
-1742.75	600	2.62	11.5	0.097	0.133	0.013
-1743.75	500	2.7	10.5	0.06	0.236	0.014
						0.015

While drawing "water-saturated" line AB, the range of porosity values of the data points is so small that a cluster of points rather than a linear trend is seen. Therefore, since R_w is known, the AB line can be defined by force –fitting a line through the mean point of the cluster and a point on $\Phi = 1.0$ axis that has resistivity= R_w (assuming a=1).

The narrow range of porosity may also prevent a definition of AC line. In this case, AC is drawn by joining A point on the line AB whose Φ value is numerically equal to C value and C point: C point is the mean value of cluster of R_t

C value is obtained by multiplying the average irreducible water saturation by average porosity of irreducible water saturation zone. (Eq. 2.5) This value of each well is tabulated in the Table 5.9.

Table 5.9 *C* values of Study Wells

	C
Well-01	0.010
Well-01*	0.015
Well-02	0.007
Well-03	

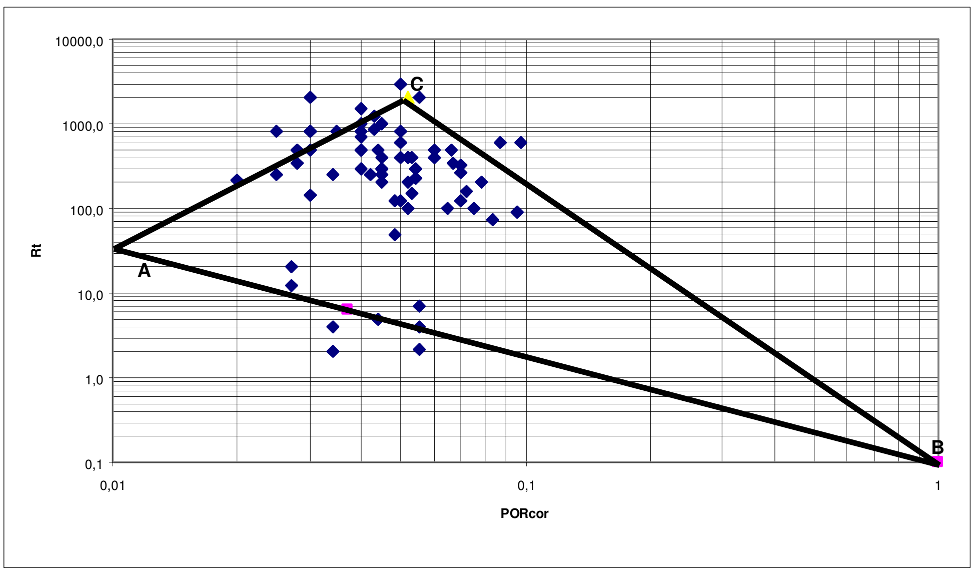


Figure 5.1 Crossplot of log-derived resistivity and porosity of Well-01

From Figure 5.1,

The slope of AB line = -1.26 then

m = 1.26

* Table 5.8 is used for the irreducible water zone for Well-01.

The slope of AC line= 2.6   Then,

n-m= 2.6

n=m+2.6

n=3.86

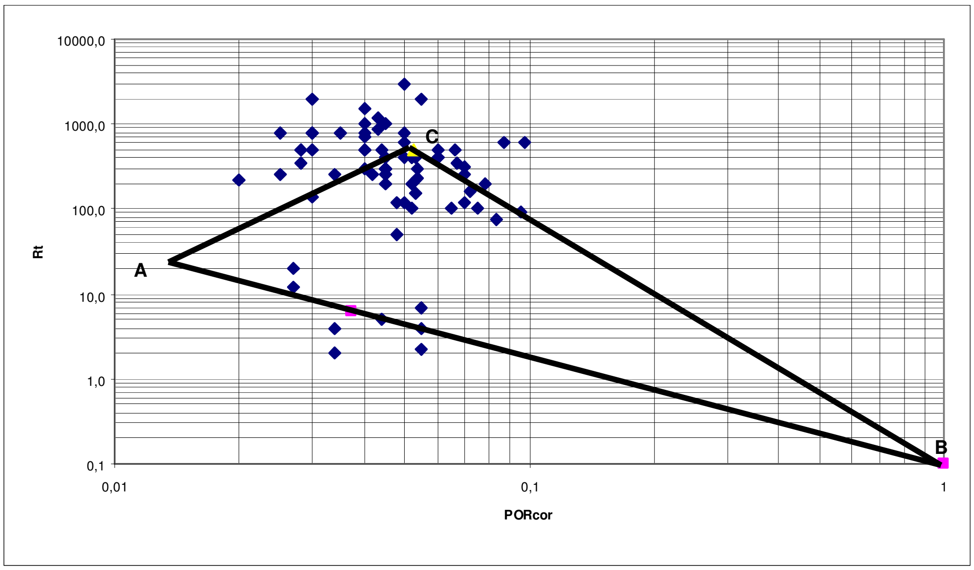


Figure 5.2 Crossplot of log-derived resistivity and porosity of Well-01*

From Figure 5.2,

The slope of AB line = -1.26   then

m = 1.26

The slope of AC line= 2.33   Then,

n-m= 2.33

n=m+2.33

n=3.59

---

* Table 5.8 is used for the irreducible water zone for Well-01.

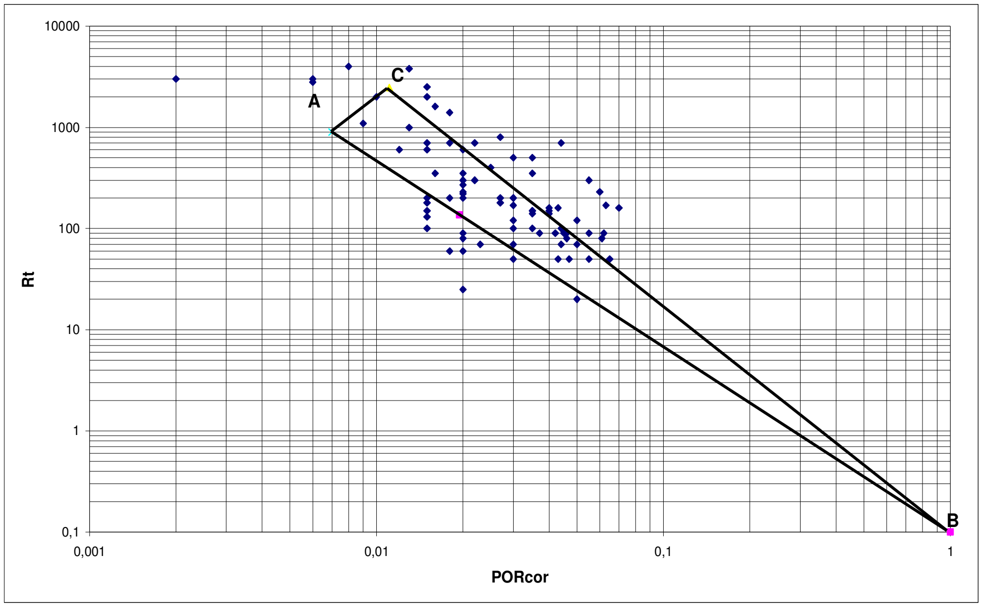


Figure 5.3 Crossplot of log-derived resistivity and porosity of Well-02

From Figure 5.3,

The slope of AB line = -1.83, then

m=1.83

The slope of AC line=2.15, then

n-m= 2.15

n=m+2.15

n=3.98

This time, water saturation is calculated using the Archie equation with m and n parameters obtained from the crossplot method. It is not possible to employ the technique to Well-03, since it has no 100% water saturated interval. Therefore its water saturation is calculated with m and n of Well-01, which is closely located to Well-03.

The following Table 5.10 shows the average water saturation of each well calculated with the m and n from the crossplot method.

Table 5.10 Average S_w calculated with the m and n from the crossplot method.

	Average S_w (frac.)
Well-01	0.418
Well-01*	0.395
Well-02	0.799
Well-03	0.358

The following Table 5.11 gives the comparison of this result with previous calculation of $m = 2 \& n = 2$.

Table 5.11 Comparison of water saturations with different m and n parameters

	Sw ($m = 2 \& n = 2$)	Sw (crossplot)
Well-01	0.790	0.418
Well-02	0.940	0.799
Well-03	0.330	0.358

From the Table 5.11, it is seen that there are considerable decreases in the average water saturations of Well-01 and Well-02, when we use the cementation factor and saturation exponent obtained from crossplot technique in water saturation calculation.

* Table 5.8 is used for the irreducible water zone for Well-01.

These decreases are, in fact, only seen in the expected 100% water saturated zones of the wells. The water saturations in these zones are brought to around the value of 1, which is normally expected. In well sections other than 100% water saturated sections, the water saturation varies a little. The following Tables 5.12 and 5.13 show this observation more clearly.

From Table 5.11, the water saturation values of Well-03 in both cases are close to each other. This is due to fact that Well-03 has no 100% water saturated zone.

Table 5.12 Comparison of Sw with different m and n parameters inWell-01

Referenced depth (m)	Sw (m=2 & n=2)	Sw (crossplot)
-1736,75	0,351	0,321
-1737,75	0,224	0,259
-1738,75	0,321	0,305
-1739,75	0,430	0,366
-1740,75	0,148	0,233
-1742,75	0,133	0,224
-1743,75	0,236	0,275
-1744,75	2,619	0,824
-1746,75	6,577	1,387
-1747,75	3,876	1,157
-1748,75	3,214	1,006
-1750,75	4,650	1,159
-1751,75	3,381	0,940
-1752,75	2,875	0,991
-1753,75	3,214	1,006

100% water saturated zone (-1744,75 to -1753,75)

Table 5.13 Comparison of Sw with different *m* and *n* parameters inWell-02

Referenced depth (m)	Sw (m=2 & n=2)	Sw (crossplot)
-1790.7	0,738	0,744
-1791.7	0,794	0,778
-1792.7	0,741	0,753
-1794.7	0,688	0,737
-1795.7	2,268	1,271
-1796.7	1,721	1,098
-1797.7	1,849	1,138
-1798.7	1,571	1,049
-1799.7	1,491	1,021
-1800.7	1,118	0,895
-1801.7	1,643	1,093
-1802.7	2,108	1,216
-1803.7	1,054	0,884
-1804.7	1,768	1,127
-1805.7	1,242	0,939

100% water saturated zone

CHAPTER 6

STATISTICAL ZONATION AND CORRELATION

6.1. ZONATION OF INDIVIDUAL WELLS

Following the procedure given in Section 2.2.1 of Chapter 2, the wells studied are divided into zones using their porosity data.

To illustrate the calculations, the porosity data in Well-03 selected because it has less data than the other wells.

Using the computational Equations 2.12, 2.13 and 2.14, B, W & R are calculated.

Equation 2.12:

$$B = \frac{1}{1}\left[\frac{5.8^2}{1} + \frac{155.7^2}{34} - \frac{161.5^2}{35}\right] = 1.447$$

Equation 2.13:

$$W = \frac{1}{33}\left[\begin{array}{l} 5.8^2 + 5.5^2 + 5^2 + 4.7^2 + 4^2 + 5.2^2 + 6^2 + 5^2 + 3.3^2 + 4^2 + 4.7^2 + 4.2^2 + \\ + 3.3^2 + 4.1^2 + 3.8^2 + 5.1^2 + 5.3^2 + 5.5^2 + 4.3^2 + 5.7^2 + 3.8^2 + 4.4^2 + 3.9^2 + \\ + 3.2^2 + 3.8^2 + 5.5^2 + 4.7^2 + 5.5^2 + 4.7^2 + 5.5^2 + 5^2 + 4.5^2 + 4.3^2 + 5^2 + \\ + 4.4^2 + 5^2 + 4^2 - \dfrac{5.8^2}{1} - \dfrac{155.7^2}{34} \end{array}\right] =$$

$$= 0.540$$

Equation 2.14:

$$R = \frac{1.447 - 0.540}{1.447} = 0.627$$

The other lines are computed in the same manner.

The best division into two zones of Well-03 occurs after the porosity data value 5 as the asterisk marks the point of division as shown in Appendix D.3.1.

Since the original porosity data have been divided into two zones, the next task is now that of separating either Zone 1 or Zone 2 into two additional zones. The Appendix D.3.2 shows the details of the calculations.

The second point of division occurs after the value 3.8, and defines the data as a set of three zones.

Now to see whether there is a third division point to divide the data into four zones, zone 2 and zone 3 are separated into two groups. Appendix D.3.3 gives the calculation of this. From Appendix D.3.3, the results of the calculations for the division of data into four zones indicate that the largest four-zone index, 0.788, is smaller than the three-zone index of 0.845. Therefore, Well-03 is better described as three zones.

The other wells were separated into zones in the same manner. Well-01 is divided into two zones and, similarly, Well-02 is also divided into two zones. The results are given respectively in Appendix D.

6.2. CORRELATION FROM WELL TO WELL

The second step of the statistical zonation technique is the correlation of zones in one well with zones in adjacent wells to determine the size and location of the continuous zones where they intercept the areas.

Calculation is conducted as described in the procedure of the technique (Section 2.2.2).

Firstly, well-zone means in order of decreasing magnitude are ranked as shown in Table 6.1 below. Zone (1, 2) is Zone 2 in Well-01.

Table 6.1 Average porosities of zones

Zones	Average Porosity	# Of data
(1,2)	6,636	28
(3,1)	5,150	8
(3,3)	4,645	20
(1,1)	4,311	122
(2,1)	4,012	83
(3,2)	3,914	7
(2,2)	2,164	86

Using all porosity data in the entire field W is calculated.

$$W = \frac{1}{354-7}\left[\begin{array}{l} 4^2 + 2.8^2 + 4^2 + 4.7^2 + \ldots + 4^2 - \frac{185.8^2}{28} - \frac{41.2^2}{8} - \\ - \ldots - \frac{186.1^2}{86} \end{array}\right]$$

$$= 1.555$$

Thus, the standard deviation is

$$s = \sqrt{w} = \sqrt{1.555} = 1.247$$

Z-values for a 95% probability level are selected from Duncan's New Multiple Range Test Table. Multiplying the z-values by the standard deviation F_p' is obtained. The following Table 6.2 gives the results.

Table 6.2 Calculation of F_p'

Zones	Average Porosity	# Of data	p	z	F_p'
(1,2)	6,636	28	2	2,772	3,457
(3,1)	5,150	8	3	2,918	3,639
(3,3)	4,645	20	4	3,017	3,762
(1,1)	4,311	122	5	3,089	3,852
(2,1)	4,012	83	6	3,146	3,923
(3,2)	3,914	7	7	3,193	3,982
(2,2)	2,164	86	8	3,232	4,031

To test for significance differences among well-zone means, the Equation (2.15) is used as mentioned in the procedure:

$$(Y_h - Y_i) \geq \sqrt{\frac{1}{2}(\frac{1}{n_h} + \frac{1}{n_i})} * sz_{(v,p)} = \sqrt{\frac{1}{2}(\frac{1}{n_h} + \frac{1}{n_i})} * F'_p$$

If we set

$$(Y_h - Y_i)\sqrt{\frac{2 * n_h * n_i}{n_h + n_i}} = Y \qquad (6.1)$$

then,

$$Y > F'_p$$

In order to be significantly different, the above expression must be satisfied.
First the largest mean is compared with each of the smaller means. Therefore Zone (1,2) is compared with the smaller 6 zones.

In order for the means of Zones (1, 2) and (2, 2) to be significantly different,

$$Y = (6.636 - 2.164)\sqrt{\frac{2 * 28 * 86}{28 + 86}} = 29.065$$

must exceed $F_p' = 4.031$. It does indeed. Therefore, the well Zones (1, 2) and Zone (2, 2) represented by the means 6.636 and 2.164, respectively, are significantly different.
The calculation of test for significance of Zone (1, 2) with the other zones are given Table 6.3.

Table 6.3 Comparison of Zone (1,2) with the smaller-zones

Zones	Average porosity	# Of data	F_p'	Y
(1,2)	6,636	28	3,457	
(3,1)	5,150	8	3,639	5,241
(3,3)	4,645	20	3,762	9,616
(1,1)	4,311	122	3,852	15,686
(2,1)	4,012	83	3,923	16,978
(3,2)	3,914	7	3,982	9,109
(2,2)	2,164	86	4,031	29,065

From the above Table 6.3, Y is greater than F_p' at each test. Therefore Zone (1,2) is significantly different than the other 6 zones.

Table 6.4 Comparison of Zone (3,1) with the smaller mean-zones

Zones	Average porosity	# Of data	F_p '	Y
(3,1)	5,150	8	3,639	
(3,3)	4,645	20	3,762	1,707
(1,1)	4,311	122	3,852	3,249
(2,1)	4,012	83	3,923	4,347
(3,2)	3,914	7	3,982	3,377
(2,2)	2,164	86	4,031	11,425

As seen in Table 6.4, Zone (3,1) is not significantly different from Zone (3,2), Zone (1,1) and Zone (3,3).

Table 6.5 Comparison of Zone (3,3) with the smaller mean-zones

Zones	Average porosity	# Of data	F_p '	Y
(3,3)	4,645	20	3,762	
(1,1)	4,311	122	3,852	1,955
(2,1)	4,012	83	3,923	3,594
(3,2)	3,914	7	3,982	2,354
(2,2)	2,164	86	4,031	14,134

Table 6.5 shows that Zone (3,3) is not significantly different from the Zone (3,2), Zone (2,1) and Zone (1,1) and significantly different from Zone (2,2).

Table 6.6 Comparison of Zone (1, 1) with the smaller mean-zones

Zones	Average porosity	# Of data	F_p '	Y
(1,1)	4,311	122	3,852	
(2,1)	4,012	83	3,923	2,976
(3,2)	3,914	7	3,982	1,446
(2,2)	2,164	86	4,031	21,570

Table 6.7 Comparison of Zone (2, 1) with the smaller mean-zones

Zones	Average porosity	# Of data	F_p '	Y
(2,1)	4,012	83	3,923	
(3,2)	3,914	7	3,982	0,352
(2,2)	2,164	86	4,031	16,986

Table 6.8 Comparison of Zone (3, 2) with the smaller mean-zones

Zones	Average porosity	# Of data	F_p '	Y
(3,2)	3,914	7	3,982	
(2,2)	2,164	86	4,031	6,297

Finally the result shows that Zone (1,1), Zone (2,1) Zone (3,1), Zone (3,2) and Zone (3,3) are not significantly different from each other. On the other hand, Zone (2,2) is significantly different alone and Zone (1,2) is also significantly different alone.

CHAPTER 7
RESULTS AND DISCUSSION

Three wells' log data were available for this study. The field was located in Southeastern part of Turkey. From the well log records, the shale amount was so small that it could be neglected. Thus, the well-known Archie equation is used for the water saturation amounts of the three wells. The important parameters of Archie equation are the cementation factor, m, saturation exponent, n, and tortousity factor, a. For water saturation estimation, it is a convention to assume that both the cementation factor and saturation exponent are equal to a value of 2 and the tortousity factor is equal to 1.

When these values are used for the study wells, the average water saturation amount was high in those wells. (Table 5.1) This was obviously due to the incorrect high water saturation amount which is much higher than 1 in the sections of the wells. (Table 5.2 and Table 5.3). If the pore is fully water saturated, then the water saturation can be at most 100%.

Hence, to determine these parameters, before the water saturation calculation, a generalized crossplot method of log-derived resistivity and porosity is employed. Here the tortousity factor was also assumed 1. The cementation factor and saturation exponent were calculated from this crossplot for Well-01 and Well-02. The crossplot technique could not be employed for Well-03, since 100% water saturation zone is needed for the application of this method. Hence, the cementation factor and saturation exponent of Well-01 was used to estimate water saturation of Well-03. The reason for this was just these wells are adjacent to each other.

The water saturation was calculated using the values from the crossplot method. Figure 7.1 shows the water saturations in both cases. This time the water saturation amount was significantly reduced. (Table 5.10). However the reduction was seen in 100% water saturated sections, whose previous water saturation amount was much higher than 1. Little reduction was detected in the other well sections. (Table 5.12 and Table 5.13). Table 5.11 shows the comparison of the average water saturations with the conventional values of *m* and *n* and the values obtained from the crossplot. The water saturation amounts of Well-03 in both cases are close to each other. This is due to fact that Well-03 has no 100% water saturated zone.

Using the porosity data, ANOVA, the statistical method divided Well-01 into 2 zones, Well-02 into again 2 zones and Well-03 into 3 zones. (Appendix D). The Zone (1, 2), the second zone of Well-01, has the largest average porosity of 6.636 %. This zone is significantly different from the other zones. Also the Zone (2, 2), which has the lowest porosity of a value of 2.164 %, is significantly different from others. The remaining zones, except these two zones, are not significantly different from each other.

The thickness of the Zone (3, 2) is 3,5 m, which is quite narrow zone compared to the other zones. Moreover the zonation index of two zones, 0.834 is close to the zonation index of three zones, 0.845. Because of these facts, the Well-03 can be considered two zone combinations, instead of three zones. Statistical zonation method assumes a priori that stratification exists within the reservoir. Even though a reservoir is not stratified, this statistical technique will always show that the reservoir is divided into, at least, two zones. In fact, the Well-03 can be taken as one stratum alone, since the correlation shows that its so divided three zones are significantly correlated with each other. Therefore, Well-03 is better described as single zone.

Using the same statistical method, the water saturation zones of each well are identified. Well-01 is divided into three water saturation zones, while Well-02 and Well-03 are described as two water saturation zones.

The water saturation zones and porosity zones of each well do not coincide with each other.

Figure 7.2 shows the final zonation, correlation and the water saturation of each zone. As seen from this figure, water saturation decreases from east to west over the entire field. More precisely, in the correlated zones, Zone (2, 1), Zone (1, 1) and Well-03, the water saturation decreases from east to west.

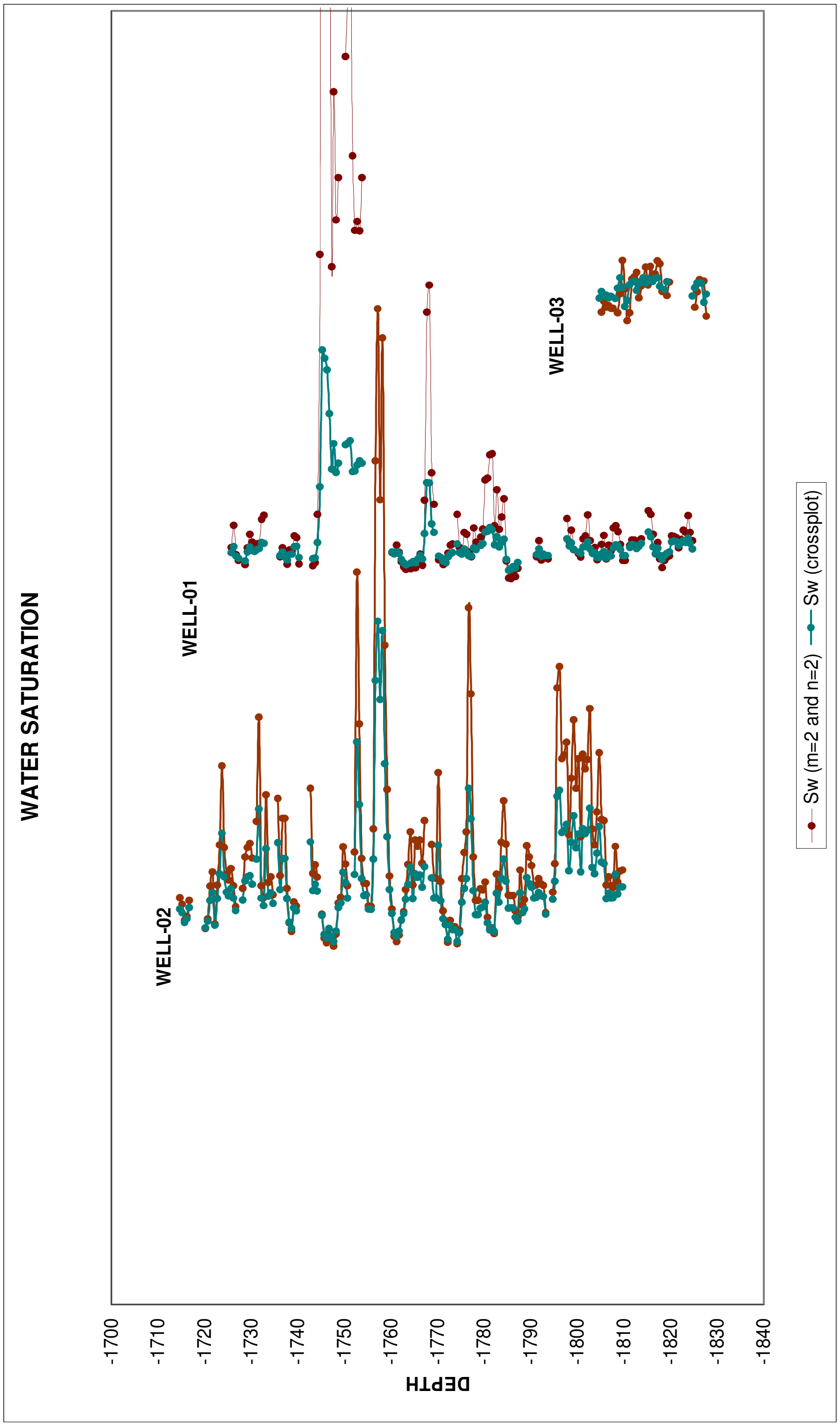


Figure 7.1 Water Saturations in both cases.

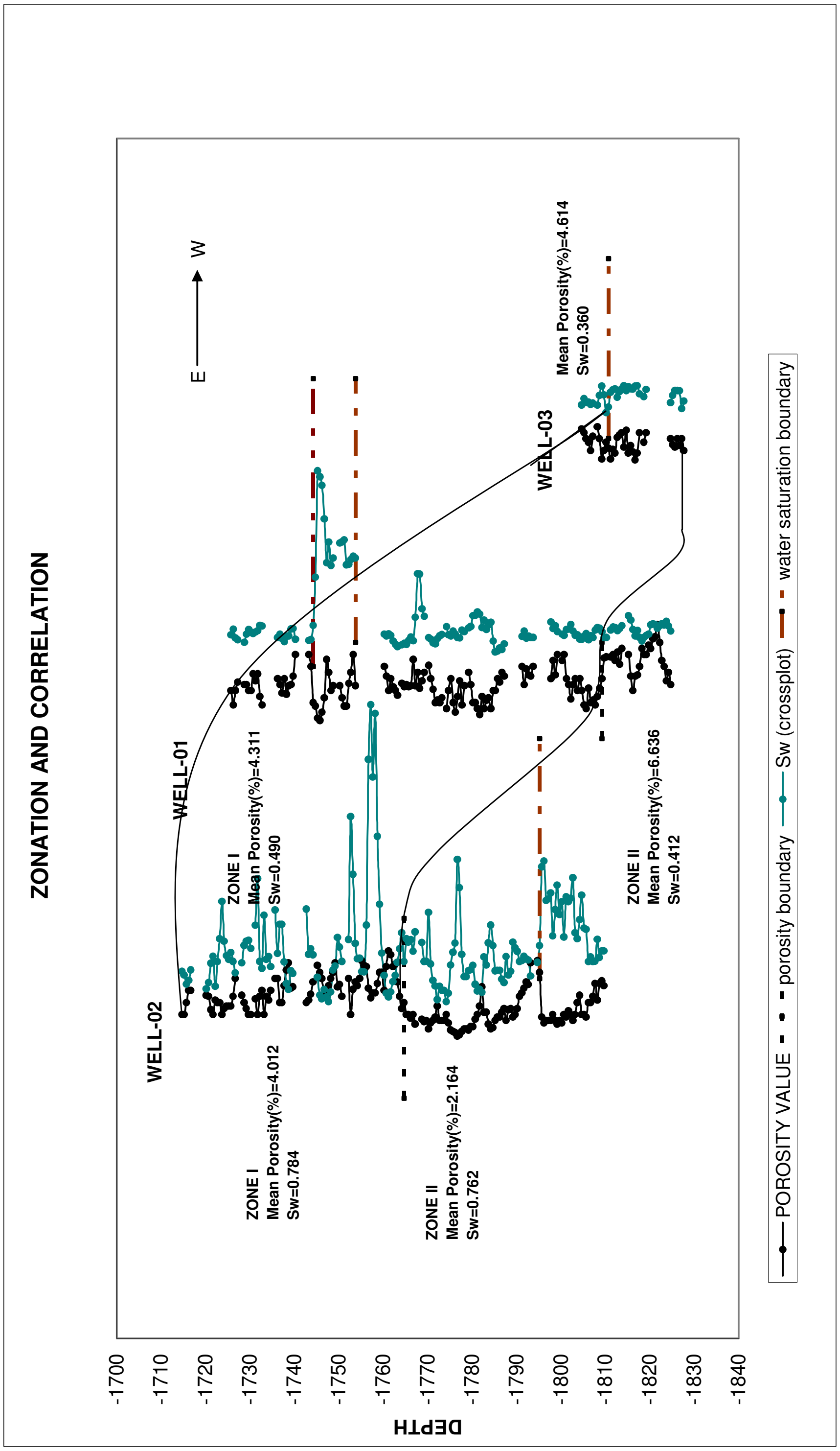


Figure 7.2 Porosity and S_w Zonation and Correlation from well to well.

CHAPTER 8

CONCLUSION

The aim of this thesis was to study water saturation models available in the literature and to apply a proper one to a real field case.

Archie equation is the most well-known water saturation model. However, it is formulated on some assumptions and is applicable to only clean sands. Archie equation cannot be used for shaly formation. There are many shaly water saturation models that account for shale effect for water saturation estimation.

The study field was located in naturally fractured reservoir. The shale amount was so small that could be neglected. Therefore, the shaly water saturation models not used for the water saturation calculation. Instead, the well known Archie equation was used. However, the *m* and *n* parameters were not assumed to equal to a value of 2.0, since the reservoir is a fractured one. Usually the value of m is assumed equal to 2.0 for formations with interparticle (grain or crystals) porosity. The core data was not available enough to analysis. Actually, determination of *m* and *n* parameters in the laboratory is not reliable because cores, which contain fractures of practical significance, are lost in the process of recovery.

Since the well log data were available, the log derived resistivity and porosity crossplot technique was employed to calculate the m and n parameters needed for water saturation calculation. Here the porosity is the corrected porosity from neutron and density tools for litholgy. The fracture effect on porosity is in-situ reflected on this porosity.

Finally, a statistical method, ANOVA is used to divide each well studied in this thesis, into different zones. Here the porosity data of the given wells is the variable. Well-01 and Well-02 are both divided into two zones. However, Well-03 is better described as a whole zone, depending on the geological analysis and engineering judgment. After the zonation, the zones are correlated from well to well. The water saturation in significantly correlated zones is examined to see whether its amount is similar throughout these zones. Moreover, the same statistical method is used to identify the water saturation zones in the well. But these zones do not coincide with the zones defined by porosity. This indicates that water saturation distribution is related to pore size distribution and probably wettability values than effective porosity.

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APPENDIX A

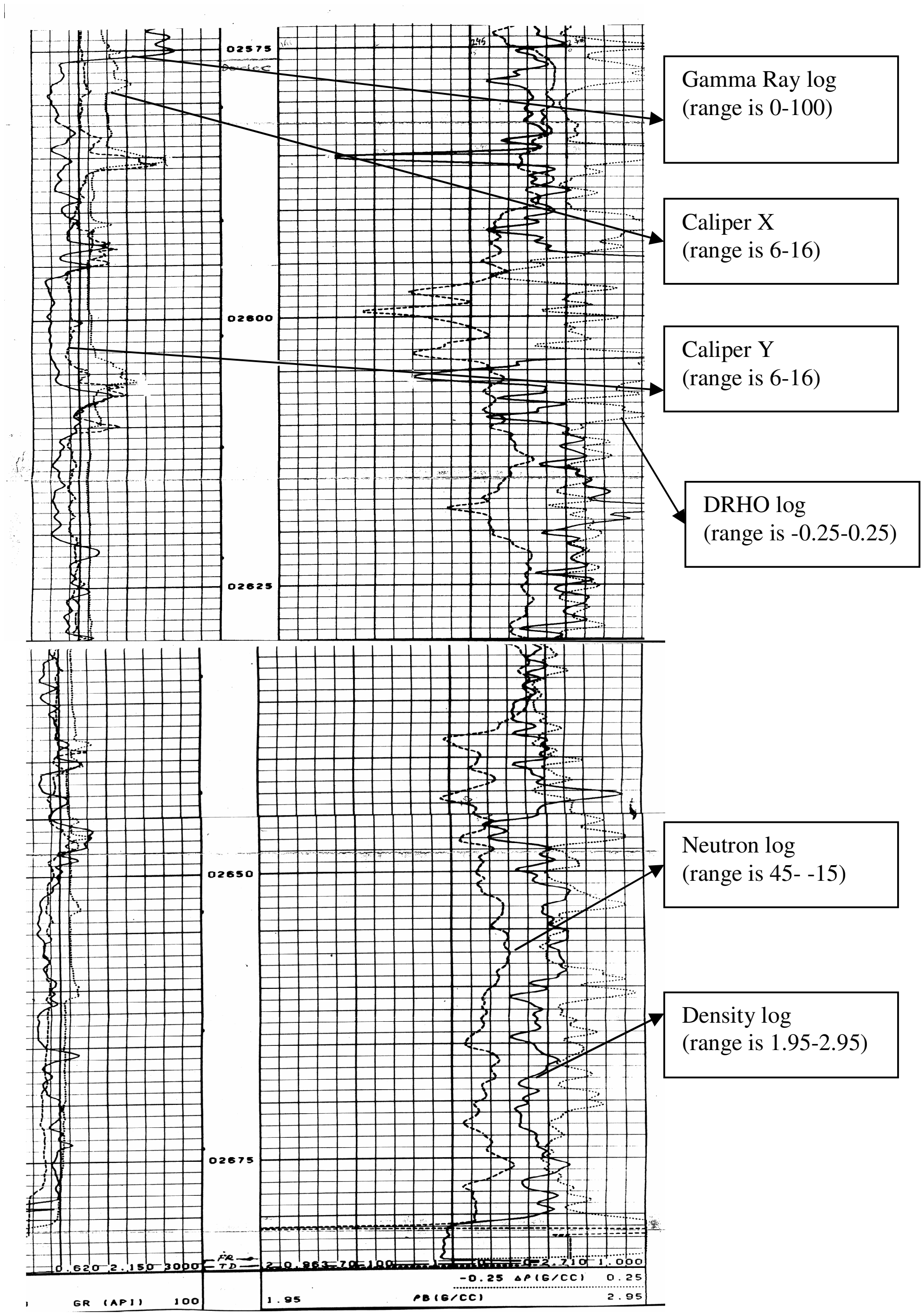


Fig A.1 Density and Neutron logs of Well-01

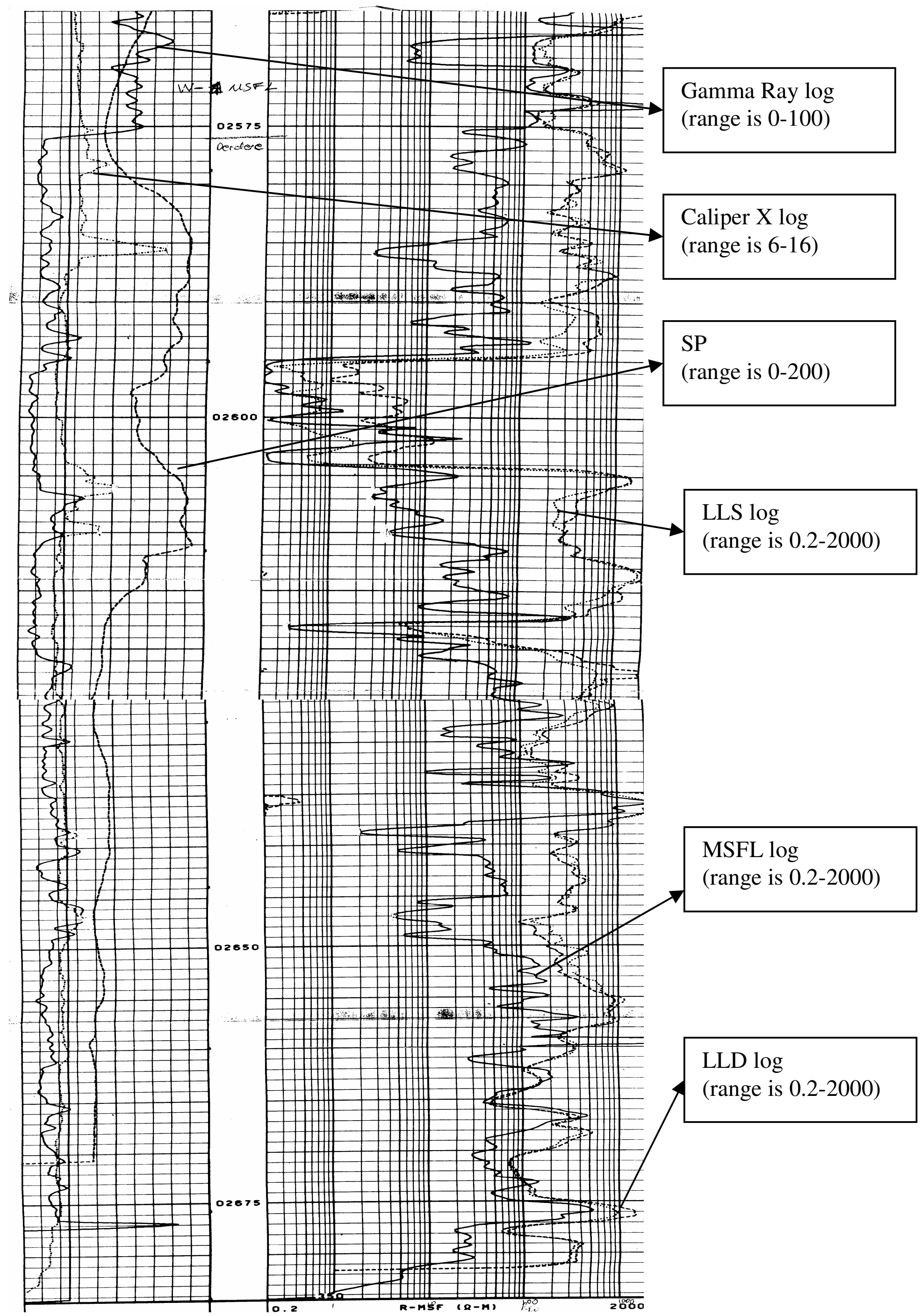


Fig A.2 MSFL (R_{xo}) and LLD (R_t) logs of Well-01

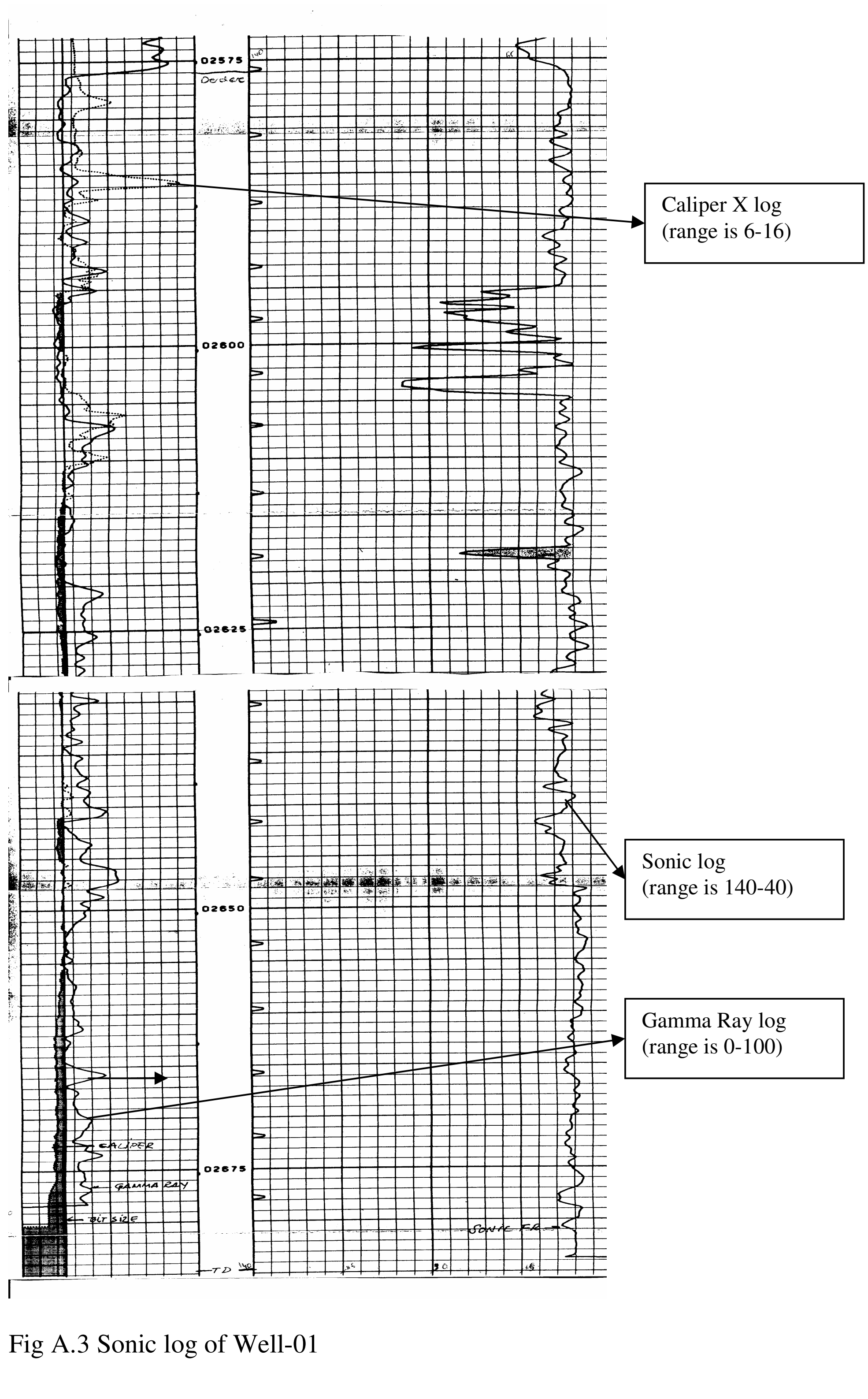


Fig A.3 Sonic log of Well-01

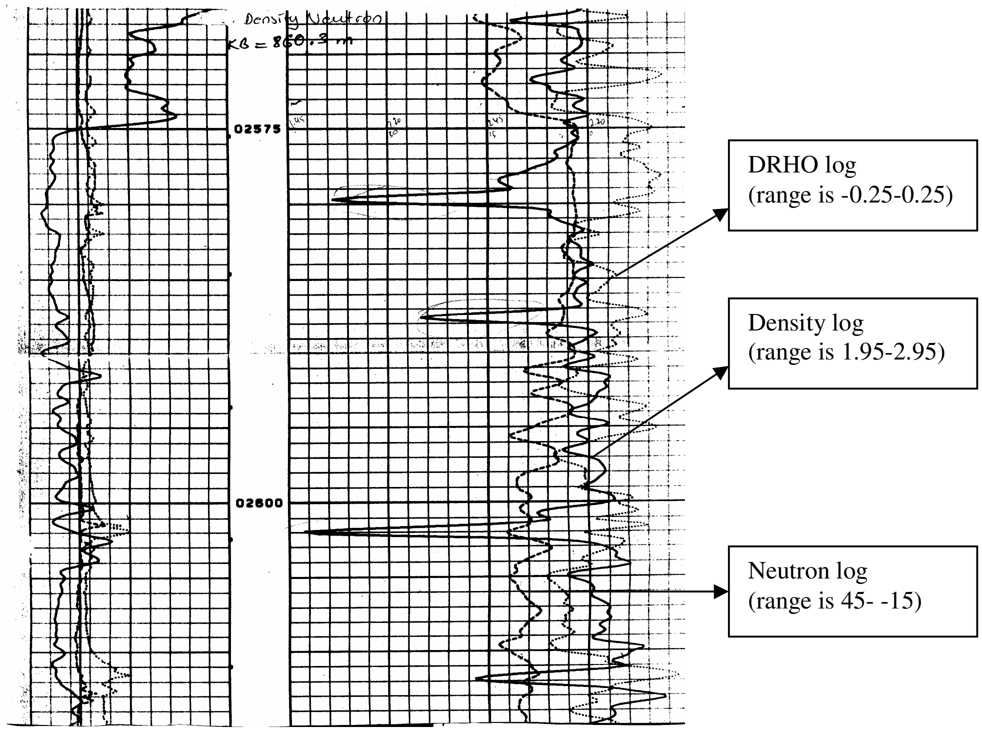


Fig A.4 Density and Neutron logs of Well-02.

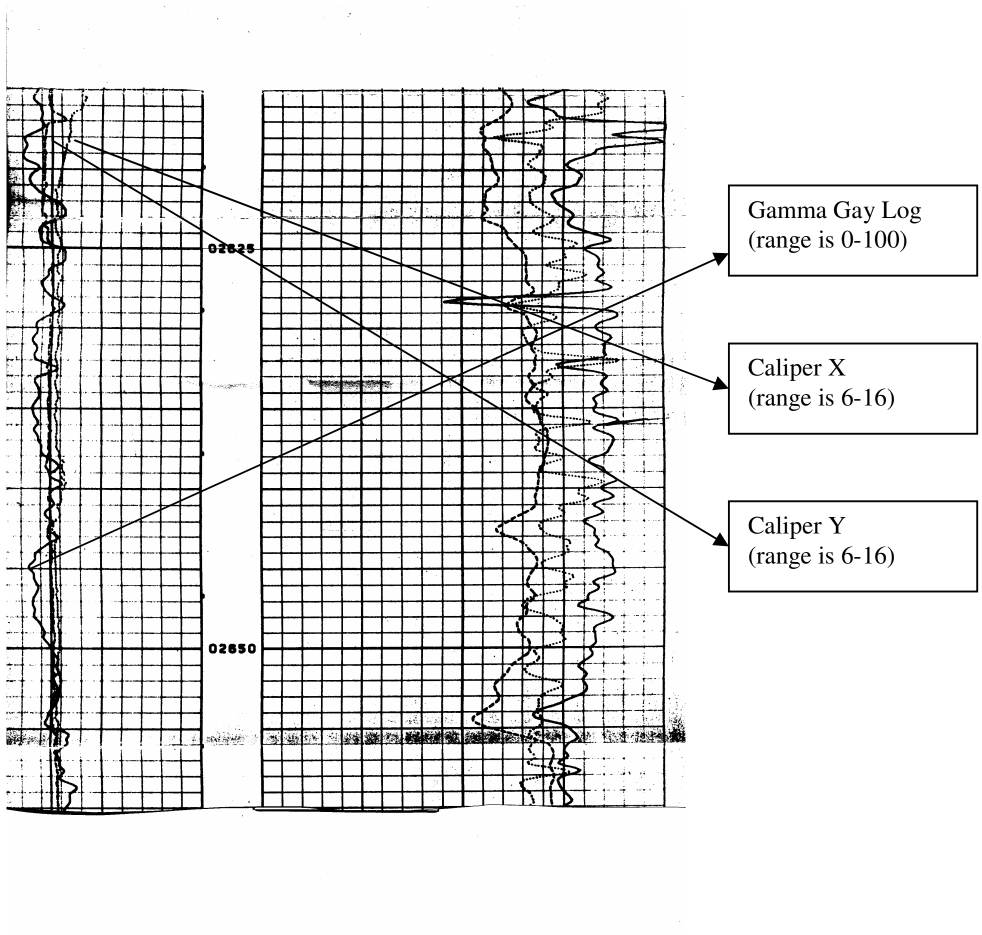


Fig A.4 Density and Neutron logs of Well-02 (cont'd.)

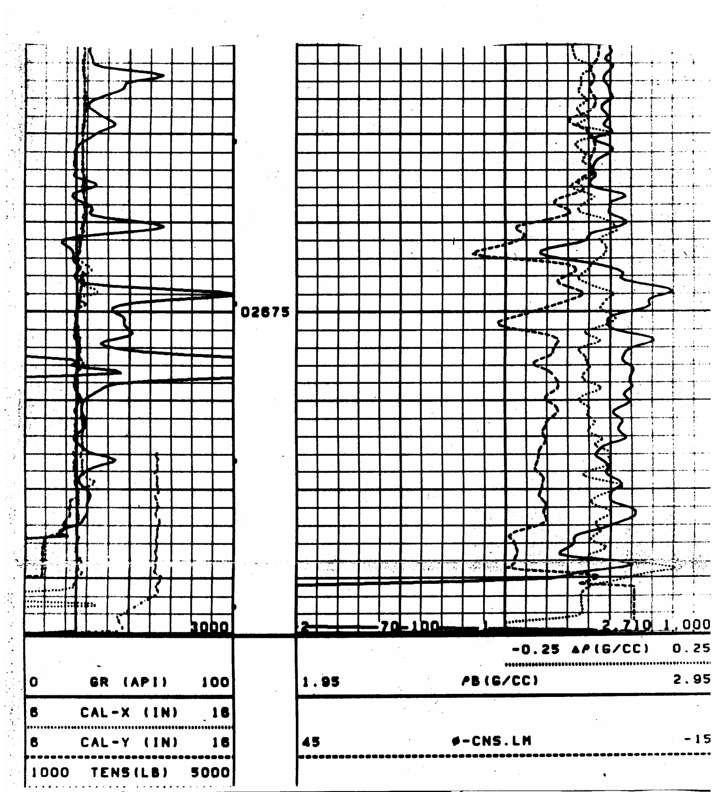


Fig A.4 Density and Neutron logs of Well-02 (cont'd.)

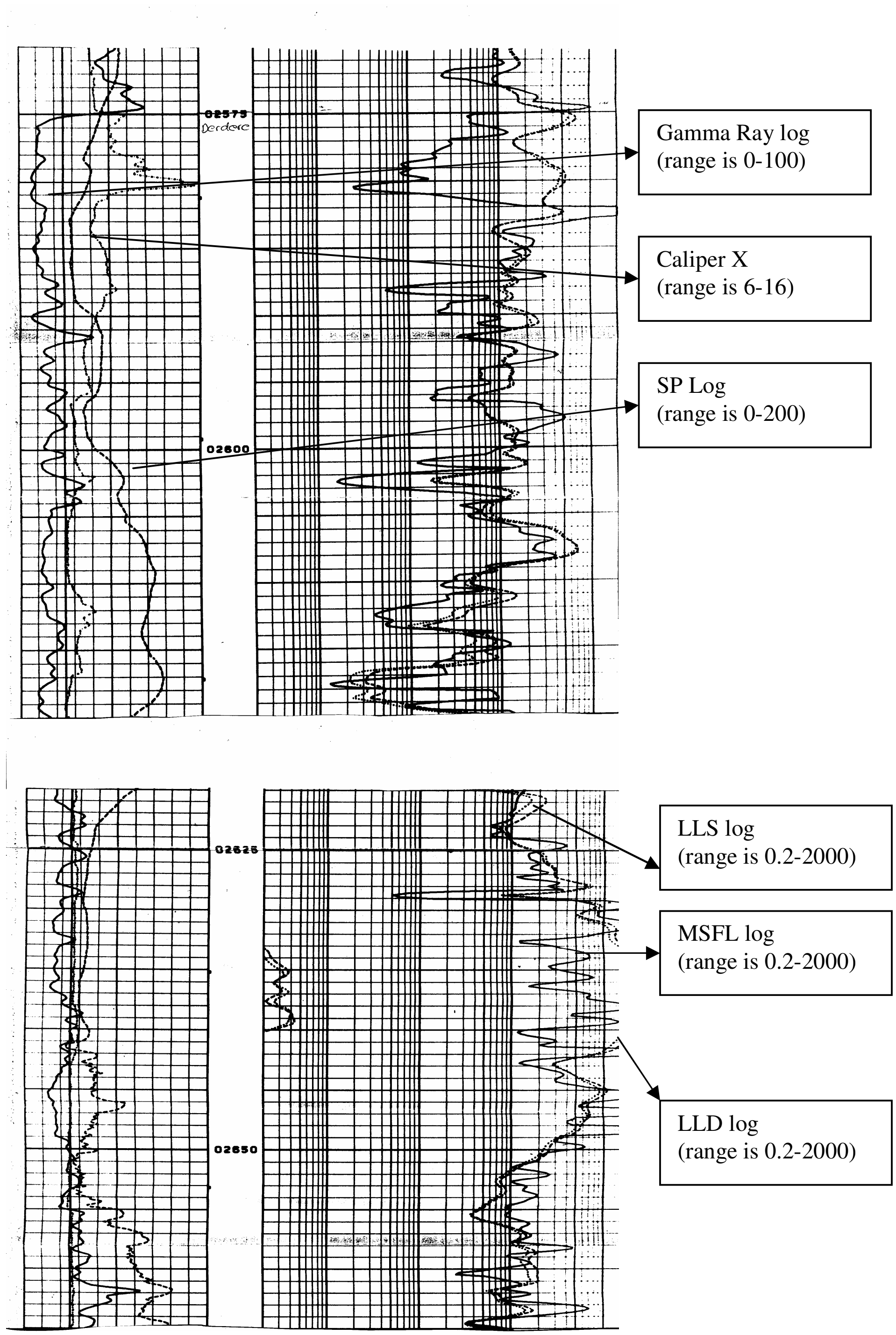


Fig A.5 MSFL (R_{xo}) and LLD (R_t) logs of Well-02.

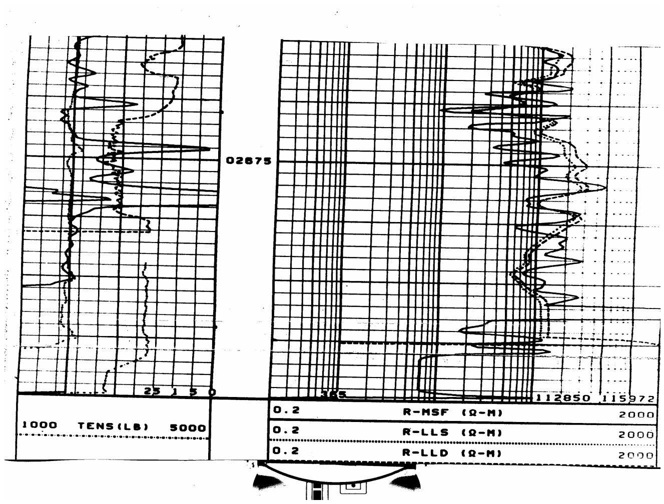


Fig A.5 MSFL (R_{xo}) and LLD (R_t) logs of Well-02 (cont'd.)

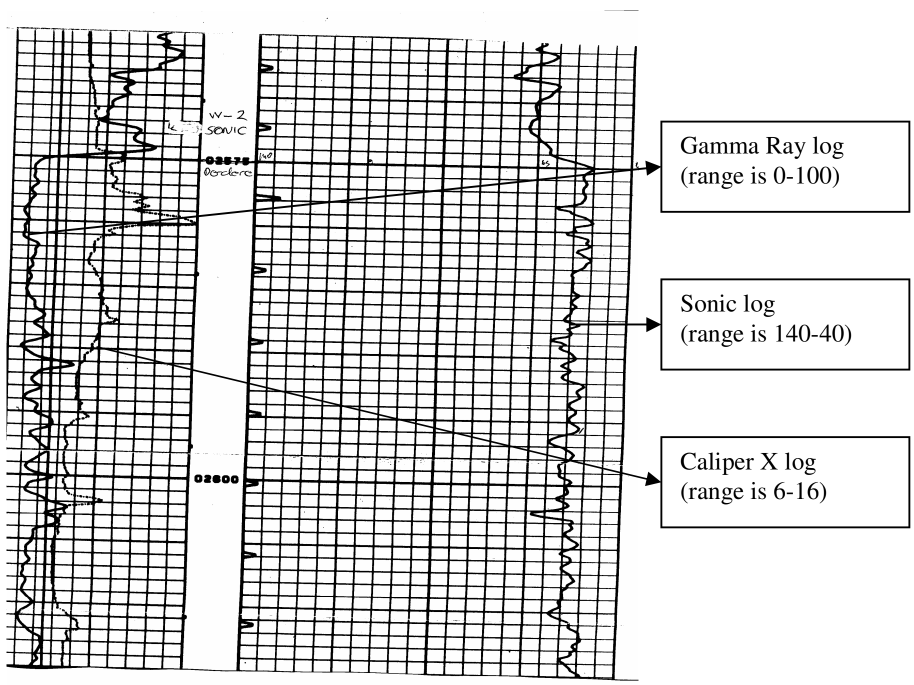


Fig A.6 Sonic log of Well-02.

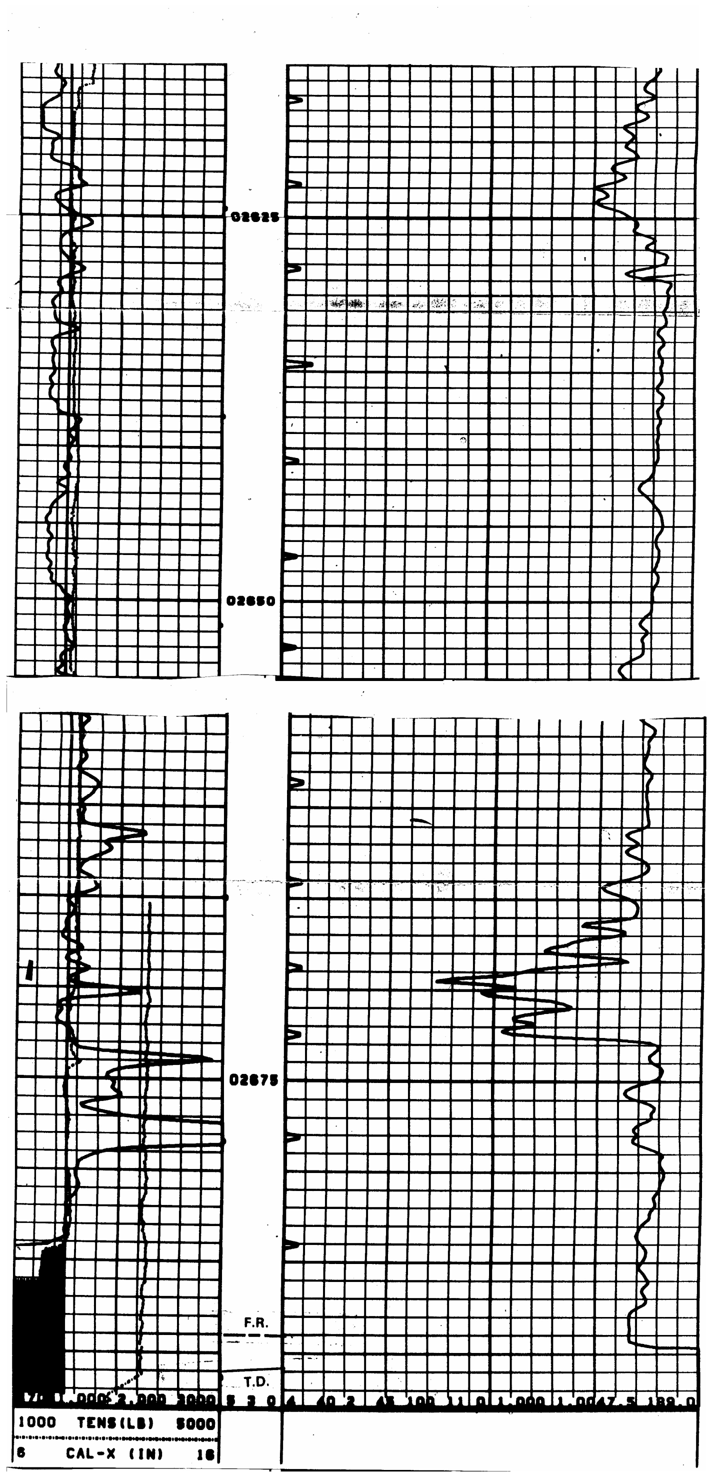


Fig A.6 Sonic log of Well-02 (cont'd.)

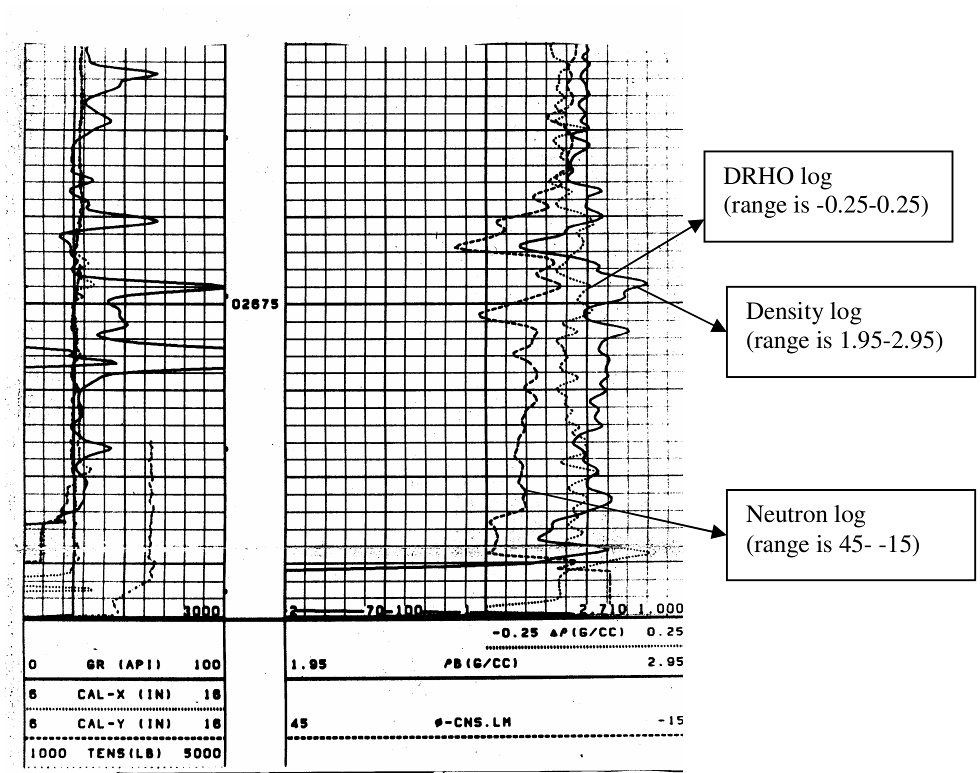


Fig A.7 Density and Neutron logs of Well-03.

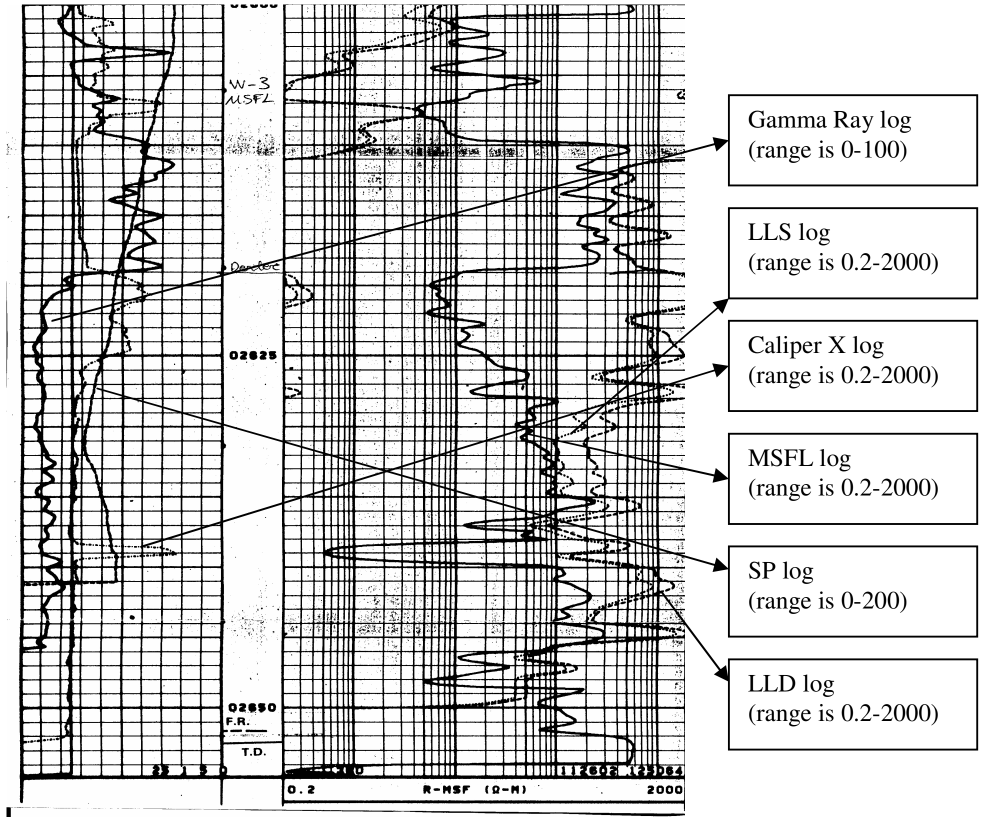


Fig A.8 MSFL (R_{xo}) and LLD (R_t) logs of Well-03.

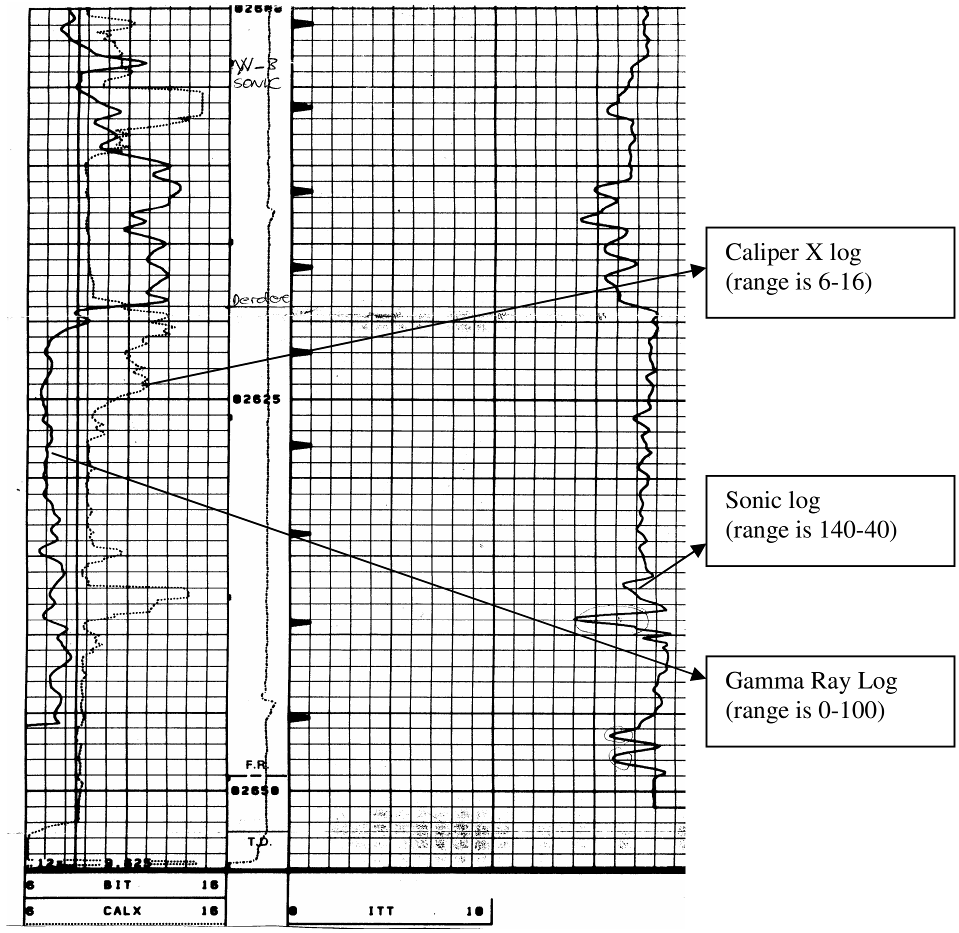


Fig A.9 Sonic log of Well-03.

APPENDIX B

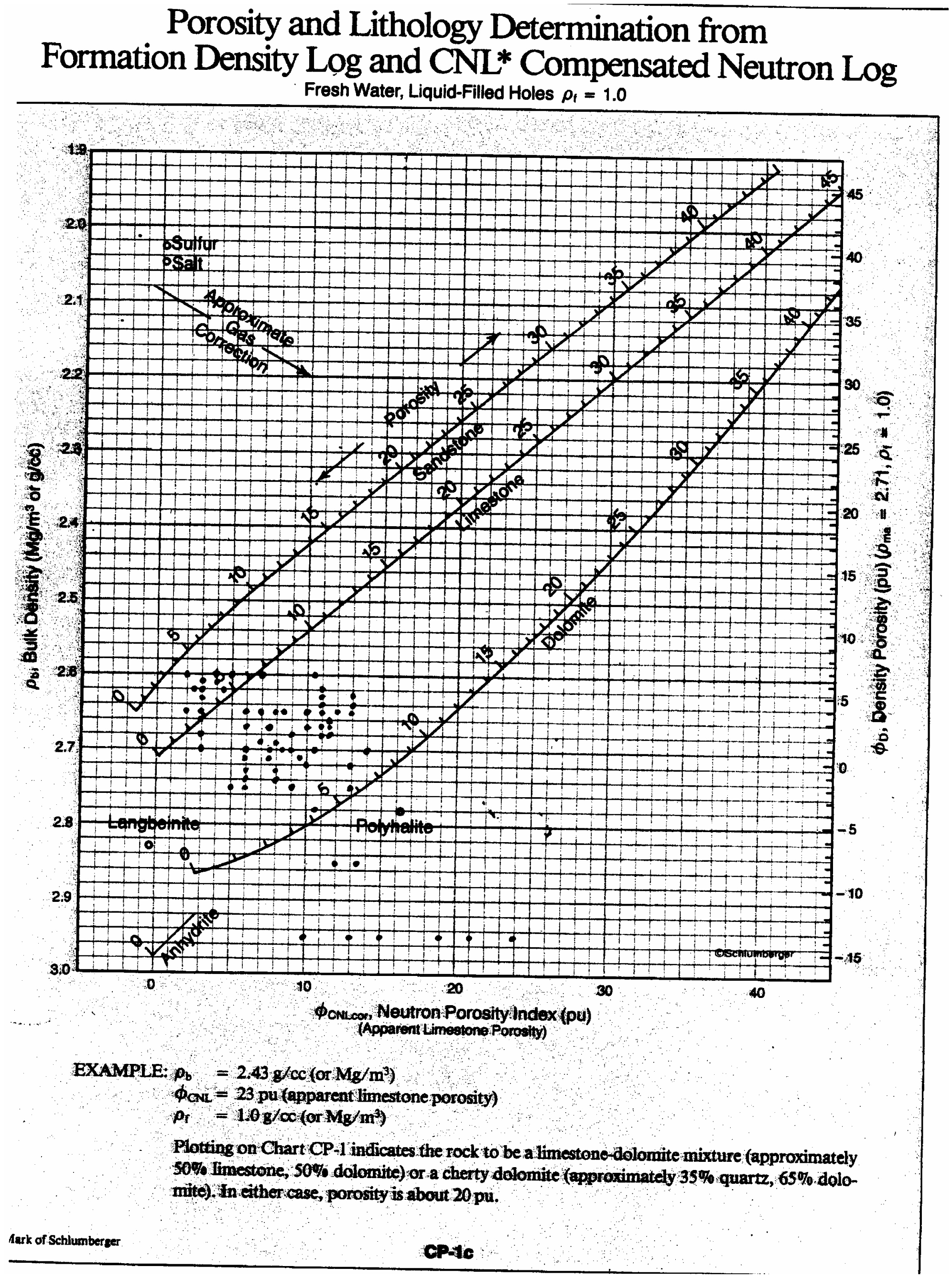


Fig B.1 Porosity Correction for lithology of Well-01.

"·" indicates porosity data.

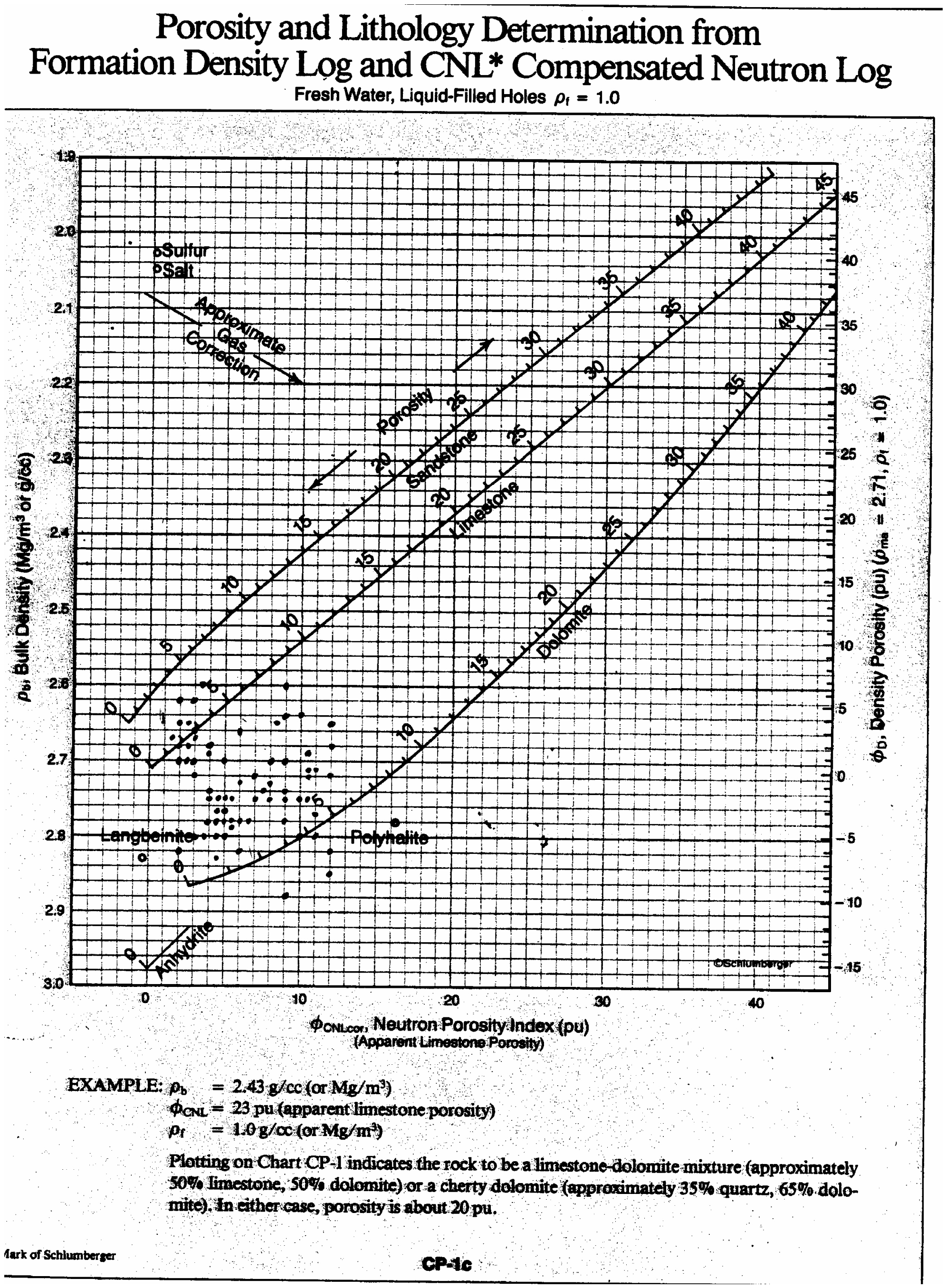
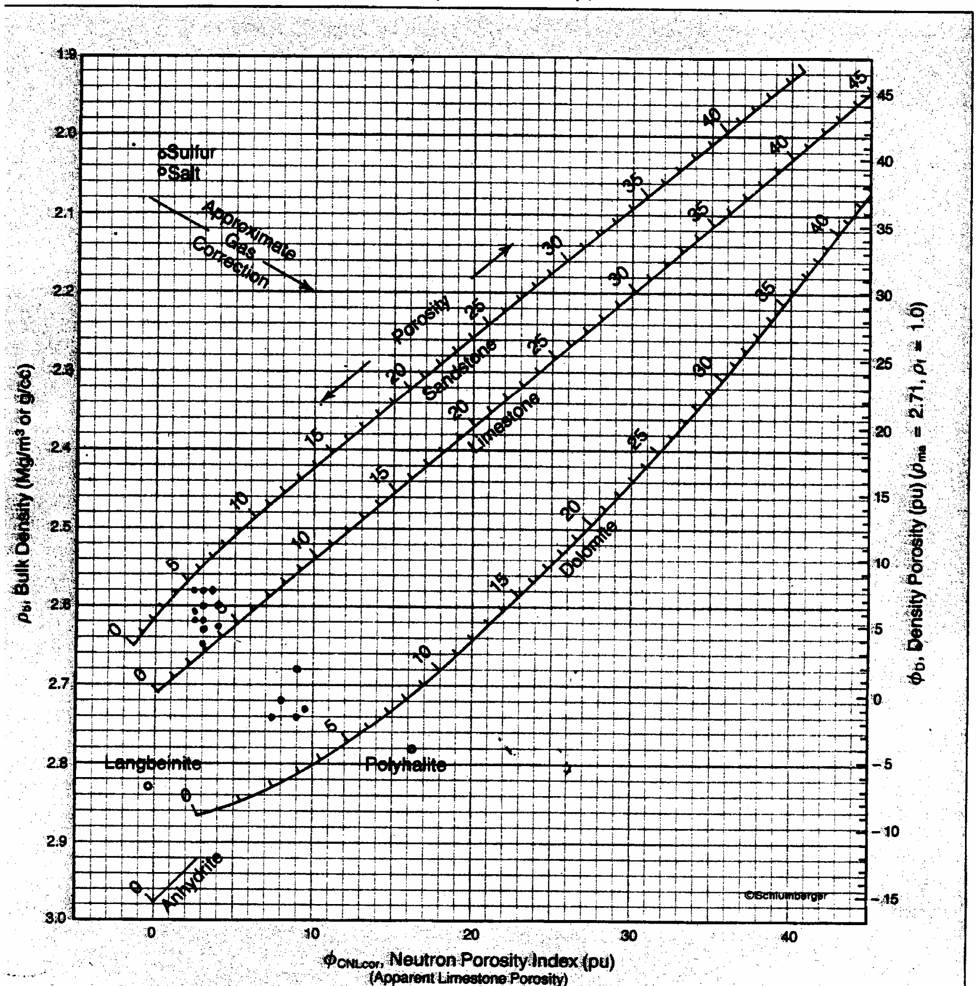


Fig B.2 Porosity Correction for lithology of Well-02.

"·" indicates porosity data.

Porosity and Lithology Determination from Formation Density Log and CNL* Compensated Neutron Log

Fresh Water, Liquid-Filled Holes $\rho_f = 1.0$



EXAMPLE: ρ_b = 2.43 g/cc (or Mg/m³)

ϕ_{CNL} = 23 pu (apparent limestone porosity)

ρ_f = 1.0 g/cc (or Mg/m³)

Plotting on Chart CP-1 indicates the rock to be a limestone-dolomite mixture (approximately 50% limestone, 50% dolomite) or a cherty dolomite (approximately 35% quartz, 65% dolomite). In either case, porosity is about 20 pu.

*Mark of Schlumberger

CP-1c

Fig B.3 Porosity Correction for lithology of Well-03.

"·" indicates porosity data.

APPENDIX C

Appendix C.1 The Well log data and Water saturation data of Well-01

Depth (m) (BSL)	R_t (ohm-m)	R_{xo} (ohm-m)	Sonic log (µsec/ ft)	Den-sity (gr/cc)	Neut-ron (%)	Corre-cted porosity (%)	S_w (m=2 & n=2)	S_w (m=1.26 & n=3.86	S_w (m=1.26 & n=3.59
-1725,75	500	70	52,5	2,62	3	4	0,35	0,31	0,29
-1726,25	460	100	51,5	2,65	2	2,8	0,53	0,36	0,33
-1726,75	700	50	51	2,6	2	4	0,30	0,29	0,26
-1727,25	700	17	50,5	2,58	1,8	4,7	0,25	0,27	0,25
-1727,75	700	28	50	2,52	2				
-1728,25	100	19	50	2,55	2				
-1728,75	1000	30	51	2,6	2,5	4,5	0,22	0,25	0,23
-1729,25	400	60	52	2,61	3	4,5	0,35	0,32	0,29
-1729,75	300	70	54	2,6	2	4	0,46	0,36	0,33
-1730,25	400	50	53	2,6	2	4	0,40	0,33	0,31
-1730,75	300	50	55	2,6	4	5,4	0,34	0,33	0,30
-1731,25	300	50	53	2,6	3	4,8	0,38	0,34	0,31
-1731,75	230	40	55	2,6	4	5,4	0,39	0,35	0,32
-1732,25	250	50	55	2,64	3	3,5	0,57	0,39	0,37
-1732,75	350	70	50	2,65	2	2,8	0,60	0,39	0,36
-1733,25	300	60	52	2,55	4,5				
-1733,75	250	36	56	2,6	5				
-1734,25	300	50	53,5	2,6	4				
-1734,75	500	14	50	2,2	6				
-1735,25	300	4	52	2,2	7				
-1735,75	400	3	52	2,6	7				
-1736,25	500	10	51	2,65	6	5	0,28	0,29	0,27
-1736,75	400	12	51,5	2,61	3	4,5	0,35	0,32	0,29
-1737,25	800	30	50	2,61	2	3,8	0,29	0,28	0,26
-1737,75	800	50	52	2,65	6	5	0,22	0,26	0,23
-1738,25	650	45	53,5	2,7	6	3,7	0,34	0,30	0,28
-1738,75	500	18	52	2,62	4,5	4,4	0,32	0,31	0,28
-1739,25	250	60	52,5	2,63	4,5	4,5	0,44	0,36	0,34
-1739,75	200	50	54	2,67	7,5	5,2	0,43	0,37	0,34
-1740,25	400	60	57	2,65	10	7	0,23	0,28	0,25
-1740,75	600	40	55	2,6	10,5				
-1741,25	620	10	53,5	2,6	11				
-1741,75	600	10	56,5	2,5	11,5				
-1742,25	640	20	53	2,6	10,5				
-1742,75	600	40	54	2,62	11,5				
-1743,25	450	125	54	2,66	10,5	7	0,21	0,27	0,24
-1743,75	500	25	52	2,7	10,5	6	0,24	0,28	0,25
-1744,25	300	40	53	2,9	12	3	0,61	0,39	0,37
-1744,75	20	0,5	55	2,95	13	2,7	2,62	0,82	0,81
-1745,25	1,5	0,2	73	2,95	10,5	1,7	15,19	1,87	1,97
-1745,75	2	0,24	67,5	2,95	10	1,5	14,91	1,81	1,90
-1746,25	1,5	0,2	85	2,95	12	2,2	11,74	1,72	1,80
-1746,75	2	0,3	66	2,95	15	3,4	6,58	1,39	1,42
-1747,25	3,6	0,3	85	2,95	22,5	6,6	2,53	0,96	0,96

Appendix C.1 (cont'd)

-1747,75	2,2	0,4	75	2,95	21	5,5	3,88	1,16	1,17
-1748,25	7,5	0,9	60	2,95	16,5	4	2,89	0,93	0,93
-1748,75	5	0,4	68	2,95	18	4,4	3,21	1,01	1,01
-1749,25	5,8	1,5	60	2,95	32				
-1749,75	3	1,4	70	2,95	24				
-1750,25	3	0,5	85	2,95	18	4,4	4,15	1,15	1,16
-1750,75	4	0,3	55	2,95	15	3,4	4,65	1,16	1,17
-1751,25	5	5	55	2,95	13	2,7	5,24	1,18	1,19
-1751,75	12	5	55	2,95	13	2,7	3,38	0,94	0,94
-1752,25	6	15	62	2,95	19	4,6	2,81	0,95	0,94
-1752,75	4	0,3	85	2,95	21	5,5	2,87	0,99	0,99
-1753,25	3	0,22	97,5	2,95	24	7	2,80	1,02	1,03
-1753,75	5	0,4	90	2,7	18	4,4	3,21	1,01	1,01
-1754,25	500	8	65	2,57	12				
-1754,75	1000	20	52,5	2,45	12				
-1755,25	1500	10	52,5	2,4	10				
-1755,75	1000	4	54	2,45	10				
-1756,25	650	4	52,1	2,65	12				
-1756,75	400	4	53,5	2,65	13				
-1757,25	400	4,5	54,5	2,55	11				
-1757,75	400	8	52	2,65	11				
-1758,25	400	10	54	2,65	13				
-1758,75	300	15	55	2,6	12				
-1759,25	300	7	52,5	2,5	10				
-1759,75	300	4	52	2,65	11				
-1760,25	280	10	54	2,7	10,5	6	0,31	0,32	0,29
-1760,75	400	35	50	2,7	9	5,2	0,30	0,31	0,28
-1761,25	450	80	48	2,75	8,5	4	0,37	0,32	0,30
-1761,75	400	45	52	2,69	8	5	0,32	0,31	0,28
-1762,25	900	25	53	2,72	8	4,3	0,25	0,26	0,24
-1762,75	1500	20	54	2,7	6	4	0,20	0,24	0,21
-1763,25	2300	25	52,5	2,68	5	3,6	0,18	0,22	0,20
-1763,75	2000	20	53,5	2,65	8,5				
-1764,25	1300	25	52	2,73	9	4,6	0,19	0,23	0,21
-1764,75	1200	40	50	2,75	9	4,3	0,21	0,25	0,22
-1765,25	1300	80	52	2,76	10	4,5	0,19	0,24	0,21
-1765,75	850	13	51	2,78	10,5	4,3	0,25	0,27	0,24
-1766,25	560	10	48	2,81	12	4,4	0,30	0,30	0,27
-1766,75	500	200	50	2,72	13	6,6	0,21	0,27	0,24
-1767,25	100	100	52	2,85	13,5	4,4	0,72	0,46	0,44
-1767,75	7	0,5	53	2,95	18	5,5	2,17	0,86	0,85
-1768,25	10	1	80	2,85	13	4,2	2,38	0,85	0,84
-1768,75	50	10	55	2,85	12	4,8	0,93	0,54	0,51
-1769,25	70	17	57	2,75	12	5,5	0,69	0,47	0,45
-1769,75	110	20	55	2,66	11,5				
-1770,25	400	10	51,5	2,7	11	6,1	0,26	0,29	0,26
-1770,75	600	20	52	2,71	9	5	0,26	0,28	0,25
-1771,25	1200	50	52	2,73	8	4,1	0,22	0,25	0,22
-1771,75	2000	60	53	2,74	6	3	0,24	0,24	0,22
-1772,25	1000	50	48	2,71	5,5	3,2	0,31	0,28	0,26
-1772,75	800	120	50	2,74	6	3	0,37	0,31	0,28

Appendix C.1 (cont'd)

-1773,25	600	60	52	2,72	6	3,4	0,38	0,32	0,29
-1773,75	600	60	51	2,65	6				
-1774,25	430	100	50	2,77	6	2,5	0,61	0,38	0,35
-1774,75	500	170	45,6	2,7	6	4	0,35	0,31	0,29
-1775,25	430	135	51	2,67	7	5	0,30	0,30	0,28
-1775,75	500	70	51,5	2,75	6	3	0,47	0,35	0,32
-1776,25	1000	180	48	2,75	5	2,2	0,45	0,32	0,29
-1776,75	800	100	49	2,71	6	3,5	0,32	0,29	0,27
-1777,25	550	280	52	2,7	6	4,8	0,28	0,29	0,26
-1777,75	500	90	50,5	2,74	6	2,8	0,51	0,35	0,33
-1778,25	330	25	52,5	2,72	8	4,4	0,40	0,34	0,31
-1778,75	200	20	56,5	2,58	8				
-1779,25	175	20	58	2,67	8,5	5,5	0,43	0,37	0,35
-1779,75	200	70	55	2,67	6	4,5	0,50	0,38	0,36
-1780,25	145	35	58	2,69	4	3	0,88	0,48	0,45
-1780,75	140	80	59	2,66	3	3	0,89	0,48	0,46
-1781,25	140	60	59	2,67	2,5	2,5	1,07	0,51	0,49
-1781,75	215	300	57	2,7	3	2	1,08	0,49	0,47
-1782,25	300	100	50	2,67	4,5	3,5	0,52	0,38	0,35
-1782,75	250	10	56	2,68	3	2,5	0,80	0,44	0,41
-1783,25	400	200	52	2,65	3	3,2	0,49	0,36	0,33
-1783,75	250	30	52,5	2,65	3	3,4	0,59	0,40	0,37
-1784,25	300	100	52	2,67	2,5	2,5	0,73	0,42	0,39
-1784,75	1000	700	52	2,63	3	4	0,25	0,26	0,24
-1785,25	4500	1000	53,5	2,62	3	4	0,12	0,18	0,16
-1785,75	3000	2000	54	2,61	4	5	0,12	0,18	0,16
-1786,25	2000	900	54	2,62	5	4,7	0,15	0,21	0,19
-1786,75	2000	1000	55	2,65	7	5,5	0,13	0,20	0,18
-1787,25	1000	100	54	2,67	7,5	5,2	0,19	0,24	0,22
-1787,75	900	25	53	2,64	12				
-1788,25	500	3	57,5	2,7	16				
-1788,75	240	3	52	2,7	14				
-1789,25	350	40	49	2,7	11				
-1789,75	380	20	52	2,7	10,5				
-1790,25	350	6	52	2,64	10,5				
-1790,75	200	20	54	2,65	12				
-1791,25	350	45	58	2,67	9	6	0,28	0,30	0,28
-1791,75	300	45	59	2,7	7,5	4,5	0,41	0,35	0,32
-1792,25	450	50	56	2,7	10	5,8	0,26	0,29	0,26
-1792,75	400	45	56	2,85	13,5	5,3	0,30	0,30	0,28
-1793,25	480	70	53	2,85	16	5,2	0,28	0,29	0,27
-1793,75	400	65	52,5	2,75	13	6	0,26	0,29	0,27
-1794,25	300	70	52,5	2,68	11				
-1794,75	300	60	53	2,68	11				
-1795,25	270	9	52,5	2,6	9				
-1795,75	300	17	53	2,55	10				
-1796,25	380	9	53,5	2,6	10,5				
-1796,75	250	4,8	58	2,55	13,5				
-1797,25	150	8	55	2,64	12				
-1797,75	120	15	52,5	2,7	8,5	5	0,58	0,42	0,40
-1798,25	150	15	48	2,68	10,5	6,5	0,40	0,37	0,34

Appendix C.1 (cont'd)

-1798,75	150	6	50	2,72	10	5,3	0,49	0,39	0,37
-1799,25	180	30	47,5	2,66	10,5	7	0,34	0,34	0,32
-1799,75	200	40	50	2,63	11				
-1800,25	250	55	49	2,67	10	6,5	0,31	0,32	0,30
-1800,75	260	80	48	2,67	11	7	0,28	0,31	0,28
-1801,25	225	140	48,5	2,75	10,5	5	0,42	0,36	0,33
-1801,75	250	155	49	2,75	9	4,5	0,44	0,36	0,34
-1802,25	250	90	48,5	2,75	7	3,3	0,61	0,40	0,37
-1802,75	300	150	46	2,69	7	4,5	0,41	0,35	0,32
-1803,25	400	180	47	2,68	7	5	0,32	0,31	0,28
-1803,75	500	60	47	2,71	7,5	4	0,35	0,31	0,29
-1804,25	600	100	48	2,7	8	5	0,26	0,28	0,25
-1804,75	800	160	50	2,74	8	4	0,28	0,28	0,25
-1805,25	900	100	48	2,75	6	2,8	0,38	0,30	0,28
-1805,75	800	60	47	2,75	6	2,5	0,45	0,32	0,30
-1806,25	800	200	48	2,7	7	4,2	0,27	0,27	0,25
-1806,75	800	400	48	2,73	6	3	0,37	0,31	0,28
-1807,25	900	130	47,5	2,73	6	3,2	0,33	0,29	0,26
-1807,75	500	150	47,5	2,74	6	2,8	0,51	0,35	0,33
-1808,25	300	250	48	2,75	7,5	3,5	0,52	0,38	0,35
-1808,75	250	160	50	2,73	8	4,2	0,48	0,37	0,34
-1809,25	280	2000	48	2,68	7,5	5	0,38	0,34	0,31
-1809,75	350	100	47,5	2,68	9	6,7	0,25	0,29	0,27
-1810,25	340	80	48	2,66	10	6,8	0,25	0,29	0,27
-1810,75	230	30	50,5	2,6	10,5				
-1811,25	160	35	50	2,66	10,5	6,8	0,37	0,36	0,33
-1811,75	120	100	50	2,68	10,5	7	0,41	0,38	0,35
-1812,25	140	200	52	2,67	10	6,5	0,41	0,37	0,35
-1812,75	160	200	50	2,67	10,5	7,2	0,35	0,35	0,32
-1813,25	160	160	50	2,68	10	6,2	0,40	0,37	0,34
-1813,75	100	100	50	2,65	11	7,5	0,42	0,39	0,36
-1814,25	80	50	52	2,6	12,5				
-1814,75	50	45	52	2,65	13				
-1815,25	50	70	53	2,67	11	7	0,64	0,48	0,45
-1815,75	100	200	51	2,7	9	5,2	0,61	0,44	0,41
-1816,25	300	400	49,5	2,73	7,5	4	0,46	0,36	0,33
-1816,75	400	300	49	2,7	9	5,2	0,30	0,31	0,28
-1817,25	230	170	50	2,69	8,5	5,3	0,39	0,35	0,32
-1817,75	400	100	49,5	2,65	8	6	0,26	0,29	0,27
-1818,25	450	60	50	2,63	10	7,5	0,20	0,26	0,24
-1818,75	320	40	50	2,65	10	7	0,25	0,29	0,27
-1819,25	260	50	50	2,65	10	7	0,28	0,31	0,28
-1819,75	200	40	50,5	2,64	11	7,8	0,29	0,32	0,29
-1820,25	90	30	51	2,63	11	7,5	0,44	0,40	0,37
-1820,75	75	40	51	2,62	11	8,3	0,44	0,41	0,38
-1821,25	75	40	51,5	2,63	12	8,5	0,43	0,40	0,38
-1821,75	90	50	52	2,63	13	9,5	0,35	0,37	0,34

Appendix C.1 (cont'd)

-1822,25	90	50	52,5	2,65	12	8	0,42	0,39	0,36
-1822,75	100	130	52,5	2,67	10	6,5	0,49	0,41	0,38
-1823,25	125	100	51,5	2,67	9	6	0,47	0,39	0,37
-1823,75	120	50	50	2,68	9	4,8	0,60	0,43	0,40
-1824,25	150	50	52	2,69	9	5,5	0,47	0,39	0,36
-1824,75	300	80	51	2,7	7,5	4,5	0,41	0,35	0,32

Appendix C.2 The Well log data and Water saturation data of Well-02

Depth (m) (BSL)	R_t (ohm -m)	R_{xo} (ohm -m)	Sonic log (µsec/ ft)	Den-sity (gr/cc)	Neut-ron (%)	Corre -cted porosi ty (%)	S_w (m=2 & n=2)	S_w (m=1,83 & n=3.98
-1714,7	600	200	50	2,67	1,5	2	0,645	0,679
-1715,2	700	50	52,5	2,67	1,5	2	0,598	0,653
-1715,7	500	70	52,5	2,65	2	3	0,471	0,590
-1716,2	250	130	52,5	2,62	2,5	4	0,500	0,615
-1716,7	160	30	52,5	2,62	3	4	0,625	0,688
-1717,2	160	25	52,5	2,53	3			
-1717,7	200	20	58	2,53	2			
-1718,2	330	15	55	2,48	2			
-1718,7	400	10	51	2,5	2			
-1719,2	540	10	52,5	2,1	2			
-1719,7	630	10	55	2,3	2			
-1720,2	460	2,7	51	2,61	1,8	3,6	0,410	0,554
-1720,7	350	15	51	2,62	2	3,5	0,483	0,601
-1721,2	320	50	54	2,67	2	2,4	0,737	0,731
-1721,7	350	200	51,5	2,68	2	2	0,845	0,778
-1722,2	500	2000	51,5	2,65	3	3,2	0,442	0,573
-1722,7	200	100	54	2,68	4	3	0,745	0,743
-1723,2	100	200	55	2,68	3,5	3	1,054	0,884
-1723,7	90	115	55	2,7	3	2	1,667	1,094
-1724,2	150	250	55	2,67	2,5	2,5	1,033	0,868
-1724,7	200	200	53,5	2,67	3	2,7	0,828	0,780
-1725,2	225	170	55	2,67	2,7	2,7	0,781	0,757
-1725,7	180	100	54	2,67	3	2,7	0,873	0,800
-1726,2	150	125	55	2,67	4,5	3,5	0,738	0,744
-1726,7	120	200	56	2,6	3,5	5	0,577	0,668
-1727,2	170	200	54	2,35	3,5			
-1727,7	125	8	55	2,45	4			
-1728,2	150	20	60	2,7	6	3,6	0,717	0,734
-1728,7	120	60	57	2,7	5	3	0,962	0,844
-1729,2	150	28	55	2,67	2,5	2,5	1,033	0,868
-1729,7	220	70	53	2,68	2	2	1,066	0,874
-1730,2	275	80	57	2,7	3	2	0,953	0,826
-1730,7	200	130	55	2,64	9			
-1731,2	60	80	57	2,75	7	3,3	1,237	0,962
-1731,7	60	70	52	2,74	4	2	2,041	1,211
-1732,2	150	200	52,5	2,73	6,5	3,5	0,738	0,744
-1732,7	150	420	52	2,72	7	4	0,645	0,699
-1733,2	120	220	54,5	2,7	3	2	1,443	1,017
-1733,7	140	70	53	2,65	2,5	3,5	0,764	0,757
-1734,2	150	65	54	2,7	5	3,2	0,807	0,775
-1734,7	140	70	54	2,73	8	4	0,668	0,712
-1735,2	150	30	52	2,67	12			
-1735,7	20	60	55	2,7	9	5	1,414	1,047
-1736,2	60	30	59	2,64	5,5	5	0,816	0,795
-1736,7	70	300	56,5	2,7	5	3	1,260	0,967

Appendix C.2 (cont'd)

-1737,2	70	500	53	2,73	5,5	3	1,260	0,967
-1737,7	100	500	55	2,74	9	4,4	0,719	0,741
-1738,2	150	250	57	2,72	11	5,7	0,453	0,594
-1738,7	170	170	56,5	2,69	10,5	6,3	0,385	0,550
-1739,2	150	150	55	2,75	9	4,2	0,615	0,684
-1739,7	160	160	55	2,75	9	4,3	0,581	0,666
-1740,2	120	70	54	2,6	10,5			
-1740,7	180	13	57	2,6	9			
-1741,2	150	20	54	2,45	9			
-1741,7	50	10	60	2	12			
-1742,2	18	1,7	60	2,45	9			
-1742,7	50	5	53	2,73	6	3	1,491	1,052
-1743,2	140	50	53	2,77	7,5	3,2	0,835	0,789
-1743,7	90	100	54	2,8	10	3,7	0,901	0,824
-1744,2	70	50	51,5	2,75	11	4,7	0,804	0,787
-1744,7	80	50	54	2,65	12			
-1745,2	100	100	55	2,7	11	6,1	0,518	0,638
-1745,7	300	170	53	2,71	10,5	5,5	0,332	0,508
-1746,2	450	200	55	2,72	9,5	5	0,298	0,479
-1746,7	500	390	53	2,75	8	3,5	0,404	0,550
-1747,2	700	240	52	2,75	8	3,7	0,323	0,492
-1747,7	700	300	54	2,74	9	4,4	0,272	0,455
-1748,2	300	200	55	2,73	10	5	0,365	0,530
-1748,7	90	80	55	2,72	10,5	5,5	0,606	0,687
-1749,2	60	50	55	2,75	13,5	6,3	0,648	0,715
-1749,7	50	30	58	2,82	12	4,3	1,040	0,892
-1750,2	60	60	55	2,77	10,5	4,5	0,907	0,834
-1750,7	150	35	53	2,78	9	3,5	0,738	0,744
-1751,2	120	60	50	2,55	7,5			
-1751,7	50	7	49,5	2,43	9			
-1752,2	40	4	50	2,7	8,5	5	1,000	0,880
-1752,7	25	6	50,5	2,88	9	2	3,162	1,509
-1753,2	15	10	53	2,8	10,5	4,1	1,991	1,233
-1753,7	50	50	54	2,75	10,5	4,7	0,952	0,856
-1754,2	90	100	52	2,75	9,5	4,4	0,758	0,761
-1754,7	70	100	49	2,7	9	5	0,756	0,764
-1755,2	70	30	50	2,62	7,5	6,5	0,581	0,678
-1755,7	80	20	52	2,65	8,5	6,1	0,580	0,675
-1756,2	20	23	53,5	2,67	9	6	1,179	0,963
-1756,7	3,5	20	50	2,8	11	4,2	4,025	1,758
-1757,2	3,2	2	54	2,9	12,5	3,4	5,199	1,982
-1757,7	5	5	53,5	2,85	12	3,8	3,722	1,683
-1758,2	2,8	90	53	2,85	12	3,8	4,973	1,947
-1758,7	7	30	58	2,77	11	4,6	2,598	1,417
-1759,2	15	20	55,5	2,72	10,5	5,5	1,485	1,078
-1759,7	50	130	56,5	2,72	10,5	5,5	0,813	0,796
-1760,2	200	120	55	2,78	10	4	0,559	0,651
-1760,7	230	120	49,5	2,71	11	6	0,348	0,521
-1761,2	200	110	6	2,67	11,5	7,3	0,306	0,493
-1761,7	160	100	60	2,68	12	7	0,357	0,532
-1762,2	125	100	58	2,71	11	6	0,471	0,608

Appendix C.2 (cont'd)

-1762,7	90	60	65	2,72	12	6,2	0,538	0,650
-1763,2	90	80	62	2,72	9	4,7	0,709	0,738
-1763,7	100	100	64	2,75	8	3,5	0,904	0,824
-1764,2	120	300	60	2,82	8	2,5	1,155	0,918
-1764,7	200	200	50	2,75	7	3	0,745	0,743
-1765,2	210	160	55	2,78	5,5	2	1,091	0,884
-1765,7	230	200	52,5	2,79	5,5	2	1,043	0,864
-1766,2	290	170	50,5	2,8	5,5	1,7	1,092	0,878
-1766,7	300	200	50	2,78	5,5	2	0,913	0,808
-1767,2	450	200	47,5	2,8	4,5	1,2	1,242	0,923
-1767,7	650	250	50	2,6	6			
-1768,2	300	10	57	2,55	8			
-1768,7	350	350	50	2,82	6	1,6	1,056	0,862
-1769,2	800	2000	47	2,81	5	1,4	0,799	0,744
-1769,7	700	1000	47	2,78	4,5	1,5	0,797	0,746
-1770,2	600	1000	47,5	2,82	4	0,8	1,614	1,035
-1770,7	1000	2000	48	2,8	4,5	1,3	0,769	0,728
-1771,2	1500	2000	47,5	2,8	4	1,5	0,544	0,616
-1771,7	1400	1000	48,5	2,75	4	1,8	0,470	0,576
-1772,2	1500	2000	49	2,7	4	2,7	0,302	0,470
-1772,7	2000	300	48,5	2,8	5	1,5	0,471	0,573
-1773,2	2500	200	49	2,8	4	1,5	0,422	0,542
-1773,7	2500	700	49	2,8	5	1,5	0,422	0,542
-1774,2	3000	300	48	2,78	5,5	2	0,289	0,453
-1774,7	3800	300	48,5	2,78	4	1,3	0,395	0,521
-1775,2	3250	780	48	2,81	3,5	0,7	0,792	0,720
-1775,7	2800	300	49,5	2,8	3	0,6	0,996	0,802
-1776,2	3000	200	47,5	2,8	2,5	0,5	1,155	0,857
-1776,7	3000	700	48	2,82	2	0,2	2,887	1,306
-1777,2	2250	800	49	2,82	2,5	0,3	2,222	1,165
-1777,7	3000	2000	48,5	2,8	3	0,6	0,962	0,788
-1778,2	4000	1000	49	2,78	3	0,8	0,625	0,642
-1778,7	4000	900	49	2,8	3,5	0,8	0,625	0,642
-1779,2	4000	1500	49,5	2,83	4	0,7	0,714	0,683
-1779,7	2000	150	49	2,8	4	1	0,707	0,690
-1780,2	1700	200	49	2,82	4,5	1	0,767	0,719
-1780,7	1600	300	50	2,77	4,5	1,6	0,494	0,588
-1781,2	1500	1500	50	2,8	6	2	0,408	0,539
-1781,7	800	2000	52	2,75	5,5	2,7	0,414	0,550
-1782,2	400	200	53,5	2,77	10	4,3	0,368	0,529
-1782,7	300	200	52,5	2,78	6	2,2	0,830	0,774
-1783,2	400	350	50	2,77	5,5	2,2	0,719	0,720
-1783,7	600	300	48	2,8	4,5	1,2	1,076	0,859
-1784,2	800	400	47	2,82	4	0,8	1,398	0,963
-1784,7	1100	2000	47,5	2,83	4,5	0,9	1,059	0,842
-1785,2	1000	2000	48	2,8	5	1,5	0,667	0,682
-1785,7	700	1000	49	2,78	5	1,8	0,664	0,686
-1786,2	700	1000	48	2,76	4,5	1,8	0,664	0,686
-1786,7	700	2000	48,5	2,75	5	2,2	0,543	0,625
-1787,2	650	450	48	2,75	5,5	2,5	0,496	0,601
-1787,7	600	1000	50	2,82	6	1,5	0,861	0,775

Appendix C.2 (cont'd)

-1788,2	500	2000	48	2,8	7	2,4	0,589	0,654
-1788,7	400	320	50	2,78	6,5	2,5	0,632	0,679
-1789,2	280	400	50	2,78	5	1,8	1,050	0,863
-1789,7	270	500	50	2,77	5	2	0,962	0,830
-1790,2	200	200	50	2,77	6	2,5	0,894	0,808
-1790,7	150	200	52	2,74	7,5	3,5	0,738	0,744
-1791,2	125	125	53	2,75	8	3,8	0,744	0,750
-1791,7	90	275	51	2,75	9	4,2	0,794	0,778
-1792,2	80	150	52,5	2,76	10,5	4,7	0,752	0,761
-1792,7	90	150	52	2,75	10	4,5	0,741	0,753
-1793,2	90	150	52,5	2,69	10,5	6,3	0,529	0,645
-1793,7	80	200	56	2,64	12			
-1794,2	60	150	58	2,65	13,5			
-1794,7	50	100	56	2,71	12	6,5	0,688	0,737
-1795,2	40	90	52,5	2,73	6	5,5	0,909	0,842
-1795,7	60	150	53	2,72	3	1,8	2,268	1,271
-1796,2	100	140	54	2,7	1,5	1,3	2,433	1,298
-1796,7	150	150	54	2,7	2	1,5	1,721	1,098
-1797,2	145	150	55	2,7	2	1,5	1,751	1,107
-1797,7	130	300	53	2,7	2	1,5	1,849	1,138
-1798,2	195	200	54	2,68	2	2	1,132	0,901
-1798,7	180	100	54	2,7	2	1,5	1,571	1,049
-1799,2	170	170	54	2,72	2	1,2	2,021	1,179
-1799,7	200	70	54	2,7	2	1,5	1,491	1,021
-1800,2	200	50	54	2,7	1,5	1,3	1,720	1,091
-1800,7	200	100	53,5	2,7	3	2	1,118	0,895
-1801,2	100	100	58,5	2,7	2,5	1,8	1,757	1,118
-1801,7	70	170	56	2,68	2,5	2,3	1,643	1,093
-1802,2	85	80	58,5	2,7	3	2	1,715	1,110
-1802,7	100	400	54,5	2,7	2	1,5	2,108	1,216
-1803,2	180	600	53	2,68	2	2	1,179	0,919
-1803,7	100	160	60	2,69	4	3	1,054	0,884
-1804,2	45	35	64	2,68	5	3,6	1,309	0,994
-1804,7	80	80	60	2,7	3	2	1,768	1,127
-1805,2	160	150	51	2,68	2	2	1,250	0,947
-1805,7	200	150	58	2,7	2,5	1,8	1,242	0,939
-1806,2	200	135	69	2,66	3	3	0,745	0,743
-1806,7	170	150	59,5	2,66	3	3	0,808	0,774
-1807,2	150	150	72,5	2,66	4	3,5	0,738	0,744
-1807,7	90	90	70	2,66	6	4,6	0,725	0,746
-1808,2	90	200	64	2,73	6	3,2	1,042	0,881
-1808,7	80	80	80	2,7	8	4,6	0,769	0,768
-1809,2	60	70	100	2,7	6	4,8	0,851	0,810
-1809,7	70	90	85	2,74	9	4,4	0,859	0,811

Appendix C.3 The Well log data and Water saturation data of Well-03.

Depth (m) (BSL)	R_t (ohm -m)	R_{xo} (ohm -m)	Sonic log (µsec/ ft)	Den-sity (gr /cc)	Neut-ron (%)	Corre-cted porosity (%)	S_w (m=2 & n=2)	S_w (from cross-plot)
-1802,7	3000	6	52	2,3	2			
-1803,2	4000	7	50	2,45	4			
-1803,7	3800	8	52	2,43	3			
-1804,2	2000	8,5	52	2,53	3			
-1804,7	1000	5,5	50	2,58	3	5,8	0,172	0,280
-1805,2	500	15	52	2,58	3	5,5	0,257	0,333
-1805,7	900	10,4	52	2,6	3	5	0,211	0,299
-1806,2	900	15	53,5	2,6	3	4,7	0,224	0,305
-1806,7	1500	10,2	52,5	2,63	3	4	0,204	0,284
-1807,2	900	15	52	2,57	2	5,2	0,203	0,296
-1807,7	1950	19	55	2,51	2			
-1808,2	1000	25	52	2,55	2	6	0,167	0,278
-1808,7	400	40	52,5	2,6	3	5	0,316	0,360
-1809,2	280	50	53,5	2,63	2	3,3	0,573	0,439
-1809,7	500	30	52,5	2,62	2,5	4	0,354	0,364
-1810,2	4000	15	53,5	2,67	1,8	4,7	0,106	0,217
-1810,7	2000	30	53	2,61	2,5	4,2	0,168	0,263
-1811,2	500	70	53	2,63	2	3,3	0,429	0,385
-1811,7	300	50,5	54,5	2,62	3	4,1	0,445	0,406
-1812,2	300	60	53,5	2,61	2	3,8	0,480	0,415
-1812,7	480	45	52	2,58	2,5	5,1	0,283	0,343
-1813,2	250	50	53	260	4	5,3	0,377	0,393
-1813,7	190	50	54	2,6	4	5,5	0,417	0,414
-1814,2	200	70	54	2,63	4	4,3	0,520	0,439
-1814,7	210	80	54	2,58	3,5	5,7	0,383	0,401
-1815,2	250	95	54	2,63	3	3,8	0,526	0,433
-1815,7	250	80	54,5	2,63	4	4,4	0,455	0,415
-1816,2	300	90	53	2,68	3,5	3,9	0,468	0,412
-1816,7	300	95	53	2,65	3	3,2	0,571	0,436
-1817,2	230	90	54	2,62	2,5	3,8	0,549	0,441
-1817,7	300	100	53	2,6	4	5,5	0,332	0,374
-1818,2	700	200	52,5	2,44	3,5			
-1818,7	500	100	52	2,63	2,5	4,7	0,301	0,348
-1819,2	200	50	50	2,69	9	5,5	0,407	0,409
-1819,7	85	13	57	2,55	16,5			
-1820,2	150	55	50	2,69	12			
-1820,7	200	70	50	2,68	9			
-1821,2	500	2	50	2,2	12			
-1821,7	250	0,5	70	1,95	24			
-1822,2	240	2	50	2,2	21			
-1822,7	700	100	47	2,7	12			
-1823,2	950	130	47,5	2,65	10,5			
-1823,7	1000	100	47,5	2,58	9,5			

Appendix C.3 (cont'd)

-1824,2	1500	150	47	2,68	9			
-1824,7	900	220	47,3	2,73	9,5	5	0,211	0,299
-1825,2	450	200	49	2,74	9	4,5	0,331	0,361
-1825,7	300	120	50	2,72	8	4,3	0,425	0,401
-1826,2	250	130	50	2,69	8	5	0,400	0,400
-1826,7	300	95	48	2,74	9	4,4	0,415	0,398
-1827,2	2000	300	48	2,7	9	5	0,141	0,250
-1827,7	1000	270	50	2,74	7,5	4	0,250	0,312

APPENDIX D

Appendix D.1.1 Division of Well-01 into two zones.

Depth (m) (BSL)	Sample No.	Porosity data (%)	Cumulative Sum	Grand Sum-Cum. Sum	B	W	R
-1725,75	1	4	4	707,8	0,559	2,377	0,000
-1726,25	2	2,8	6,8	705	3,669	2,356	0,358
-1726,75	3	4	10,8	701	4,016	2,354	0,414
-1727,25	4	4,7	15,5	696,3	3,113	2,360	0,242
-1728,75	5	4,5	20	691,8	2,873	2,362	0,178
-1729,25	6	4,5	24,5	687,3	2,739	2,363	0,137
-1729,75	7	4	28,5	683,3	3,335	2,359	0,293
-1730,25	8	4	32,5	679,3	3,940	2,355	0,402
-1730,75	9	5,4	37,9	673,9	2,732	2,363	0,135
-1731,25	10	4,8	42,7	669,1	2,421	2,365	0,023
-1731,75	11	5,4	48,1	663,7	1,648	2,370	0,000
-1732,25	12	3,5	51,6	660,2	2,587	2,364	0,086
-1732,75	13	2,8	54,4	657,4	4,475	2,351	0,475
-1736,25	14	5	59,4	652,4	3,899	2,355	0,396
-1736,75	15	4,5	63,9	647,9	3,926	2,355	0,400
-1737,25	16	3,8	67,7	644,1	4,733	2,349	0,504
-1737,75	17	5	72,7	639,1	4,215	2,353	0,442
-1738,25	18	3,7	76,4	635,4	5,132	2,346	0,543
-1738,75	19	4,4	80,8	631	5,281	2,345	0,556
-1739,25	20	4,5	85,3	626,5	5,324	2,345	0,560
-1739,75	21	5,2	90,5	621,3	4,638	2,350	0,493
-1740,25	22	7	97,5	614,3	2,534	2,364	0,067
-1743,25	23	7	104,5	607,3	1,107	2,374	0,000
-1743,75	24	6	110,5	601,3	0,569	2,377	0,000
-1744,25	25	3	113,5	598,3	1,265	2,373	0,000
-1744,75	26	2,7	116,2	595,6	2,398	2,365	0,014
-1745,25	27	1,7	117,9	593,9	4,721	2,349	0,502
-1745,75	28	1,5	119,4	592,4	7,966	2,327	0,708
-1746,25	29	2,2	121,6	590,2	10,963	2,307	0,790
-1746,75	30	3,4	125	586,8	12,557	2,296	0,817
-1747,25	31	6,6	131,6	580,2	9,776	2,315	0,763
-1747,75	32	5,5	137,1	574,7	8,643	2,323	0,731
-1748,25	33	4	141,1	570,7	9,329	2,318	0,752
-1748,75	34	4,4	145,5	566,3	9,544	2,317	0,757
-1750,25	35	4,4	149,9	561,9	9,764	2,315	0,763
-1750,75	36	3,4	153,3	558,5	11,234	2,305	0,795
-1751,25	37	2,7	156	555,8	13,750	2,288	0,834
-1751,75	38	2,7	158,7	553,1	16,478	2,270	0,862
-1752,25	39	4,6	163,3	548,5	16,419	2,270	0,862
-1752,75	40	5,5	168,8	543	15,053	2,279	0,849
-1753,25	41	7	175,8	536	11,811	2,301	0,805

Appendix D.1.1

-1753,75	42	4,4	180,2	531,6	12,069	2,300	0,809
-1760,25	43	6	186,2	525,6	10,387	2,311	0,778
-1760,75	44	5,2	191,4	520,4	9,731	2,315	0,762
-1761,25	45	4	195,4	516,4	10,446	2,311	0,779
-1761,75	46	5	200,4	511,4	10,030	2,313	0,769
-1762,25	47	4,3	204,7	507,1	10,411	2,311	0,778
-1762,75	48	4	208,7	503,1	11,149	2,306	0,793
-1763,25	49	3,6	212,3	499,5	12,393	2,297	0,815
-1764,25	50	4,6	216,9	494,9	12,444	2,297	0,815
-1764,75	51	4,3	221,2	490,6	12,868	2,294	0,822
-1765,25	52	4,5	225,7	486,1	13,052	2,293	0,824
-1765,75	53	4,3	230	481,8	13,491	2,290	0,830
-1766,25	54	4,4	234,4	477,4	13,812	2,288	0,834
-1766,75	55	6,6	241	470,8	11,476	2,304	0,799
-1767,25	56	4,4	245,4	466,4	11,787	2,302	0,805
-1767,75	57	5,5	250,9	460,9	10,853	2,308	0,787
-1768,25	58	4,2	255,1	456,7	11,390	2,304	0,798
-1768,75	59	4,8	259,9	451,9	11,259	2,305	0,795
-1769,25	60	5,5	265,4	446,4	10,368	2,311	0,777
-1770,25	61	6,1	271,5	440,3	8,917	2,321	0,740
-1770,75	62	5	276,5	435,3	8,624	2,323	0,731
-1771,25	63	4,1	280,6	431,2	9,221	2,319	0,749
-1771,75	64	3	283,6	428,2	11,012	2,307	0,791
-1772,25	65	3,2	286,8	425	12,722	2,295	0,820
-1772,75	66	3	289,8	422	14,805	2,281	0,846
-1773,25	67	3,4	293,2	418,6	16,506	2,270	0,862
-1774,25	68	2,5	295,7	416,1	19,586	2,249	0,885
-1774,75	69	4	299,7	412,1	20,635	2,242	0,891
-1775,25	70	5	304,7	407,1	20,217	2,245	0,889
-1775,75	71	3	307,7	404,1	22,831	2,227	0,902
-1776,25	72	2,2	309,9	401,9	26,948	2,199	0,918
-1776,75	73	3,5	313,4	398,4	29,077	2,185	0,925
-1777,25	74	4,8	318,2	393,6	28,965	2,185	0,925
-1777,75	75	2,8	321	390,8	32,480	2,162	0,933
-1778,25	76	4,4	325,4	386,4	33,132	2,157	0,935
-1779,25	77	5,5	330,9	380,9	31,745	2,167	0,932
-1779,75	78	4,5	335,4	376,4	32,227	2,163	0,933
-1780,25	79	3	338,4	373,4	35,592	2,141	0,940
-1780,75	80	3	341,4	370,4	39,141	2,117	0,946
-1781,25	81	2,5	343,9	367,9	43,961	2,084	0,953
-1781,75	82	2	345,9	365,9	50,244	2,042	0,959
-1782,25	83	3,5	349,4	362,4	53,325	2,021	0,962
-1782,75	84	2,5	351,9	359,9	59,027	1,982	0,966
-1783,25	85	3,2	355,1	356,7	63,214	1,954	0,969
-1783,75	86	3,4	358,5	353,3	67,043	1,928	0,971
-1784,25	87	2,5	361	350,8	73,558	1,884	0,974
-1784,75	88	4	365	346,8	76,035	1,867	0,975
-1785,25	89	4	369	342,8	78,594	1,850	0,976
-1785,75	90	5	374	337,8	78,264	1,852	0,976
-1786,25	91	4,7	378,7	333,1	78,850	1,848	0,977
-1786,75	92	5,5	384,2	327,6	77,100	1,860	0,976

Appendix D.1.1

-1787,25	93	5,2	389,4	322,4	76,267	1,866	0,976
-1791,25	94	6	395,4	316,4	73,136	1,887	0,974
-1791,75	95	4,5	399,9	311,9	74,397	1,878	0,975
-1792,25	96	5,8	405,7	306,1	71,910	1,895	0,974
-1792,75	97	5,3	411	300,8	70,907	1,902	0,973
-1793,25	98	5,2	416,2	295,6	70,220	1,907	0,973
-1793,75	99	6	422,2	289,6	67,279	1,927	0,971
-1797,75	100	5	427,2	284,6	67,213	1,927	0,971
-1798,25	101	6,5	433,7	278,1	62,965	1,956	0,969
-1798,75	102	5,3	439	272,8	62,107	1,962	0,968
-1799,25	103	7	446	265,8	56,679	1,998	0,965
-1800,25	104	6,5	452,5	259,3	52,745	2,025	0,962
-1800,75	105	7	459,5	252,3	47,693	2,059	0,957
-1801,25	106	5	464,5	247,3	47,684	2,059	0,957
-1801,75	107	4,5	469	242,8	48,955	2,050	0,958
-1802,25	108	3,3	472,3	239,5	53,430	2,020	0,962
-1802,75	109	4,5	476,8	235	54,895	2,010	0,963
-1803,25	110	5	481,8	230	55,056	2,009	0,964
-1803,75	111	4	485,8	226	58,054	1,989	0,966
-1804,25	112	5	490,8	221	58,317	1,987	0,966
-1804,75	113	4	494,8	217	61,558	1,965	0,968
-1805,25	114	2,8	497,6	214,2	68,742	1,917	0,972
-1805,75	115	2,5	500,1	211,7	77,537	1,857	0,976
-1806,25	116	4,2	504,3	207,5	81,033	1,834	0,977
-1806,75	117	3	507,3	204,5	89,153	1,779	0,980
-1807,25	118	3,2	510,5	201,3	97,136	1,725	0,982
-1807,75	119	2,8	513,3	198,5	107,404	1,655	0,985
-1808,25	120	3,5	516,8	195	115,457	1,601	0,986
-1808,75	121	4,2	521	190,8	120,918	1,564	0,987
-1809,25	122	5	526	185,8	123,024	1,550	0,987*
-1809,75	123	6,7	532,7	179,1	117,369	1,588	0,986
-1810,25	124	6,8	539,5	172,3	111,351	1,629	0,985
-1811,25	125	6,8	546,3	165,5	105,431	1,669	0,984
-1811,75	126	7	553,3	158,5	98,722	1,714	0,983
-1812,25	127	6,5	559,8	152	94,321	1,744	0,982
-1812,75	128	7,2	567	144,8	86,952	1,794	0,979
-1813,25	129	6,2	573,2	138,6	83,995	1,814	0,978
-1813,75	130	7,5	580,7	131,1	75,574	1,871	0,975
-1815,25	131	7	587,7	124,1	69,415	1,912	0,972
-1815,75	132	5,2	592,9	118,9	70,781	1,903	0,973
-1816,25	133	4	596,9	114,9	77,730	1,856	0,976
-1816,75	134	5,2	602,1	109,7	79,808	1,842	0,977
-1817,25	135	5,3	607,4	104,4	81,746	1,829	0,978
-1817,75	136	6	613,4	98,4	80,498	1,837	0,977
-1818,25	137	7,5	620,9	90,9	71,864	1,896	0,974
-1818,75	138	7	627,9	83,9	65,818	1,936	0,971
-1819,25	139	7	634,9	76,9	59,858	1,977	0,967
-1819,75	140	7,8	642,7	69,1	50,205	2,042	0,959
-1820,25	141	7,5	650,2	61,6	42,188	2,096	0,950
-1820,75	142	8,3	658,5	53,3	31,061	2,171	0,930
-1821,25	143	8,5	667	44,8	20,104	2,245	0,888

Appendix D.1.1

-1821,75	144	9,5	676,5	35,3	8,094	2,326	0,713
-1822,25	145	8	684,5	27,3	2,642	2,363	0,105
-1822,75	146	6,5	691	20,8	0,850	2,375	0,000
-1823,25	147	6	697	14,8	0,108	2,380	0,000
-1823,75	148	4,8	701,8	10	0,131	2,380	0,000
-1824,25	149	5,5	707,3	4,5	0,061	2,381	0,000
-1824,75	150	4,5	711,8	0			
		711,8 (Grand Sum))					

Appendix D.1.2 Division of Well-01 into three zones

Depth (m) (BSL)	Sample No.	Porosity data (%)	Cumulative Sum	Grand Sum-Cum. Sum	B	W	R
Zone 1							
-1725,75	1	4	4	522	0,098	1,545	0,000
-1726,25	2	2,8	6,8	519,2	1,689	1,531	0,093
-1726,75	3	4	10,8	515,2	1,557	1,533	0,016
-1727,25	4	4,7	15,5	510,5	0,788	1,539	0,000
-1728,75	5	4,5	20	506	0,506	1,541	0,000
-1729,25	6	4,5	24,5	501,5	0,328	1,543	0,000
-1729,75	7	4	28,5	497,5	0,428	1,542	0,000
-1730,25	8	4	32,5	493,5	0,531	1,541	0,000
-1730,75	9	5,4	37,9	488,1	0,098	1,545	0,000
-1731,25	10	4,8	42,7	483,3	0,019	1,545	0,000
-1731,75	11	5,4	48,1	477,9	0,045	1,545	0,000
-1732,25	12	3,5	51,6	474,4	0,002	1,546	0,000
-1732,75	13	2,8	54,4	471,6	0,234	1,544	0,000
-1736,25	14	5	59,4	466,6	0,074	1,545	0,000
-1736,75	15	4,5	63,9	462,1	0,045	1,545	0,000
-1737,25	16	3,8	67,7	458,3	0,119	1,545	0,000
-1737,75	17	5	72,7	453,3	0,024	1,545	0,000
-1738,25	18	3,7	76,4	449,6	0,095	1,545	0,000
-1738,75	19	4,4	80,8	445,2	0,078	1,545	0,000
-1739,25	20	4,5	85,3	440,7	0,052	1,545	0,000
-1739,75	21	5,2	90,5	435,5	0,000	1,546	0,000
-1740,25	22	7	97,5	428,5	0,389	1,542	0,000
-1743,25	23	7	104,5	421,5	1,526	1,533	0,000
-1743,75	24	6	110,5	415,5	2,560	1,524	0,405
-1744,25	25	3	113,5	412,5	1,642	1,532	0,067
-1744,75	26	2,7	116,2	409,8	0,822	1,539	0,000
-1745,25	27	1,7	117,9	408,1	0,106	1,545	0,000
-1745,75	28	1,5	119,4	406,6	0,081	1,545	0,000
-1746,25	29	2,2	121,6	404,4	0,533	1,541	0,000
-1746,75	30	3,4	125	401	0,834	1,539	0,000

Appendix D.1.2 (cont'd)

-1747,25	31	6,6	131,6	394,4	0,183	1,544	0,000
-1747,75	32	5,5	137,1	388,9	0,032	1,545	0,000
-1748,25	33	4	141,1	384,9	0,058	1,545	0,000
-1748,75	34	4,4	145,5	380,5	0,048	1,545	0,000
-1750,25	35	4,4	149,9	376,1	0,040	1,545	0,000
-1750,75	36	3,4	153,3	372,7	0,144	1,544	0,000
-1751,25	37	2,7	156	370	0,482	1,542	0,000
-1751,75	38	2,7	158,7	367,3	1,008	1,537	0,000
-1752,25	39	4,6	163,3	362,7	0,886	1,538	0,000
-1752,75	40	5,5	168,8	357,2	0,498	1,541	0,000
-1753,25	41	7	175,8	350,2	0,035	1,545	0,000
-1753,75	42	4,4	180,2	345,8	0,028	1,545	0,000
-1760,25	43	6	186,2	339,8	0,023	1,545	0,000
-1760,75	44	5,2	191,4	334,6	0,102	1,545	0,000
-1761,25	45	4	195,4	330,6	0,067	1,545	0,000
-1761,75	46	5	200,4	325,6	0,150	1,544	0,000
-1762,25	47	4,3	204,7	321,3	0,147	1,544	0,000
-1762,75	48	4	208,7	317,3	0,105	1,545	0,000
-1763,25	49	3,6	212,3	313,7	0,037	1,545	0,000
-1764,25	50	4,6	216,9	309,1	0,060	1,545	0,000
-1764,75	51	4,3	221,2	304,8	0,058	1,545	0,000
-1765,25	52	4,5	225,7	300,3	0,076	1,545	0,000
-1765,75	53	4,3	230	296	0,074	1,545	0,000
-1766,25	54	4,4	234,4	291,6	0,083	1,545	0,000
-1766,75	55	6,6	241	285	0,496	1,541	0,000
-1767,25	56	4,4	245,4	280,6	0,517	1,541	0,000
-1767,75	57	5,5	250,9	275,1	0,872	1,538	0,000
-1768,25	58	4,2	255,1	270,9	0,833	1,539	0,000
-1768,75	59	4,8	259,9	266,1	1,001	1,537	0,000
-1769,25	60	5,5	265,4	260,6	1,477	1,533	0,000
-1770,25	61	6,1	271,5	254,5	2,369	1,526	0,356
-1770,75	62	5	276,5	249,5	2,769	1,522	0,450
-1771,25	63	4,1	280,6	245,4	2,645	1,523	0,424
-1771,75	64	3	283,6	242,4	1,931	1,529	0,208
-1772,25	65	3,2	286,8	239,2	1,414	1,534	0,000
-1772,75	66	3	289,8	236,2	0,907	1,538	0,000
-1773,25	67	3,4	293,2	232,8	0,621	1,540	0,000
-1774,25	68	2,5	295,7	230,3	0,211	1,544	0,000
-1774,75	69	4	299,7	226,3	0,163	1,544	0,000
-1775,25	70	5	304,7	221,3	0,281	1,543	0,000
-1775,75	71	3	307,7	218,3	0,085	1,545	0,000
-1776,25	72	2,2	309,9	216,1	0,009	1,545	0,000
-1776,75	73	3,5	313,4	212,6	0,061	1,545	0,000
-1777,25	74	4,8	318,2	207,8	0,025	1,545	0,000
-1777,75	75	2,8	321	205	0,193	1,544	0,000
-1778,25	76	4,4	325,4	200,6	0,180	1,544	0,000
-1779,25	77	5,5	330,9	195,1	0,041	1,545	0,000
-1779,75	78	4,5	335,4	190,6	0,028	1,545	0,000
-1780,25	79	3	338,4	187,6	0,175	1,544	0,000
-1780,75	80	3	341,4	184,6	0,449	1,542	0,000
-1781,25	81	2,5	343,9	182,1	1,043	1,537	0,000

Appendix D.1.2 (cont'd)

-1781,75	82	2	345,9	180,1	2,172	1,527	0,297
-1782,25	83	3,5	349,4	176,6	2,693	1,523	0,434
-1782,75	84	2,5	351,9	174,1	4,026	1,512	0,624
-1783,25	85	3,2	355,1	170,9	5,020	1,504	0,700
-1783,75	86	3,4	358,5	167,5	5,949	1,496	0,749
-1784,25	87	2,5	361	165	7,964	1,479	0,814
-1784,75	88	4	365	161	8,467	1,475	0,826
-1785,25	89	4	369	157	9,002	1,471	0,837
-1785,75	90	5	374	152	8,342	1,476	0,823
-1786,25	91	4,7	378,7	147,3	8,051	1,478	0,816
-1786,75	92	5,5	384,2	141,8	6,858	1,488	0,783
-1787,25	93	5,2	389,4	136,6	6,053	1,495	0,753
-1791,25	94	6	395,4	130,6	4,523	1,508	0,667
-1791,75	95	4,5	399,9	126,1	4,466	1,508	0,662
-1792,25	96	5,8	405,7	120,3	3,288	1,518	0,538
-1792,75	97	5,3	411	115	2,618	1,524	0,418
-1793,25	98	5,2	416,2	109,8	2,075	1,528	0,263
-1793,75	99	6	422,2	103,8	1,152	1,536	0,000
-1797,75	100	5	427,2	98,8	0,864	1,538	0,000
-1798,25	101	6,5	433,7	92,3	0,178	1,544	0,000
-1798,75	102	5,3	439	87	0,036	1,545	0,000
-1799,25	103	7	446	80	0,229	1,544	0,000
-1800,25	104	6,5	452,5	73,5	1,099	1,536	0,000
-1800,75	105	7	459,5	66,5	3,156	1,519	0,519
-1801,25	106	5	464,5	61,5	4,029	1,512	0,625
-1801,75	107	4,5	469	57	4,474	1,508	0,663
-1802,25	108	3,3	472,3	53,7	3,580	1,516	0,577
-1802,75	109	4,5	476,8	49,2	4,039	1,512	0,626
-1803,25	110	5	481,8	44,2	5,251	1,502	0,714
-1803,75	111	4	485,8	40,2	5,218	1,502	0,712
-1804,25	112	5	490,8	35,2	6,824	1,489	0,782
-1804,75	113	4	494,8	31,2	6,935	1,488	0,785
-1805,25	114	2,8	497,6	28,4	4,964	1,504	0,697
-1805,75	115	2,5	500,1	25,9	2,777	1,522	0,452
-1806,25	116	4,2	504,3	21,7	3,046	1,520	0,501
-1806,75	117	3	507,3	18,7	1,703	1,531	0,101
-1807,25	118	3,2	510,5	15,5	0,788	1,539	0,000
-1807,75	119	2,8	513,3	12,7	0,019	1,545	0,000
-1808,25	120	3,5	516,8	9,2	0,169	1,544	0,000
-1808,75	121	4,2	521	5	0,478	1,542	0,000
-1809,25	122	5	526	0			
		526 (Grand Sum)					
Zone 2							
-1809,75	1	6,7	6,7	179,1	0,004	1,689	0,000
-1810,25	2	6,8	13,5	172,3	0,028	1,688	0,000
-1811,25	3	6,8	20,3	165,5	0,058	1,687	0,000
-1811,75	4	7	27,3	158,5	0,167	1,683	0,000

Appendix D.1.2 (cont'd)

-1812,25	5	6,5	33,8	152	0,094	1,686	0,000
-1812,75	6	7,2	41	144,8	0,298	1,678	0,000
-1813,25	7	6,2	47,2	138,6	0,107	1,685	0,000
-1813,75	8	7,5	54,7	131,1	0,456	1,672	0,000
-1815,25	9	7	61,7	124,1	0,641	1,665	0,000
-1815,75	10	5,2	66,9	118,9	0,046	1,688	0,000
-1816,25	11	4	70,9	114,9	0,656	1,664	0,000
-1816,75	12	5,2	76,1	109,7	1,816	1,620	0,108
-1817,25	13	5,3	81,4	104,4	3,398	1,559	0,541
-1817,75	14	6	87,4	98,4	4,321	1,523	0,648
-1818,25	15	7,5	94,9	90,9	3,086	1,571	0,491
-1818,75	16	7	101,9	83,9	2,661	1,587	0,404
-1819,25	17	7	108,9	76,9	2,286	1,601	0,299
-1819,75	18	7,8	116,7	69,1	1,170	1,644	0,000
-1820,25	19	7,5	124,2	61,6	0,578	1,667	0,000
-1820,75	20	8,3	132,5	53,3	0,008	1,689	0,000
-1821,25	21	8,5	141	44,8	0,519	1,669	0,000
-1821,75	22	9,5	150,5	35,3	4,323	1,523	0,648
-1822,25	23	8	158,5	27,3	8,414	1,366	0,838
-1822,75	24	6,5	165	20,8	9,619	1,319	0,863
-1823,25	25	6	171	14,8	9,738	1,315	0,865
-1823,75	26	4,8	175,8	10	5,763	1,468	0,745
-1824,25	27	5,5	181,3	4,5	4,730	1,507	0,681
-1824,75	28	4,5	185,8	0			
		185,8 (Grand Sum)					

Appendix D.2.1 Division of Well-02 into two zones.

Depth (m) (BSL)	Sample No.	Porosity data (%)	Cumulative Sum	Grand Sum-Cum. Sum	B	W	R
-1714,7	1	2	2	517,1	1,155	2,634	0,000
-1715,2	2	2	4	515,1	2,324	2,627	0,000
-1715,7	3	3	7	512,1	1,665	2,631	0,000
-1716,2	4	4	11	508,1	0,424	2,638	0,000
-1716,7	5	4	15	504,1	0,026	2,640	0,000
-1720,2	6	3,6	18,6	500,5	0,005	2,640	0,000
-1720,7	7	3,5	22,1	497	0,053	2,640	0,000
-1721,2	8	2,4	24,5	494,6	0,001	2,640	0,000
-1721,7	9	2	26,5	492,6	0,154	2,640	0,000
-1722,2	10	3,2	29,7	489,4	0,110	2,640	0,000
-1722,7	11	3	32,7	486,4	0,115	2,640	0,000
-1723,2	12	3	35,7	483,4	0,121	2,640	0,000
-1723,7	13	2	37,7	481,4	0,415	2,638	0,000
-1724,2	14	2,5	40,2	478,9	0,612	2,637	0,000
-1724,7	15	2,7	42,9	476,2	0,737	2,636	0,000
-1725,2	16	2,7	45,6	473,5	0,868	2,635	0,000
-1725,7	17	2,7	48,3	470,8	1,004	2,634	0,000
-1726,2	18	3,5	51,8	467,3	0,757	2,636	0,000
-1726,7	19	5	56,8	462,3	0,144	2,640	0,000
-1728,2	20	3,6	60,4	458,7	0,060	2,640	0,000
-1728,7	21	3	63,4	455,7	0,066	2,640	0,000
-1729,2	22	2,5	65,9	453,2	0,147	2,640	0,000
-1729,7	23	2	67,9	451,2	0,380	2,638	0,000
-1730,2	24	2	69,9	449,2	0,708	2,636	0,000
-1731,2	25	3,3	73,2	445,9	0,605	2,637	0,000
-1731,7	26	2	75,2	443,9	0,988	2,635	0,000
-1732,2	27	3,5	78,7	440,4	0,790	2,636	0,000
-1732,7	28	4	82,7	436,4	0,468	2,638	0,000
-1733,2	29	2	84,7	434,4	0,797	2,636	0,000
-1733,7	30	3,5	88,2	430,9	0,632	2,637	0,000
-1734,2	31	3,2	91,4	427,7	0,576	2,637	0,000
-1734,7	32	4	95,4	423,7	0,322	2,639	0,000
-1735,7	33	5	100,4	418,7	0,035	2,640	0,000
-1736,2	34	5	105,4	413,7	0,034	2,640	0,000
-1736,7	35	3	108,4	410,7	0,029	2,640	0,000
-1737,2	36	3	111,4	407,7	0,024	2,640	0,000
-1737,7	37	4,4	115,8	403,3	0,160	2,640	0,000
-1738,2	38	5,7	121,5	397,6	0,775	2,636	0,000
-1738,7	39	6,3	127,8	391,3	2,137	2,628	0,000
-1739,2	40	4,2	132	387,1	2,734	2,624	0,040
-1739,7	41	4,3	136,3	382,8	3,459	2,620	0,243
-1742,7	42	3	139,3	379,8	3,357	2,620	0,219
-1743,2	43	3,2	142,5	376,6	3,388	2,620	0,227
-1743,7	44	3,7	146,2	372,9	3,752	2,618	0,302

Appendix D.2.1 (cont'd)

-1744,2	45	4,7	150,9	368,2	4,868	2,611	0,464
-1745,2	46	6,1	157	362,1	7,369	2,596	0,648
-1745,7	47	5,5	162,5	356,6	9,693	2,582	0,734
-1746,2	48	5	167,5	351,6	11,713	2,570	0,781
-1746,7	49	3,5	171	348,1	12,069	2,568	0,787
-1747,2	50	3,7	174,7	344,4	12,670	2,565	0,798
-1747,7	51	4,4	179,1	340	14,152	2,556	0,819
-1748,2	52	5	184,1	335	16,507	2,542	0,846
-1748,7	53	5,5	189,6	329,5	19,751	2,522	0,872
-1749,2	54	6,3	195,9	323,2	24,548	2,494	0,898
-1749,7	55	4,3	200,2	318,9	26,342	2,483	0,906
-1750,2	56	4,5	204,7	314,4	28,541	2,470	0,913
-1750,7	57	3,5	208,2	310,9	29,037	2,467	0,915
-1752,2	58	5	213,2	305,9	32,244	2,447	0,924
-1752,7	59	2	215,2	303,9	30,059	2,461	0,918
-1753,2	60	4,1	219,3	299,8	31,663	2,451	0,923
-1753,7	61	4,7	224	295,1	34,424	2,434	0,929
-1754,2	62	4,4	228,4	290,7	36,710	2,421	0,934
-1754,7	63	5	233,4	285,7	40,267	2,399	0,940
-1755,2	64	6,5	239,9	279,2	47,190	2,358	0,950
-1755,7	65	6,1	246	273,1	53,699	2,319	0,957
-1756,2	66	6	252	267,1	60,360	2,279	0,962
-1756,7	67	4,2	256,2	262,9	62,824	2,264	0,964
-1757,2	68	3,4	259,6	259,5	63,330	2,261	0,964
-1757,7	69	3,8	263,4	255,7	64,859	2,252	0,965
-1758,2	70	3,8	267,2	251,9	66,420	2,243	0,966
-1758,7	71	4,6	271,8	247,3	70,084	2,221	0,968
-1759,2	72	5,5	277,3	241,8	76,279	2,184	0,971
-1759,7	73	5,5	282,8	236,3	82,736	2,145	0,974
-1760,2	74	4	286,8	232,3	85,112	2,131	0,975
-1760,7	75	6	292,8	226,3	93,430	2,081	0,978
-1761,2	76	7,3	300,1	219	106,243	2,004	0,981
-1761,7	77	7	307,1	212	118,866	1,929	0,984
-1762,2	78	6	313,1	206	128,679	1,870	0,985
-1762,7	79	6,2	319,3	199,8	139,628	1,804	0,987
-1763,2	80	4,7	324	195,1	145,419	1,770	0,988
-1763,7	81	3,5	327,5	191,6	146,850	1,761	0,988
-1764,2	82	2,5	330	189,1	144,603	1,775	0,988
-1764,7	83	3	333	186,1	144,257	1,777	0,988*
-1765,2	84	2	335	184,1	140,285	1,800	0,987
-1765,7	85	2	337	182,1	136,406	1,824	0,987
-1766,2	86	1,7	338,7	180,4	131,559	1,853	0,986
-1766,7	87	2	340,7	178,4	127,875	1,875	0,985
-1767,2	88	1,2	341,9	177,2	121,545	1,913	0,984
-1768,7	89	1,6	343,5	175,6	116,731	1,942	0,983
-1769,2	90	1,4	344,9	174,2	111,389	1,974	0,982
-1769,7	91	1,5	346,4	172,7	106,513	2,003	0,981
-1770,2	92	0,8	347,2	171,9	99,597	2,044	0,979
-1770,7	93	1,3	348,5	170,6	94,424	2,075	0,978
-1771,2	94	1,5	350	169,1	89,989	2,102	0,977
-1771,7	95	1,8	351,8	167,3	86,538	2,122	0,975

Appendix D.2.1 (cont'd)

-1772,2	96	2,7	354,5	164,6	85,738	2,127	0,975
-1772,7	97	1,5	356	163,1	81,557	2,152	0,974
-1773,2	98	1,5	357,5	161,6	77,490	2,176	0,972
-1773,7	99	1,5	359	160,1	73,534	2,200	0,970
-1774,2	100	2	361	158,1	70,999	2,215	0,969
-1774,7	101	1,3	362,3	156,8	66,713	2,241	0,966
-1775,2	102	0,7	363	156,1	61,076	2,275	0,963
-1775,7	103	0,6	363,6	155,5	55,444	2,308	0,958
-1776,2	104	0,5	364,1	155	49,849	2,342	0,953
-1776,7	105	0,2	364,3	154,8	43,904	2,378	0,946
-1777,2	106	0,3	364,6	154,5	38,513	2,410	0,937
-1777,7	107	0,6	365,2	153,9	34,012	2,437	0,928
-1778,2	108	0,8	366	153,1	30,123	2,460	0,918
-1778,7	109	0,8	366,8	152,3	26,454	2,482	0,906
-1779,2	110	0,7	367,5	151,6	22,853	2,504	0,890
-1779,7	111	1	368,5	150,6	19,928	2,521	0,873
-1780,2	112	1	369,5	149,6	17,188	2,538	0,852
-1780,7	113	1,6	371,1	148	15,395	2,548	0,834
-1781,2	114	2	373,1	146	14,182	2,556	0,820
-1781,7	115	2,7	375,8	143,3	13,858	2,558	0,815
-1782,2	116	4,3	380,1	139	15,564	2,547	0,836
-1782,7	117	2,2	382,3	136,8	14,596	2,553	0,825
-1783,2	118	2,2	384,5	134,6	13,656	2,559	0,813
-1783,7	119	1,2	385,7	133,4	11,567	2,571	0,778
-1784,2	120	0,8	386,5	132,6	9,218	2,585	0,720
-1784,7	121	0,9	387,4	131,7	7,206	2,597	0,640
-1785,2	122	1,5	388,9	130,2	5,914	2,605	0,559
-1785,7	123	1,8	390,7	128,4	4,966	2,611	0,474
-1786,2	124	1,8	392,5	126,6	4,091	2,616	0,361
-1786,7	125	2,2	394,7	124,4	3,551	2,619	0,262
-1787,2	126	2,5	397,2	121,9	3,232	2,621	0,189
-1787,7	127	1,5	398,7	120,4	2,347	2,626	0,000
-1788,2	128	2,4	401,1	118	2,028	2,628	0,000
-1788,7	129	2,5	403,6	115,5	1,776	2,630	0,000
-1789,2	130	1,8	405,4	113,7	1,237	2,633	0,000
-1789,7	131	2	407,4	111,7	0,856	2,635	0,000
-1790,2	132	2,5	409,9	109,2	0,685	2,636	0,000
-1790,7	133	3,5	413,4	105,7	0,840	2,635	0,000
-1791,2	134	3,8	417,2	101,9	1,132	2,634	0,000
-1791,7	135	4,2	421,4	97,7	1,670	2,631	0,000
-1792,2	136	4,7	426,1	93	2,633	2,625	0,003
-1792,7	137	4,5	430,6	88,5	3,696	2,618	0,291
-1793,2	138	6,3	436,9	82,2	6,696	2,600	0,612
-1794,7	139	6,5	443,4	75,7	10,964	2,575	0,765
-1795,2	140	5,5	448,9	70,2	14,832	2,552	0,828
-1795,7	141	1,8	450,7	68,4	13,267	2,561	0,807
-1796,2	142	1,3	452	67,1	11,050	2,574	0,767
-1796,7	143	1,5	453,5	65,6	9,245	2,585	0,720
-1797,2	144	1,5	455	64,1	7,560	2,595	0,657
-1797,7	145	1,5	456,5	62,6	6,003	2,605	0,566
-1798,2	146	2	458,5	60,6	5,080	2,610	0,486

Appendix D.2.1 (cont'd)

-1798,7	147	1,5	460	59,1	3,754	2,618	0,303
-1799,2	148	1,2	461,2	57,9	2,371	2,626	0,000
-1799,7	149	1,5	462,7	56,4	1,436	2,632	0,000
-1800,2	150	1,3	464	55,1	0,630	2,637	0,000
-1800,7	151	2	466	53,1	0,298	2,639	0,000
-1801,2	152	1,8	467,8	51,3	0,055	2,640	0,000
-1801,7	153	2,3	470,1	49	0,001	2,640	0,000
-1802,2	154	2	472,1	47	0,063	2,640	0,000
-1802,7	155	1,5	473,6	45,5	0,486	2,638	0,000
-1803,2	156	2	475,6	43,5	1,062	2,634	0,000
-1803,7	157	3	478,6	40,5	1,189	2,633	0,000
-1804,2	158	3,6	482,2	36,9	0,942	2,635	0,000
-1804,7	159	2	484,2	34,9	1,861	2,629	0,000
-1805,2	160	2	486,2	32,9	3,242	2,621	0,191
-1805,7	161	1,8	488	31,1	5,590	2,607	0,534
-1806,2	162	3	491	28,1	6,489	2,602	0,599
-1806,7	163	3	494	25,1	7,689	2,594	0,663
-1807,2	164	3,5	497,5	21,6	8,030	2,592	0,677
-1807,7	165	4,6	502,1	17	5,689	2,606	0,542
-1808,7	167	4,6	509,9	9,2	4,728	2,612	0,448
-1809,2	168	4,8	514,7	4,4	1,775	2,630	0,000
-1809,7	169	4,4	519,1	0			
		519,1 (Grand Sum)					

Appendix D.2.2 Division of Well-02 into three zones.

Depth (m)	Sample No.	Porosity data (%)	Cumulative Sum	Grand Sum-Cum. Sum	B	W	R
Zone 1							
-1714,7	1	2	2	331	4,098	1,771	0,568
-1715,2	2	2	4	329	8,297	1,719	0,793
-1715,7	3	3	7	326	8,771	1,714	0,805
-1716,2	4	4	11	322	6,694	1,739	0,740
-1716,7	5	4	15	318	5,449	1,755	0,678
-1720,2	6	3,6	18,6	314,4	5,380	1,755	0,674
-1720,7	7	3,5	22,1	310,9	5,587	1,753	0,686
-1721,2	8	2,4	24,5	308,5	7,983	1,723	0,784
-1721,7	9	2	26,5	306,5	11,506	1,680	0,854
-1722,2	10	3,2	29,7	303,3	12,346	1,669	0,865
-1722,7	11	3	32,7	300,3	13,697	1,653	0,879
-1723,2	12	3	35,7	297,3	15,087	1,636	0,892
-1723,7	13	2	37,7	295,3	19,062	1,586	0,917
-1724,2	14	2,5	40,2	292,8	21,910	1,551	0,929
-1724,7	15	2,7	42,9	290,1	24,300	1,522	0,937
-1725,2	16	2,7	45,6	287,4	26,765	1,491	0,944
-1725,7	17	2,7	48,3	284,7	29,309	1,460	0,950
-1726,2	18	3,5	51,8	281,2	29,571	1,457	0,951
-1726,7	19	5	56,8	276,2	25,766	1,504	0,942
-1728,2	20	3,6	60,4	272,6	25,932	1,502	0,942
-1728,7	21	3	63,4	269,6	27,721	1,480	0,947
-1729,2	22	2,5	65,9	267,1	30,936	1,440	0,953
-1729,7	23	2	67,9	265,1	35,741	1,381	0,961
-1730,2	24	2	69,9	263,1	40,819	1,318	0,968
-1731,2	25	3,3	73,2	259,8	42,042	1,303	0,969
-1731,7	26	2	75,2	257,8	47,469	1,236	0,974
-1732,2	27	3,5	78,7	254,3	48,178	1,227	0,975
-1732,7	28	4	82,7	250,3	47,341	1,237	0,974
-1733,2	29	2	84,7	248,3	53,091	1,166	0,978
-1733,7	30	3,5	88,2	244,8	53,995	1,155	0,979
-1734,2	31	3,2	91,4	241,6	55,981	1,131	0,980
-1734,7	32	4	95,4	237,6	55,336	1,139	0,979
-1735,7	33	5	100,4	232,6	51,503	1,186	0,977
-1736,2	34	5	105,4	227,6	47,907	1,230	0,974
-1736,7	35	3	108,4	224,6	50,659	1,196	0,976
-1737,2	36	3	111,4	221,6	53,529	1,161	0,978
-1737,7	37	4,4	115,8	217,2	51,972	1,180	0,977
-1738,2	38	5,7	121,5	211,5	46,518	1,248	0,973
-1738,7	39	6,3	127,8	205,2	39,757	1,331	0,967
-1739,2	40	4,2	132	201	39,146	1,339	0,966
-1739,7	41	4,3	136,3	196,7	38,314	1,349	0,965
-1742,7	42	3	139,3	193,7	41,114	1,314	0,968
-1743,2	43	3,2	142,5	190,5	43,483	1,285	0,970

Appendix D.2.2 (cont'd)

-1743,7	44	3,7	146,2	186,8	44,495	1,273	0,971
-1744,2	45	4,7	150,9	182,1	42,648	1,295	0,970
-1745,2	46	6,1	157	176	37,025	1,365	0,963
-1745,7	47	5,5	162,5	170,5	33,330	1,410	0,958
-1746,2	48	5	167,5	165,5	31,072	1,438	0,954
-1746,7	49	3,5	171	162	32,625	1,419	0,957
-1747,2	50	3,7	174,7	158,3	33,750	1,405	0,958
-1747,7	51	4,4	179,1	153,9	33,108	1,413	0,957
-1748,2	52	5	184,1	148,9	30,973	1,439	0,954
-1748,7	53	5,5	189,6	143,4	27,707	1,480	0,947
-1749,2	54	6,3	195,9	137,1	22,822	1,540	0,933
-1749,7	55	4,3	200,2	132,8	22,567	1,543	0,932
-1750,2	56	4,5	204,7	128,3	21,902	1,551	0,929
-1750,7	57	3,5	208,2	124,8	23,506	1,532	0,935
-1752,2	58	5	213,2	119,8	21,763	1,553	0,929
-1752,7	59	2	215,2	117,8	27,122	1,487	0,945
-1753,2	60	4,1	219,3	113,7	27,603	1,481	0,946
-1753,7	61	4,7	224	109	26,591	1,494	0,944
-1754,2	62	4,4	228,4	104,6	26,392	1,496	0,943
-1754,7	63	5	233,4	99,6	24,687	1,517	0,939
-1755,2	64	6,5	239,9	93,1	19,428	1,582	0,919
-1755,7	65	6,1	246	87	15,503	1,630	0,895
-1756,2	66	6	252	81	12,111	1,672	0,862
-1756,7	67	4,2	256,2	76,8	12,306	1,670	0,864
-1757,2	68	3,4	259,6	73,4	14,220	1,646	0,884
-1757,7	69	3,8	263,4	69,6	15,500	1,630	0,895
-1758,2	70	3,8	267,2	65,8	16,978	1,612	0,905
-1758,7	71	4,6	271,8	61,2	16,604	1,617	0,903
-1759,2	72	5,5	277,3	55,7	14,023	1,649	0,882
-1759,7	73	5,5	282,8	50,2	11,551	1,679	0,855
-1760,2	74	4	286,8	46,2	12,692	1,665	0,869
-1760,7	75	6	292,8	40,2	9,084	1,710	0,812
-1761,2	76	7,3	300,1	32,9	3,618	1,777	0,509
-1761,7	77	7	307,1	25,9	0,600	1,814	0,000
-1762,2	78	6	313,1	19,9	0,005	1,822	0,000
-1762,7	79	6,2	319,3	13,7	1,448	1,804	0,000
-1763,2	80	4,7	324	9	3,188	1,782	0,441
-1763,7	81	3,5	327,5	5,5	3,264	1,782	0,454
-1764,2	82	2,5	330	3	1,037	1,809	0,000
-1764,7	83	3	333	0			
		333 (Grand Sum)					
Zone 2							
-1765,2	1	2	2	184,1	0,027	1,775	0,000
-1765,7	2	2	4	182,1	0,055	1,775	0,000
-1766,2	3	1,7	5,7	180,4	0,217	1,773	0,000
-1766,7	4	2	7,7	178,4	0,240	1,773	0,000
-1767,2	5	1,2	8,9	177,2	0,783	1,766	0,000
-1768,7	6	1,6	10,5	175,6	1,105	1,762	0,000

Appendix D.2.2 (cont'd)

-1769,2	7	1,4	11,9	174,2	1,640	1,756	0,000
-1769,7	8	1,5	13,4	172,7	2,109	1,750	0,170
-1770,2	9	0,8	14,2	171,9	3,454	1,734	0,498
-1770,7	10	1,3	15,5	170,6	4,265	1,725	0,596
-1771,2	11	1,5	17	169,1	4,825	1,718	0,644
-1771,7	12	1,8	18,8	167,3	4,975	1,716	0,655
-1772,2	13	2,7	21,5	164,6	3,985	1,728	0,566
-1772,7	14	1,5	23	163,1	4,541	1,721	0,621
-1773,2	15	1,5	24,5	161,6	5,116	1,715	0,665
-1773,7	16	1,5	26	160,1	5,710	1,707	0,701
-1774,2	17	2	28	158,1	5,661	1,708	0,698
-1774,7	18	1,3	29,3	156,8	6,544	1,698	0,741
-1775,2	19	0,7	30	156,1	8,346	1,676	0,799
-1775,7	20	0,6	30,6	155,5	10,474	1,651	0,842
-1776,2	21	0,5	31,1	155	12,961	1,621	0,875
-1776,7	22	0,2	31,3	154,8	16,242	1,582	0,903
-1777,2	23	0,3	31,6	154,5	19,597	1,542	0,921
-1777,7	24	0,6	32,2	153,9	22,509	1,507	0,933
-1778,2	25	0,8	33	153,1	25,104	1,477	0,941
-1778,7	26	0,8	33,8	152,3	27,816	1,444	0,948
-1779,2	27	0,7	34,5	151,6	30,907	1,408	0,954
-1779,7	28	1	35,5	150,6	33,338	1,379	0,959
-1780,2	29	1	36,5	149,6	35,862	1,349	0,962
-1780,7	30	1,6	38,1	148	36,818	1,337	0,964
-1781,2	31	2	40,1	146	36,723	1,338	0,964
-1781,7	32	2,7	42,8	143,3	34,809	1,361	0,961
-1782,2	33	4,3	47,1	139	29,060	1,430	0,951
-1782,7	34	2,2	49,3	136,8	28,662	1,434	0,950
-1783,2	35	2,2	51,5	134,6	28,305	1,438	0,949
-1783,7	36	1,2	52,7	133,4	30,346	1,414	0,953
-1784,2	37	0,8	53,5	132,6	33,478	1,377	0,959
-1784,7	38	0,9	54,4	131,7	36,518	1,341	0,963
-1785,2	39	1,5	55,9	130,2	38,093	1,322	0,965
-1785,7	40	1,8	57,7	128,4	38,924	1,312	0,966
-1786,2	41	1,8	59,5	126,6	39,804	1,302	0,967
-1786,7	42	2,2	61,7	124,4	39,641	1,304	0,967
-1787,2	43	2,5	64,2	121,9	38,713	1,315	0,966
-1787,7	44	1,5	65,7	120,4	40,537	1,293	0,968
-1788,2	45	2,4	68,1	118	39,956	1,300	0,967
-1788,7	46	2,5	70,6	115,5	39,150	1,309	0,967
-1789,2	47	1,8	72,4	113,7	40,294	1,296	0,968
-1789,7	48	2	74,4	111,7	40,947	1,288	0,969
-1790,2	49	2,5	76,9	109,2	40,262	1,296	0,968
-1790,7	50	3,5	80,4	105,7	36,918	1,336	0,964
-1791,2	51	3,8	84,2	101,9	32,975	1,383	0,958
-1791,7	52	4,2	88,4	97,7	28,312	1,438	0,949
-1792,2	53	4,7	93,1	93	22,919	1,503	0,934
-1792,7	54	4,5	97,6	88,5	18,449	1,556	0,916
-1793,2	55	6,3	103,9	82,2	11,527	1,638	0,858
-1794,7	56	6,5	110,4	75,7	5,950	1,705	0,714

Appendix D.2.2 (cont'd)

-1795,2	57	5,5	115,9	70,2	2,884	1,741	0,396
-1795,7	58	1,8	117,7	68,4	3,230	1,737	0,462
-1796,2	59	1,3	119	67,1	4,061	1,727	0,575
-1796,7	60	1,5	120,5	65,6	4,806	1,718	0,643
-1797,2	61	1,5	122	64,1	5,641	1,708	0,697
-1797,7	62	1,5	123,5	62,6	6,574	1,697	0,742
-1798,2	63	2	125,5	60,6	6,960	1,693	0,757
-1798,7	64	1,5	127	59,1	8,068	1,679	0,792
-1799,2	65	1,2	128,2	57,9	9,777	1,659	0,830
-1799,7	66	1,5	129,7	56,4	11,216	1,642	0,854
-1800,2	67	1,3	131	55,1	13,213	1,618	0,878
-1800,7	68	2	133	53,1	14,066	1,608	0,886
-1801,2	69	1,8	134,8	51,3	15,442	1,592	0,897
-1801,7	70	2,3	137,1	49	15,871	1,587	0,900
-1802,2	71	2	139,1	47	17,073	1,572	0,908
-1802,7	72	1,5	140,6	45,5	19,724	1,541	0,922
-1803,2	73	2	142,6	43,5	21,404	1,521	0,929
-1803,7	74	3	145,6	40,5	20,454	1,532	0,925
-1804,2	75	3,6	149,2	36,9	17,880	1,563	0,913
-1804,7	76	2	151,2	34,9	19,898	1,539	0,923
-1805,2	77	2	153,2	32,9	22,364	1,509	0,933
-1805,7	78	1,8	155	31,1	26,202	1,464	0,944
-1806,2	79	3	158	28,1	26,090	1,465	0,944
-1806,7	80	3	161	25,1	26,302	1,462	0,944
-1807,2	81	3,5	164,5	21,6	24,677	1,482	0,940
-1807,7	82	4,6	169,1	17	18,255	1,558	0,915
-1808,2	83	3,2	172,3	13,8	18,446	1,556	0,916
-1808,7	84	4,6	176,9	9,2	12,151	1,631	0,866
-1809,2	85	4,8	181,7	4,4	5,059	1,715	0,661
-1809,7	86	4,4	186,1	0			
		186,1 (Grand Sum)					

Appendix D.3.1 Division of Well-03 into two zones.

Depth (m) (BSL)	Sample No.	Porosity data (%)	Cumulative Sum	Grand Sum-Cum. Sum	B	W	R
-1804,7	1	5,8	5,8	155,7	1,447	0,540	0,627
-1805,2	2	5,5	11,3	150,2	2,275	0,515	0,774
-1805,7	3	5	16,3	145,2	2,201	0,518	0,765
-1806,2	4	4,7	21	140,5	1,825	0,529	0,710
-1806,7	5	4	25	136,5	0,868	0,558	0,357
-1807,2	6	5,2	30,2	131,3	1,272	0,546	0,571
-1808,2	7	6	36,2	125,3	2,716	0,502	0,815
-1808,7	8	5	41,2	120,3	2,976	0,494	0,834*
-1809,2	9	3,3	44,5	117	1,321	0,544	0,588
-1809,7	10	4	48,5	113	0,778	0,561	0,279
-1810,2	11	4,7	53,2	108,3	0,791	0,560	0,292
-1810,7	12	4,2	57,4	104,1	0,522	0,569	0,000
-1811,2	13	3,3	60,7	100,8	0,062	0,582	0,000
-1811,7	14	4,1	64,8	96,7	0,005	0,584	0,000
-1812,2	15	3,8	68,6	92,9	0,044	0,583	0,000
-1812,7	16	5,1	73,7	87,8	0,002	0,584	0,000
-1813,2	17	5,3	79	82,5	0,036	0,583	0,000
-1813,7	18	5,5	84,5	77	0,238	0,577	0,000
-1814,2	19	4,3	88,8	72,7	0,147	0,580	0,000
-1814,7	20	5,7	94,5	67	0,572	0,567	0,009
-1815,2	21	3,8	98,3	63,2	0,233	0,577	0,000
-1815,7	22	4,4	102,7	58,8	0,172	0,579	0,000
-1816,2	23	3,9	106,6	54,9	0,028	0,583	0,000
-1816,7	24	3,2	109,8	51,7	0,118	0,581	0,000
-1817,2	25	3,8	113,6	47,9	0,432	0,571	0,000
-1817,7	26	5,5	119,1	42,4	0,114	0,581	0,000
-1818,7	27	4,7	123,8	37,7	0,100	0,581	0,000
-1819,2	28	5,5	129,3	32,2	0,002	0,584	0,000
-1824,7	29	5	134,3	27,2	0,047	0,583	0,000

Appendix D.3.1 (cont'd)

-1825,2	30	4,5	138,8	22,7	0,032	0,583	0,000
-1825,7	31	4,3	143,1	18,4	0,001	0,584	0,000
-1826,2	32	5	148,1	13,4	0,072	0,582	0,000
-1826,7	33	4,4	152,5	9	0,028	0,583	0,000
-1827,2	34	5	157,5	4	0,388	0,573	0,000
-1827,7	35	4	161,5	0			
		161,5 (Grand Sum)					

Appendix D.3.2 Division of Well-3 into three zones.

Depth (m) (BSL)	Sample No.	Porosity data (%)	Cumulative Sum	Grand Sum-Cum. Sum	B	W	R
Zone 1							
-1804,7	1	5,8	5,8	35,4	0,483	0,393	0,186
-1805,2	2	5,5	11,3	29,9	0,667	0,362	0,457
-1805,7	3	5	16,3	24,9	0,385	0,409	0,000
-1806,2	4	4,7	21	20,2	0,080	0,460	0,000
-1806,7	5	4	25	16,2	0,300	0,423	0,000
-1807,2	6	5,2	30,2	11	0,327	0,419	0,000
-1808,2	7	6	36,2	5	0,026	0,469	0,000
-1808,7	8	5	41,2	0			
		41.2 (Grand Sum)					
Zone 2							
-1809,2	1	3,3	3,3	117	1,387	0,483	0,652
-1809,7	2	4	7,3	113	1,402	0,483	0,656
-1810,2	3	4,7	12	108,3	0,700	0,511	0,271

Appendix D.3.2 (cont'd)

-1810,7	4	4,2	16,2	104,1	0,772	0,508	0,343
-1811,2	5	3,3	19,5	100,8	1,894	0,463	0,756
-1811,7	6	4,1	23,6	96,7	2,104	0,455	0,784
-1812,2	7	3,8	27,4	92,9	2,769	0,428	0,845*
-1812,7	8	5,1	32,5	87,8	1,756	0,468	0,733
-1813,2	9	5,3	37,8	82,5	0,882	0,503	0,429
-1813,7	10	5,5	43,3	77	0,250	0,529	0,000
-1814,2	11	4,3	47,6	72,7	0,305	0,526	0,000
-1814,7	12	5,7	53,3	67	0,004	0,539	0,000
-1815,2	13	3,8	57,1	63,2	0,100	0,535	0,000
-1815,7	14	4,4	61,5	58,8	0,114	0,534	0,000
-1816,2	15	3,9	65,4	54,9	0,308	0,526	0,000
-1816,7	16	3,2	68,6	51,7	1,109	0,494	0,554
-1817,2	17	3,8	72,4	47,9	1,776	0,468	0,737
-1817,7	18	5,5	77,9	42,4	0,882	0,503	0,429
-1818,7	19	4,7	82,6	37,7	0,751	0,509	0,322
-1819,2	20	5,5	88,1	32,2	0,197	0,531	0,000
-1824,7	21	5	93,1	27,2	0,047	0,537	0,000
-1825,2	22	4,5	97,6	22,7	0,044	0,537	0,000
-1825,7	23	4,3	101,9	18,4	0,098	0,535	0,000
-1826,2	24	5	106,9	13,4	0,000	0,539	0,000
-1826,7	25	4,4	111,3	9	0,004	0,538	0,000
-1827,2	26	5	116,3	4	0,216	0,530	0,000
-1827,7	27	4	120,3	0			
		120,3 (Grand Sum)					

Appendix D.3.3 Division of Well-3 into four zones.

Depth (m) (BSL)	Sample No.	Porosity data (%)	Cumulative Sum	Grand Sum-Cum. Sum	B	W	R
Zone 2							

Appendix D.3.3 (cont'd)

-1809,2	1	3,3	3,3	24,1	0,440	0,214	0,515
-1809,7	2	4	7,3	20,1	0,196	0,263	0,000
-1810,2	3	4,7	12	15,4	0,039	0,294	0,000
-1810,7	4	4,2	16,2	11,2	0,172	0,267	0,000
-1811,2	5	3,3	19,5	7,9	0,004	0,301	0,000
-1811,7	6	4,1	23,6	3,8	0,015	0,299	0,000
-1812,2	7	3,8	27,4	0			
		27,4 (Grand Sum)					
Zone 3							
-1812,7	1	5,1	5,1	87,8	0,218	0,498	0,000
-1813,2	2	5,3	10,4	82,5	0,684	0,473	0,310
-1813,7	3	5,5	15,9	77	1,514	0,426	0,718
-1814,2	4	4,3	20,2	72,7	0,820	0,465	0,433
-1814,7	5	5,7	25,9	67	1,908	0,405	0,788*
-1815,2	6	3,8	29,7	63,2	0,797	0,466	0,415
-1815,7	7	4,4	34,1	58,8	0,552	0,480	0,131
-1816,2	8	3,9	38	54,9	0,147	0,502	0,000
-1816,7	9	3,2	41,2	51,7	0,074	0,506	0,000
-1817,2	10	3,8	45	47,9	0,421	0,487	0,000
-1817,7	11	5,5	50,5	42,4	0,072	0,507	0,000
-1818,7	12	4,7	55,2	37,7	0,061	0,507	0,000
-1819,2	13	5,5	60,7	32,2	0,022	0,509	0,000
-1824,7	14	5	65,7	27,2	0,107	0,505	0,000
-1825,2	15	4,5	70,2	22,7	0,073	0,506	0,000
-1825,7	16	4,3	74,5	18,4	0,010	0,510	0,000
-1826,2	17	5	79,5	13,4	0,112	0,504	0,000
-1826,7	18	4,4	83,9	9	0,047	0,508	0,000
-1827,2	19	5	88,9	4	0,438	0,486	0,000
-1827,7	20	4	92,9	0			
		92,9 (Grand sum)					