Discriminant Analysis of Kalhur and Pabdeh Formation Members

By

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Dissertation submitted in partial fulfilment

of the requirements for

MSc. Petroleum Engineering

(MSc. PE)

JUNE 2014

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Petroleum Engineering Programme

Universiti Teknologi PETRONAS

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MSc. of PETROLEUM ENGINEERING

Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am are responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgement, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHAMMED YAASIR

ABSTRACT

Lithology identification and petrophysical estimation has always been a challenging task especially when it comes to carbonate reservoirs due to their heterogeneity. Traditionally, inspection of well log data along with core data are the basic source of reservoir characterization. The data available is a single borehole well log data with limited core data of a carbonate reservoir located in Iran. This project demonstrates a simple practical approach to identify the lithology and to estimate the petrophysical properties of an unknown zone from the well log data and limited core data available using statistical analysis.

Discriminant analysis is a statistical multivariate technique which allows statistical distinction between two or more groups which have been previously defined. To find the lithology of the unknown zone, the members which had already been identified by the core analysis has been divided. Statistical classification of members in the formations have been improved by combining certain members within the formation in zones which showed weak discrimination. After the discriminant analysis was proved to be effective in distinguishing the members, this data is used to determine the lithology of the unknown zone.

The unknown members is classified as 80% anhydrite with 20% traces of salts and other limestone members. Thus discriminant analysis proved to be a very effective statistical technique in discriminating members especially while working with limited data. Member determination permits refinement of the formation evaluation process because each members can be examined separately. This procedure makes possible the choice, for each members, of the parameters for log interpretation. The petrophysical properties such as porosity and permeability can also be estimated if the core data for that members which showed similar classification result as the unknown zone is available.

ACKNOWLEDGEMENT

First and foremost I would like to thank the almighty Allah S.W.T for giving me the strength and confidence to complete this project.

I would also like to show my sincere appreciation to my coordinators Dr. Ahmed Mohamed Ahmed Salim and Dr. Masoud Rashidi for the endless support and guidance throughout the whole period of completing this final year project despite their many other obligation. It is solely the source of their motivation that has driven me to complete this project successfully.

Appreciation is also extended to the coordinator Engr. Saleem Qadir Tunio for his systematic approach and timely arrangement as well as valuable advices for this project. Genuine gratitude is dedicated to the examiners and evaluators, both internal and external.

Also I would like to thank all my friends and loved ones who have been patient and supportive throughout the period of this project. Last but not the least I would like to specially thank my family, especially my mother and father for inspiring me with their sincere and continuous support.

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LIST OF ABBREVIATIONS

FL	Fuzzy logic
SS	Salt Sequence
MA	Massive Anhydrite
OLS	Operculina Limestone
GMM	Green marl member
PLSM	Platy limestone member
BBS&SM	Brown bituminous shale and marl member
MLSM	Marly limestone member
CLSM	Cherty limestone member
GM&PSM	Grey marl and purple shale member
ANN	Artificial neural network
SP	Spontaneous potential

CHAPTER 1

INTRODUCTION

1.1 Background

Well logging plays an essential role in the determination of the production potential of a hydrocarbon reservoir (D.V. Ellis, 1987). Well logging technique was adopted in 1927 and since then the logging tools and interpretive methods are developing at a significant rate with sophistication and accuracy. Well logging is the process of collecting data at different depths by lowering different tools in to the borehole. Basically, these measurements can be categorized into 3 types namely, acoustic, nuclear and electrical. The logging data plays a crucial role in obtaining information all the way from the geologist to the production engineers.

Determining the porosity, permeability and understanding the lithology is the most important feature of reservoir characterization. Over the life of the reservoir many critical decisions are taken on the basis of the estimated porosity. Porosity generally correlates with permeability which is defined as the measure of ease with which a fluid flows through a rock. And this factor plays a vital role in deciding the production capacity of the reservoir. Lithology refers to characteristics of a rock that differentiates a particular rock. Lithofacies identification is important for many geological and engineering disciplines. Lithofacies, rock or sediment units, characterized by texture or other features can be used to correlate and predict important reservoir characteristics such as permeability and porosity (Chikhi et al., 2005). Identifying various lithofacies of the reservoir rocks is a primary task for petroleum reservoir characterization.

To obtain the accurate or close to precise values, one must conduct a core analysis. But since laboratory analysis is very time consuming and expensive, limited core data is usually available that too at certain intervals of depth only. The cores are usually used as a base to predict the values of logs with similar responses. For this prediction, the knowledge of the tool response and the geology of the region are of critical importance. Achieving a precise well log interpretation is challenging as different factors affect and influence the response of logs.

To achieve a quality data one must analyse the data which involves preprocessing of the raw data. This involves the correction of environmental effects, for the indication of special minerals, the reaction of drilling fluids etc. Statistical packages are applied to the well log data and the results are used to delineate the reservoir zone. The results can then be used to predict lithofacies in non-cored wells (or un-cored intervals in cored wells) or more especially in wells that do not have useful lithofacies identification logs (Chang et al., 2000).The statistical method aids in analysing ,discriminating and reducing high dimension data therefore making it easier to highlight the similarities and differences between reservoir intervals. The use of the logs as control in the estimation is to provide information on the subsurface geology which is useful in bridging the gap between the geologists and the engineers. It also helps to integrate the statistical analysis with the geology of the environment with a view to maximize the accuracy of the estimation.

1.2 Problem statement

An oil field named “X” is located 20 km southeast of Hamran city, west of Iran and sharing borders with Iraq. The field which is a carbonate reservoir has undergone well logging and core analysis. The geology of this field is very complex and since the core data is not available for one of the zones in the well it is difficult to understand the petrophysical properties as well as to interpret the lithology for that particular zone. The estimated porosity, permeability and lithology for the unknown zone are to be predicted by the application statistical analysis.

1.3 Objectives

The main objectives of this project are the following

- To delineate the reservoir zones using statistical package. (IBM -SPSS) and to improve the statistical classification of members in the formations.
- To predict the lithology of the unknown zone.
- Estimate the petrophysical properties of the unknown zone with limited data provided.

1.4 Scope of study

The scope of study can be compartmentalized into four stages.

The first stage of scope of study revolve around the fundamentals of well log interpretation which encompasses the basic concept and terminology associated with log interpretation, understanding the basic well logging tools in order to implement and apply to the real log readings provided.

The second stage includes familiarizing basic application and utilization of SPSS software delineate the reservoir zones based on the discriminant analysis. This stage also includes combining certain zones within the each formations based on statistical classification results.

The third stage includes classification based on which the lithology of the unknown zone is predicted.

The fourth and final stage includes estimating the porosity and permeability of the unknown zone with the limited core data available.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to carbonate reservoirs

More than 60% and 40% of the world's oil and gas reserves (respectively) are retained in carbonate reservoirs. The carbonate rocks which are mainly deposited through biological activities have rock compositions of fossil fragments and grains of varying morphology. This produces rocks that contain pores with highly complex shapes and sizes. This heterogeneous pore system causes these rocks to defy petrophysical analysis unlike sandstones that have well characterized correlations of porosity, permeability and other reservoir properties. The carbonate mineral species are relatively unstable and processes such as dissolution, precipitation and recrystallization add onto the complexity of the pores and the permeability of the rocks. These multiple physical, biological, and chemical influences render any other comparatively simple relationships between the depositional attributes, porosity and permeability - indistinguishable. The primary challenge for the accurate assessment of carbonate formations is accounting for reservoir heterogeneity on a range of scales – of the grains, pores, and textures.

Over 90% of the carbonates sediments formed are believed to be formed by biological process under marine conditions (Milliman, 1974). The carbonate sediments are formed by environmental process which favors the growth of calcium carbonate secreting organisms. These parameters include temperature, salinity, substrate, and the presence/absence of siliciclastics (Lees, 1975). Due to the variety of grain shapes in carbonate rocks, they have a much more complicated pore system. Carbonate porosity classifications have been explained by Choquette and Pray (1970) which is based on size and sorting of grains and crystals while Lucia (1983;1995; 1999) determined that three porosity/permeability fields can be defined using particle size boundaries as shown in Figure 2.1.

A relationship that appears to be limited to particle sizes less than 500 microns. These three permeability fields form the basis for Lucia's (1983) petro physical and rock-fabric classes (Fig. 2.2). These classes are termed class 1, with particle sizes from 500-100 microns, class 2, with particles from 100-20 microns, and class 3, with particles <20 microns.

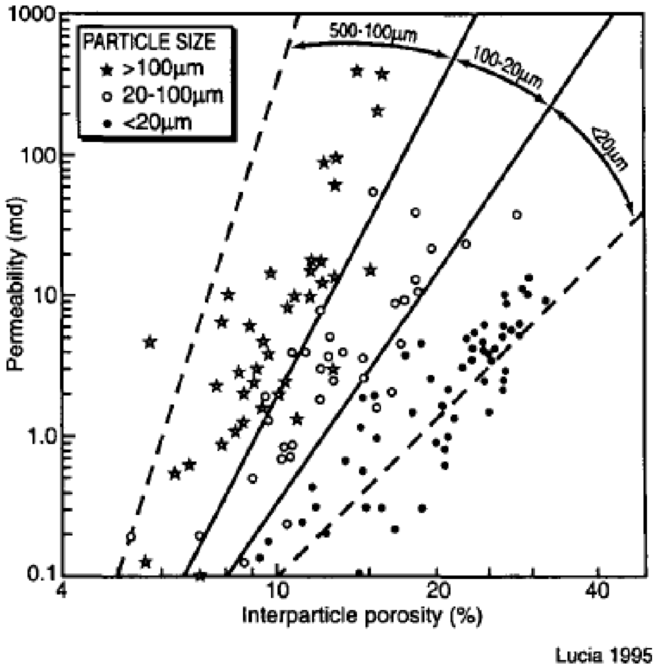


Fig 2.1 Porsity v/s air permeability relationship for different particle sizes in carbonate rocks (Lucia 1995).

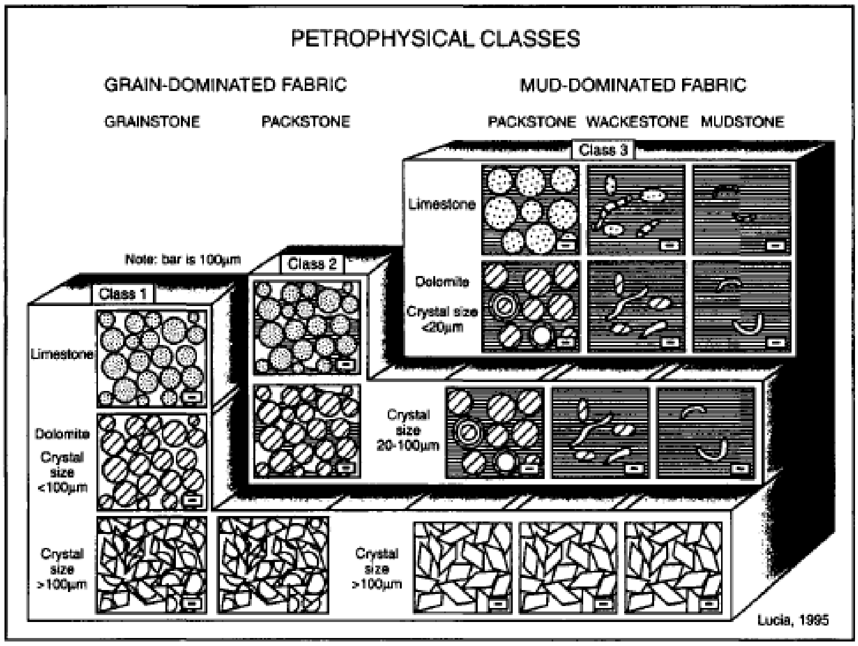


Fig 2.2 Petrophysical and rock fabric classes based on similar capillary properties and interparticle porosity/ permeability transforms. Lucia (1995).

2.2 Petrophysical rock properties

The main purpose of this section is to understand the basic definitions and measurements of basic petrophysical properties i.e. porosity and permeability.

2.2.1 Porosity

Porosity is defined as the pore volume per unit volume of formation; it is the fraction of the total volume of a sample that is occupied by pores or voids as shown in equation(1). The symbol for porosity is "Φ". It is an important rock property because it is a measure of the potential storage volume for hydrocarbons. Porosities in carbonate reservoir ranges from 1 to 35% and about 12 % in limestone reservoirs (Schmoker et al. 1985).

Porosity is given by $\frac{pore\ volume}{bulk\ volume} = \frac{bulk\ volume - grain\ volume}{bulk\ volume}$ ……. (1)

Porosity can be found by visual as well as laboratory measurements. Visual measurement completely depends on the method and magnification power. Higher the magnification means higher accuracy .while laboratory porosity shows greater values as even the small pores can be observed in laboratory measurements. The measurement of porosity in laboratory is done by passing mercury through the sample and the volumetric displacement shows the bulk volume. The pore volume is calculated from the grain density and sample weight of the known mineral.

The most precise method of calculating the porosity in the laboratory is the helium expansion method. In this method the volume of gas is kept constant and the sample pressure and volume is measure with the presence of the gas and without. The pore volume is indicated by the difference in pressure.

For accurate porosity measurements, the removal of fluids present in the sample is very critical as this will lead to that fluid to be included in mineral volume and it will under estimate the porosity values. An example of such a situation is shown below in Figure 2.3 where the incomplete removal of fluids from core showed lower values of porosity.

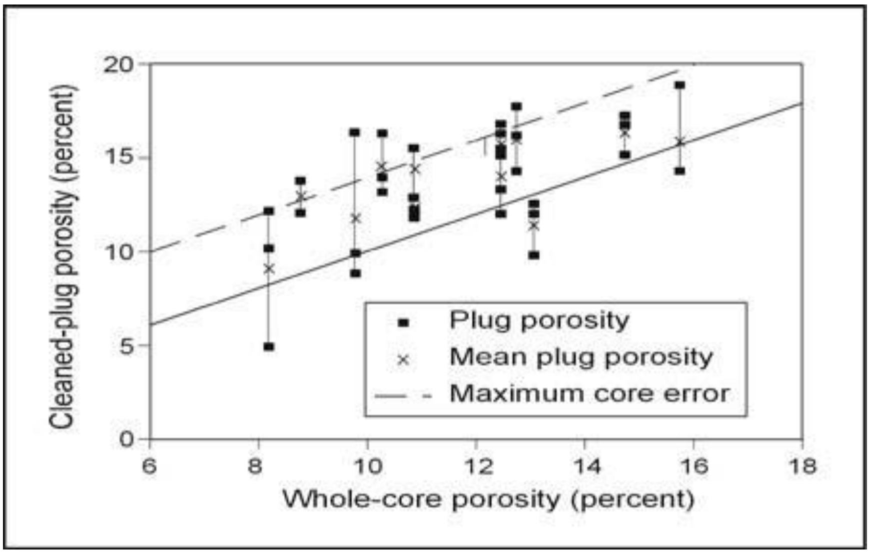


Figure 2.3 whole core porosity v/s cleaned plug porosity

Carbonate rocks are prone to be very compressible and the porosity decreases with increase in stress. Hence when conducting laboratory measurements care should be taken to consider the stress conditions. Laboratories increase the confining pressure while maintaining constant pressure. The resulting decrease in porosity is normally very small (2%) in Paleozoic and many Mesozoic reservoirs (Fig 2.4), and porosity measurements at ambient conditions are usually adequate (Harari et al. 1995). Porosity values of all high-porosity carbonates, however, should be checked for porosity loss with increasing confining pressure. The stresses in the formation can cause the formation to have cracks or fractures which may increase the volume of the pore. This porosity is called secondary porosity and is believed to not increase the porosity of the rock considerably but may increase its permeability substantially.

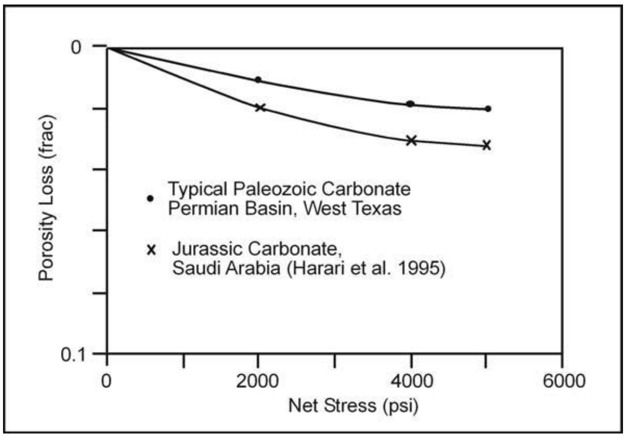


Fig. 2.4 Effect of confining pressure on porosity (Harari et al. 1995)

2.2.2 Permeability

Permeability is the measure of ease with which fluid can flow through a formation. The value of permeability ranges from 0.01 millidarcy to over 1 darcy. Permeability can be explained by Darcy law (equation 2). Formations such as limestone, which is usually composed of a dense rock broken by small fissures or fractures maybe show very less porosity but since the fracture acts as a conduit can show high permeability values.

$$\text{Darcy's Law: } Q = A\left(\frac{k}{\mu}\right)\left(\frac{\Delta p}{L}\right)\ldots\ldots \qquad (2)$$

Where Q is rate of flow, k is permeability, μ is fluid viscosity, ΔP is the potential drop across a horizontal sample, and A is the cross-sectional area of the sample. Permeability is a rock property, viscosity is a fluid property, and ΔP/L is a measure of flow potential.

The most conventional permeability measurement approach has been to use the measurement of the pressure drop associated with a fixed flow rate. To determine specific permeability nitrogen or air is usually caused to flow through a prepared sample of measured dimensions. The pressure differential and flow rates are measured and the permeability calculated from the Darcy equation. A schematic set up is shown in the sketch below, Figure 2.5.

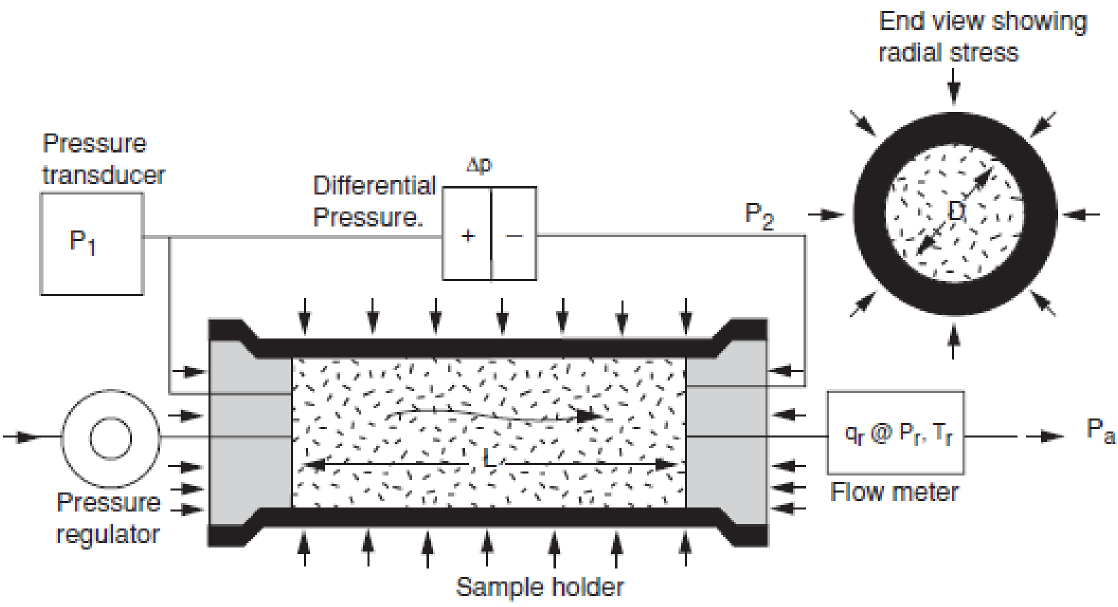


Figure 2.5 Permeability measurement of a core plug in laboratory.

The important thing to be taken into consideration is that the measurements should be made taking the confining pressure into consideration which is equivalent to the in-situ conditions. Permeability can vary a lot especially when the samples contain small fractures which can increase the flow rate and overestimate the permeability.

2.3 Core analysis

Cores obtained from the reservoir formation contain a considerable amount of information about the nature of the rocks themselves and various properties. They are also a source of material for investigating rock behavior with respect to fluid displacement and its reaction to various fluid types. Cores are recovered from the formation of interest using an annular shaped coring bit. The integrity of the recovered core depends on the nature of the rock and can vary from rock which is well formed to that which is friable in character or even is so unconsolidated that it would form a pile of sand on the rig floor when recovered from the core barrel. The core from the core barrel provides a record, over the well section recovered, of the properties of the formation. Figure 2.6 illustrates the wide range of measurements and procedures carried out on core samples (Graham and Trotman 1986).

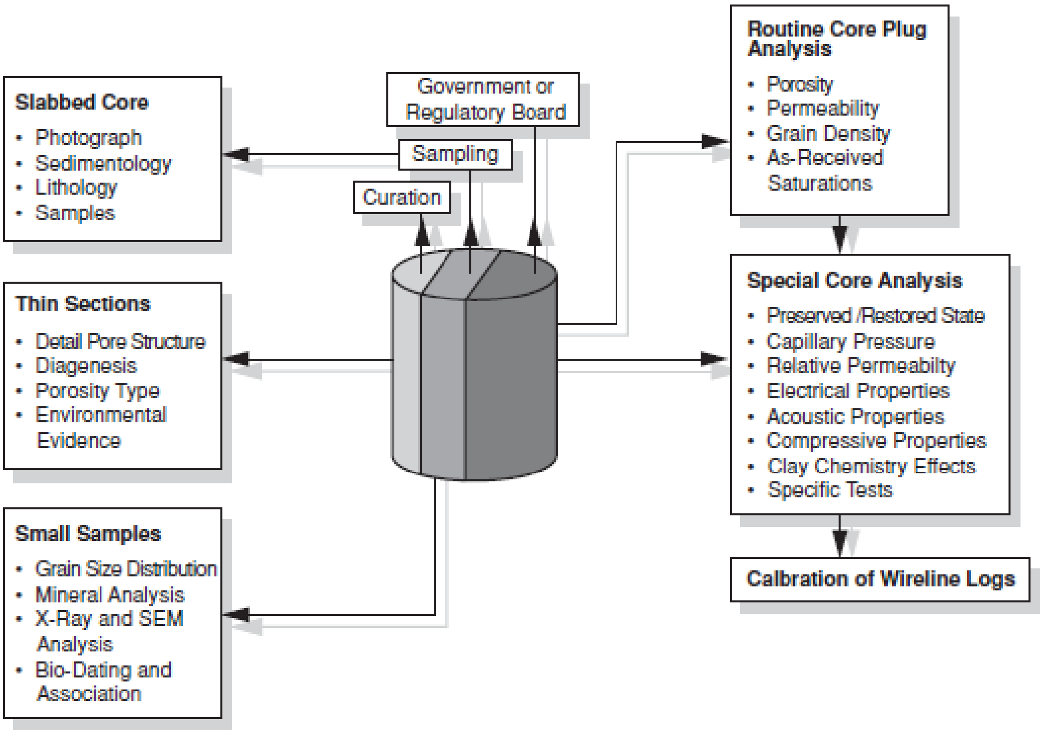


Figure 2.6 Data obtained from cored wells.

Petrophysical data obtained from core analysis are generally reliable, but can be inaccurate for the reasons discussed below:

- Biased sampling of core data can result in misrepresentations of porosity and permeability
- The values of "k" obtained from whole core analysis are less reliable compared to controlled laboratory procedures due to the insufficient care taken with the measurements.
- Unsatisfactory results in the values of permeability due to the insufficient confining pressure applied.
- Low values of porosity due to incomplete removal of hydrocarbon or other fluids.
- Change in properties of the minerals (clay , gypsum) when high temperature procedures practiced

2.4 Introduction to well logging

Well logging can be defined as "a recording against a depth of any property reflecting the characteristics of the rock formation transversed by a measuring apparatus in the well bore". The measuring equipment's are lowered by the help of a cable into the well. The collected details then transmitted upwards to a surface laboratory or computer. Well logging is normal run after an interruption of drilling activity and is thus distinguished from drilling logs and mud logs which are gained during drilling operations.

The main applications of well logging were previously limited to determining the porosities, saturation and for depth correlation. But in recent years, the log data has also appreciated for its use to determine more geological information of the penetrated area. Logging has therefore helped equally both the geologist and petro physicists to work together. The data attained from logs are sometimes incomplete or distorted, but are always permanent, continuous and objective. Hence it is termed as the "signature" of the rock. The characteristics that they portray are the result of all the chemical and biological changes that occurred with time. Well log interpretation should be aimed towards the same objectives as that of laboratory core analyses. This will only be able if there is a well-defined relationship between what's measured by logs and rock parameters of interest to the geologist and reservoir engineers. The logs that will be relied on for this project are the gamma ray log and density neutron porosity log since they are the only data available. The applications of the logs are explained in detail below.

2.4.1 Gamma ray log

The Gamma ray log is the measurement of the natural radioactive elements present in the formations. It is useful for location of shales and nonshaley beds and also for correlations. Other applications are mentioned below:

- Assessment of lithology.
- Approximation of shale fraction of reservoir rocks:

$$V_{sh} \leq (V_{sh})_{GR} = \frac{GR - GR_{min}}{GR_{sh} - GR_{min}} \quad \text{….(3)}$$

- Establishing well-to-well correlations.
- Detection of abnormalities.
- Sedimentology: the gamma-ray evolution with depth gives information on the grain-size evolution.
- Depth control of perforating and testing equipment in open holes where the SP is poor developed or is through tubing or casing.
- Evaluation of injection profiles using radioactive tracer materials.
- As a method of estimating permeability.

2.4.2 Density logs

The application of density logs are as follows.

- Used as porosity logs.
- Determination of hydrocarbon density.
- Evaluation of shaly sands and complex lithologies.
- Determination of oil-shale yield.
- Calculation of overburden pressure and rock mechanical properties.

2.4.3 Neutron logs

The main application of neutron logs are mentioned below:

- Delineation of porous formations

- Neutron log reflects amount of liquid filled porosity
- Neutron log along with density log can identify gas zones
- Combination of density log with neutron log yields a more accurate porosity value (Density neutron cross plots).

2.5 Porosity determination in complex conditions.

The measurements of the neutron, density, and sonic logs depend not only on porosity but also on the formation lithology, on the fluid in the pores, and, in some instances, on the geometry of the pore structure. When the lithology and, therefore, the matrix parameters are known, correct porosity values can be derived from these logs, appropriately corrected for environmental effects, in clean water-filled formations.

Under these conditions, a single log, either the neutron or the density or, if there is no secondary porosity, the sonic, can be used to determine porosity. Accurate porosity determination is more difficult when the matrix lithology is unknown or consists of two or more minerals in unknown proportions. Determination is further complicated when the response of the pore fluids in the portion of the formation investigated by the tool differs appreciably from that of water. In particular, light hydrocarbons (gas) can significantly influence the response of all three porosity logs. Even the nature of type of pore structure affects the tool response. The neutron and density logs respond to total porosity - that is, the sum of the primary (intergranular or intercrystalline) porosity and the secondary (vugs, fissures, fractures) porosity. The sonic logs, however, tend to respond only to evenly distributed primary porosity.

To determine porosity when any of these complicating situations exists requires more data than provided by a single porosity log. Fortunately, neutron, density, and sonic logs respond differently to matrix minerals, to the presence of gas or light oils, and to the geometry of pore structure. Combinations of these logs and the photoelectric cross section index, Pe, measurement from the Litho-Density log and the thorium, uranium, and potassium measurement from the NGS* natural gamma ray spectrometry log can be used to unravel complex matrix or fluid mixtures and thereby provide a more accurate porosity determination.

The combination of measurements depends upon the situation. For example, if a formation consists of only two known minerals in unknown proportions, the combination of density and neutron logs or the combination of bulk density (ρb) and photoelectric cross section will define the proportions of the two minerals and a better value of porosity. If it is known that the lithology is more complex but consists of only quartz, limestone, dolomite, and anhydrite, then a relatively accurate value of porosity can again be determined from the density-neutron combination; however, the mineral fractions of the matrix cannot be precisely determined. Crossplots are a convenient way to demonstrate how various combinations of logs respond to lithology and porosity.

2.6 Problems in the analysis of well logs in carbonate rocks

The analysis of wireline logs in carbonate rocks are commonly not very reliable. Depending upon the nature of the carbonate rock it has been understood that results of log analysis shows they are less reliable compared to sandstone reservoirs. The main reasons for this unreliability are the following.

- The rocks commonly have mixed or intermingled lithology
- Porosity distributions involves a wide range and the porosity systems encountered in carbonate rocks are large
- Miscellaneous geochemical effects introduce error in analyses, such as formation waters of uncommon chemistry and coprecipitation of uranium in high quantities.
- Heterogeneity in carbonate reservoirs is high.

Most of the errors can be dodged by careful inspection of data, while others can be addresses by performing other log runs. In short, an analyst should be aware of the unreliability and uncertainty of the results obtained. If the results are not properly analyzed it may lead to gross errors in the calculations. The wide range of porosities make the distribution very far from normal. This in turn affects the whole calculation of net pay.

2.7 Lithology determination using statistical packages.

The first stage in reservoir characterization involves accumulation of well log data which include the Gamma ray, resistivity and density neutron logs. The core data which is extracted from particular depth intervals are limited since it consumes time and is expensive. The data obtained from the core is known as core data. Petrophysical characteristics such as porosity, permeability, saturation etc. can be determined by core analysis in the laboratory.

Since there is a strong relationship between lithofacies and corresponding petrophysical properties, it is very important to understand the lithology which in turn will make it easier to determine and estimate the petrophysical properties. Due to the non-linear relationship between lithofacies and petrophysical properties, it is hard to obtain a precise value for petrophysical properties from wireline logs.

As discussed earlier, due to the limited availability of core data, it makes it challenging for the log analyst to interpret and relate the lithofacies to its corresponding petrophysical properties. Traditionally, discriminant analysis, statistical and graphical methods have been used for the establishment of well log data interpretation models (Wong P.M, 1995; Condert et al 1994). Also in recent years there have been various improvements in computational intelligence techniques such as artificial neural networks and fuzzy (Fung C.C 1995; Wong P.M 1996; Rogers, 1992). In this report, the main aim is to apply statistical analysis to well log data and to explore and interpret the area under investigation.

Eventhough there exist a number of new computational intelligence techniques such as artificial neural network (ANN) and Fuzzy logic (FL), these require very large number of data and since there is only limited data for one well available for a particular depth, the concept of applying discriminant analysis is applied to facilitate the understanding of large amounts data by discovering patterns existing in the data.

2.8 Discriminant analysis

Discriminant analysis computes a set of linear functions for the purpose of classifying an individual item into one of several groups. The input data consist of a set of items for each of the classification groups and each item consists of the values of a complete set of variables. The group assignment procedure is derived from a model of a multivariate normal distribution of observations within groups such that the covariance matrix is the same for all groups. An item is classified into the group for which the estimated probability density is largest. The equivalent computational procedure evaluates the computed linear function for each of the groups and assigns an item to the group for which the value is largest.

The computed linear functions are more likely to be normally distributed than the individual component variants. Therefore the multivariate normal distribution assumption in discriminant analysis is inherently satisfied by the computational procedure. This makes the technique very robust; however, transformation of highly skewed variables into a more normally distributed form may improve the group classification. The linear functions may be computed by choosing the variables in a stepwise manner. The variable entered or deleted at each step can be selected by various criteria, the most common being the magnitude of its F-statistic. Optional two dimensional pictures of the separation of the groups can also be made by plotting the first two canonical variables.

2.8.1 Data editor in SPSS.

The Data Editor provides a convenient, spreadsheet-like method for creating and editing data files. The Data Editor window opens automatically when a session is started. There are 2 types of view available in the data editor. They are:

- Data View. This view exhibits the actual data values or defined value labels.
- Variable View. This view displays variable definition information, plus distinct variable

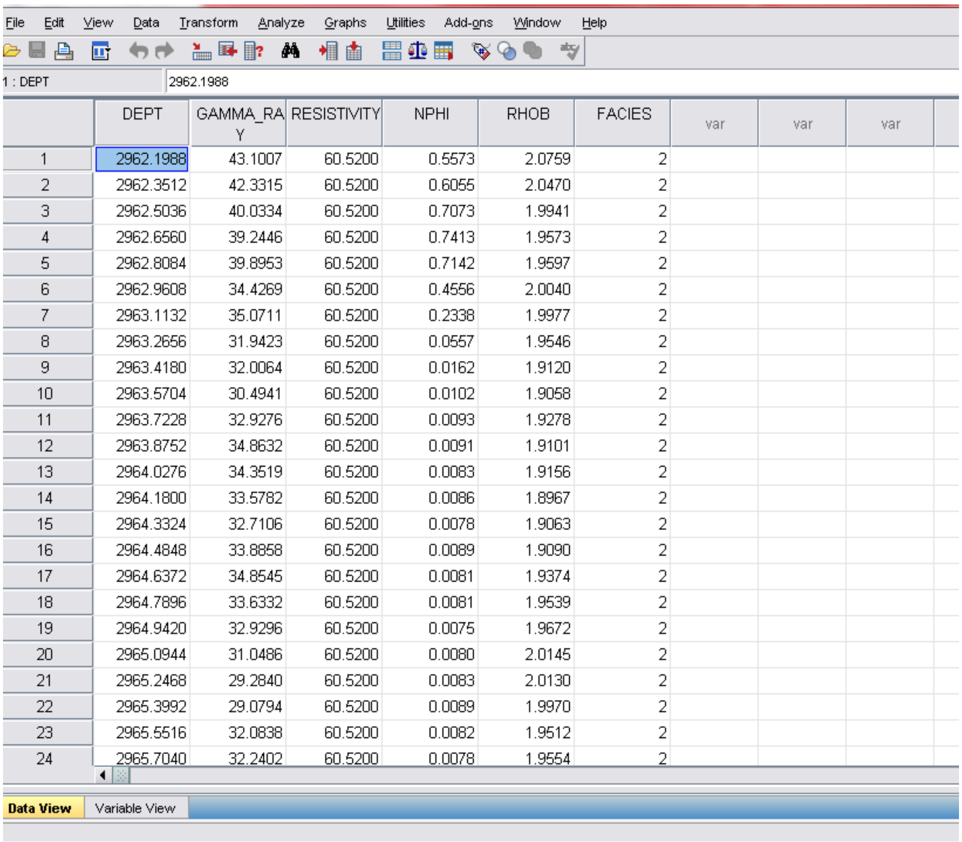
In both views, values can be can added, changed, and information can be deleted that is contained in the data file.

Data view

Even though data view (fig 2.7) is similar to spreadsheet, there are several differences as mentioned below.

- Rows represents cases. Each row represents a case or an observation. In this case the different logs represent each case.
- Columns represents variables. Each column represents a variable or characteristic that is being measured. In this case, the log readings represents the variables its respective depth.

- The cell can contain only single value of a variable for a case. Cells can contain only data values and cannot contain any kind of formulas.



	DEPT	GAMMA_RAY	RESISTIVITY	NPHI	RHOB	FACIES	var	var	var
1	2962.1988	43.1007	60.5200	0.5573	2.0759	2			
2	2962.3512	42.3315	60.5200	0.6055	2.0470	2			
3	2962.5036	40.0334	60.5200	0.7073	1.9941	2			
4	2962.6560	39.2446	60.5200	0.7413	1.9573	2			
5	2962.8084	39.8953	60.5200	0.7142	1.9597	2			
6	2962.9608	34.4269	60.5200	0.4556	2.0040	2			
7	2963.1132	35.0711	60.5200	0.2338	1.9977	2			
8	2963.2656	31.9423	60.5200	0.0557	1.9546	2			
9	2963.4180	32.0064	60.5200	0.0162	1.9120	2			
10	2963.5704	30.4941	60.5200	0.0102	1.9058	2			
11	2963.7228	32.9276	60.5200	0.0093	1.9278	2			
12	2963.8752	34.8632	60.5200	0.0091	1.9101	2			
13	2964.0276	34.3519	60.5200	0.0083	1.9156	2			
14	2964.1800	33.5782	60.5200	0.0086	1.8967	2			
15	2964.3324	32.7106	60.5200	0.0078	1.9063	2			
16	2964.4848	33.8858	60.5200	0.0089	1.9090	2			
17	2964.6372	34.8545	60.5200	0.0081	1.9374	2			
18	2964.7896	33.6332	60.5200	0.0081	1.9539	2			
19	2964.9420	32.9296	60.5200	0.0075	1.9672	2			
20	2965.0944	31.0486	60.5200	0.0080	2.0145	2			
21	2965.2468	29.2840	60.5200	0.0083	2.0130	2			
22	2965.3992	29.0794	60.5200	0.0089	1.9970	2			
23	2965.5516	32.0838	60.5200	0.0082	1.9512	2			
24	2965.7040	32.2402	60.5200	0.0078	1.9554	2			

Fig 2.7. Data view in SPSS

Variable view

Variable View contains descriptions of the attributes of each variable in the data file (fig 2.8). In Variable View:

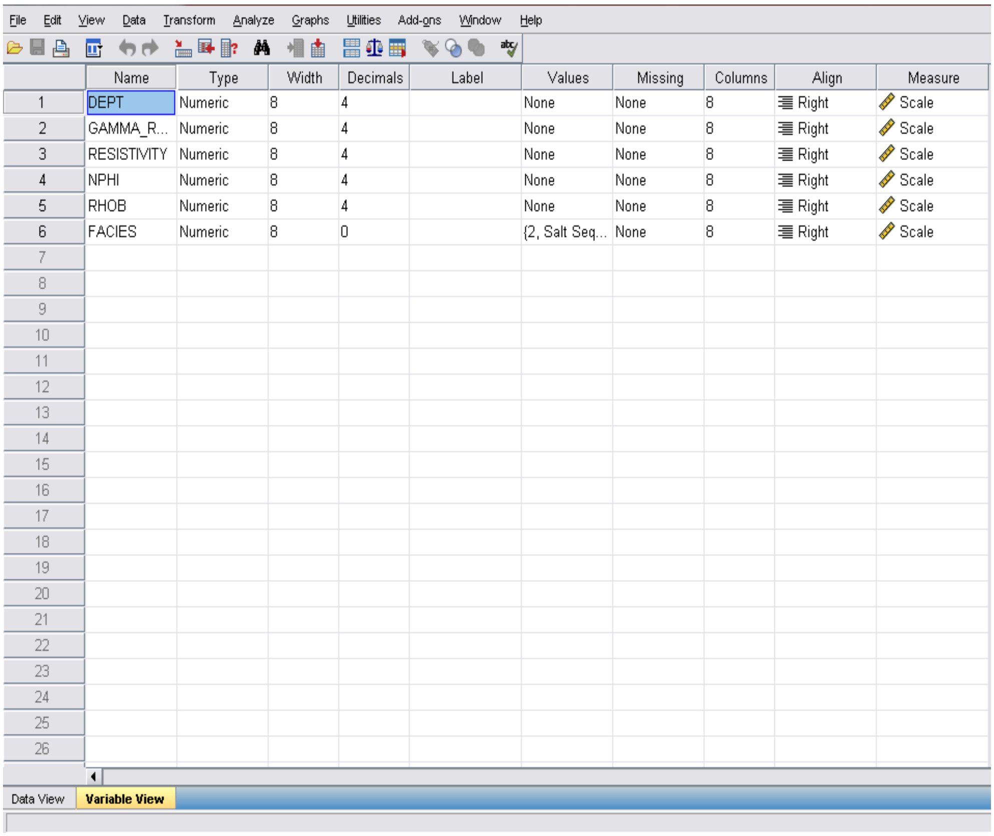
- Rows are variables.
- Columns are variable attributes.

Variables can be added or deleted or modified, this includes.

- Variable name
- Data type
- Number of digits or characters
- Number of decimal places
- Descriptive variable and value labels

User-defined missing values

- Column width
- Measurement level



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure
1	DEPT	Numeric	8	4		None	None	8	Right	Scale
2	GAMMA_R...	Numeric	8	4		None	None	8	Right	Scale
3	RESISTIVITY	Numeric	8	4		None	None	8	Right	Scale
4	NPHI	Numeric	8	4		None	None	8	Right	Scale
5	RHOB	Numeric	8	4		None	None	8	Right	Scale
6	FACIES	Numeric	8	0		{2, Salt Seq...	None	8	Right	Scale

Fig 2.8 Variable view in SPSS

2.8.2 Applications of discriminant analysis.

- **Formation evaluation**

Using predicted members enhances formation evaluation because each lithology can be analyzed separately. This gives the analyst a clear picture of lithology which makes it easier to predict the petrophysical properties.

- **Facies maps**

The processing of the wells of the whole area produced output lists, analog displays, and data sets compatible with mapping software. The above methods yield improved statistical data useful for mapping several parameters (porosity, fluid saturation, etc.) for each producing zone and also useful in quality control.

- **Automatic stratigraphic correlation**

Probably the most common application of well logs is in stratigraphic correlation. The log curves assist in the mapping of subsurface structural relief and in the characterization of depositional systems. On a more detailed scale they are used in the interpretation of the morphology of the flow units and the barriers to flow between wells. Stratigraphic correlation can be defined as the correct determination of the spatial equivalence of rocks based on their physical properties; a general discussion of correlation methods and a comparison of several techniques are found in Olea and Davis (1986). Most correlation methods in the literature depend on curve-matching procedures that determine the degree of similarity between two series in the space domain. This algorithm utilizes sequences of strata previously recognized in this study and is thus compatible with the results obtained for facies determination. The problem is to find the best possible alignment or correlation between two lithological series; that is, the maximum number of good matches of the layers. The algorithm allows attributing two lithological types to a single stratum, which permits the interpreter to assign the relative importance of the primary and the secondary components. The influence of the thickness in the matching of the layers can be controlled. This method permits multiple correlation in which two or more units of a given series are associated with a unique stratum of the other series.

2.8.3 Limitations

The main limitation of discriminant analysis are:

- The number of items in each group must be greater than or equal to the number of variables used in the analysis.
- The number of a priority groups must be less than or equal to the number of variables.

CHAPTER 3

METHODOLOGY AND PROJECT PLANNING

3.1 Project activities and tools

To achieve the main goal of this topic, careful study was done to understand the basic concepts of well logging and application of statistical packages to determine lithology and predict petrophysical properties. Information has been gathered from textbooks, online references, technical references to understand the characteristics of carbonate reservoirs and the application of statistical analysis in well log data. All the resources have proved to be very significant in understanding the advantages and drawbacks of each technique in determining lithology and petro physical properties.

The well log data given is of a single borehole of depth range 2962 meters to 3554 meters which is a carbonate reservoir located in Iran .Hence the lithology of the area was thoroughly studied, understood and analyzed. Data gathering is considered as one of the basic steps of this project as it functions as an input to the statistical software which is used to delineate the reservoir. The software used is IBM SPSS 16. Other software's used in this project includes:

- Petrel
- LAS viewer :alternate for petrel using just basic LAS file
  Website: www.kgs.ku.edu/stratigraphic/LAS/LASViewer.html)
- Microsoft excel: large quantity data handling and calculations.

The core data for the following depths from 2962 m to 3514 m was also included in the data given and is mentioned below along with the geologic information. Figure below depicts the methodology employed in all phases of this project. Also a Gantt chart which illustrated the schedule of the project has been included in the section project planning

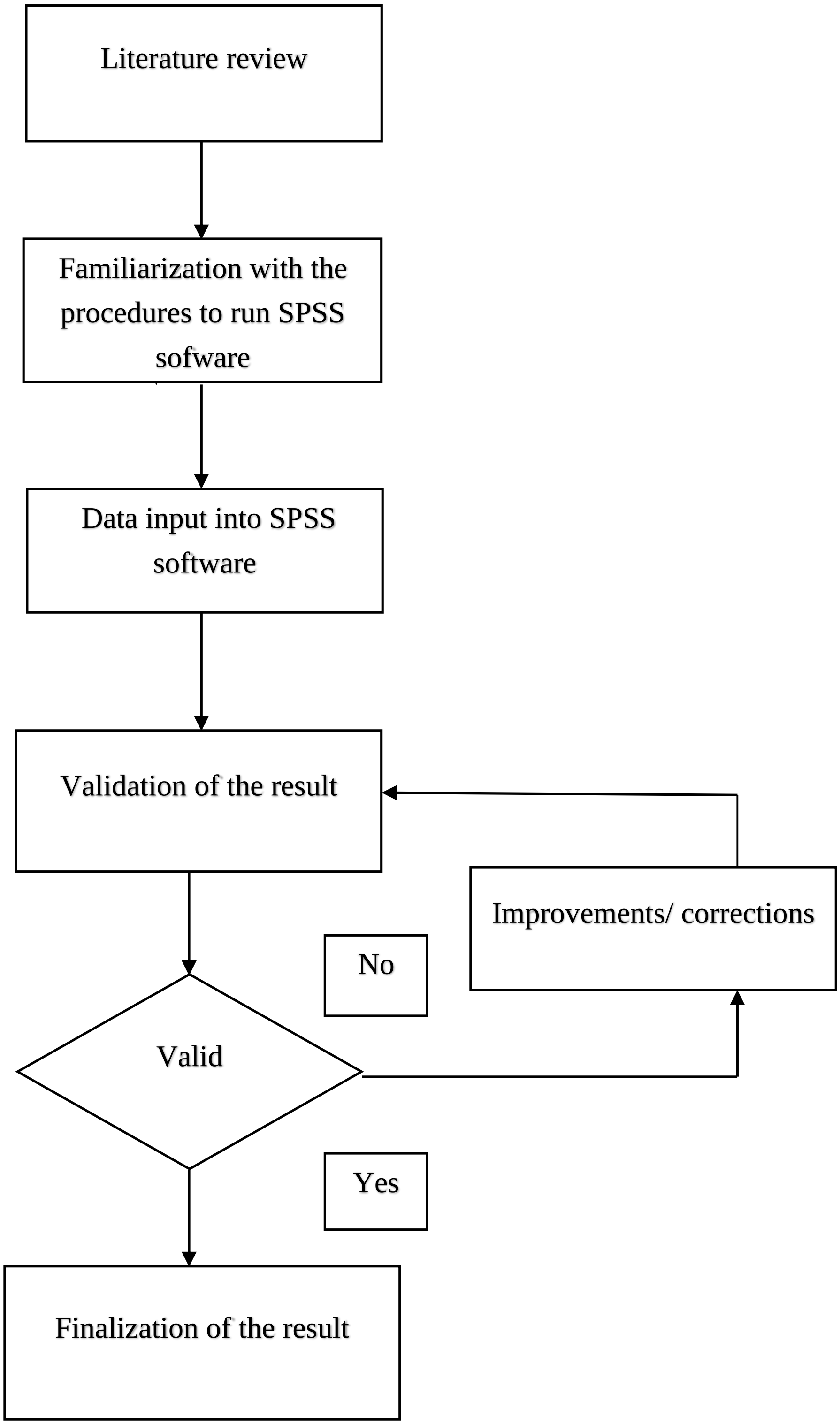


Fig 3.1 Project flow chart

3.2 Procedure for lithology determination of the unknown zone.

The steps are explained in detail below with the help of a flow chart.

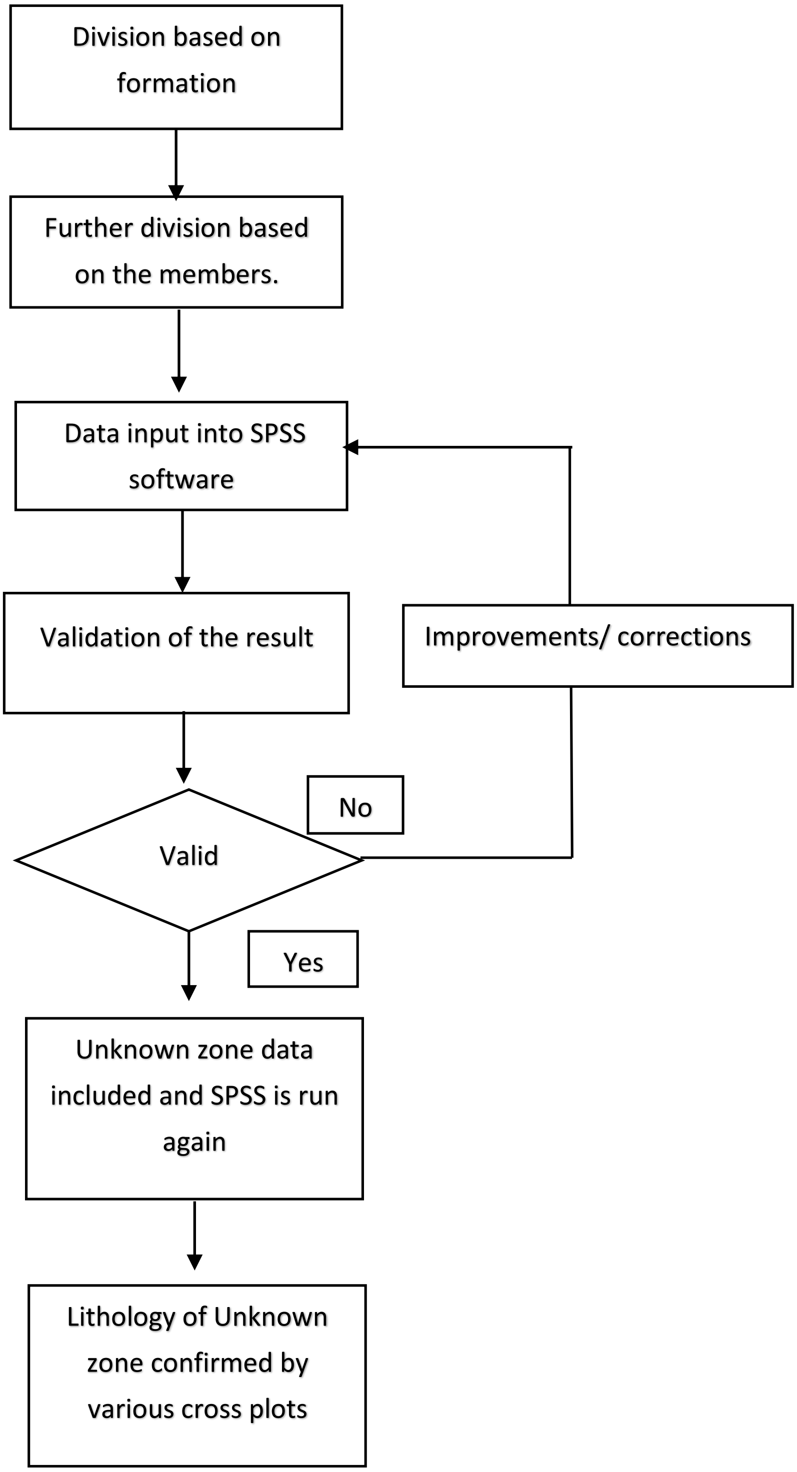


Fig 3.2 Flowchart for determining lithology of unknown zone

3.3 Data extraction

The well log data is separated into different intervals by extracting data from LAS file and exporting it into Microsoft excel. This simply done by copying the data from the las file and pasting it into the Microsoft excel. The Gamma ray logs, resistivity log (deep), and the porosity log readings are all aligned with their respective depths and then they are differentiated on the basis of the lithological information which is derived from the core data. This is illustrated by an example shown in the table 3.1 for two different members for kalhur formation.

Similar interval separation is done for the Pabdeh Formation as per the lithological information obtained from core data.

Table 3.1 Separation of intervals of members within single formation.

Members No	Depth (M)	CGR	LLD	NPHI	RHOB	FORMATION	MEMBERS DECRIPTION
4	3068.12	56.18	1.55	0.31	2.54	Kalhur Formation (2845.5-3077 m)	Operculina Limestone (3038-3068.5m)
4	3068.27	55.51	2.01	0.3	2.62	Kalhur Formation (2845.5-3077 m)	Operculina Limestone (3038-3068.5m)
4	3068.42	55.05	2.34	0.26	2.67	Kalhur Formation (2845.5-3077 m)	Operculina Limestone (3038-3068.5m)
5	3068.57	53.77	3.37	0.2	2.7	Kalhur Formation (2845.5-3077 m)	Basal Anhydrite (3068.5-3077m)
5	3068.73	51.99	5.9	0.15	2.79	Kalhur Formation (2845.5-3077 m)	Basal Anhydrite (3068.5-3077m)
5	3068.88	37.54	7.4	0.09	2.92	Kalhur Formation (2845.5-3077 m)	Basal Anhydrite (3068.5-3077m)
5	3069.03	31.61	21.07	0.04	3.03	Kalhur Formation (2845.5-3077 m)	Basal Anhydrite (3068.5-3077m)

3.4 Running discriminant analysis in SPSS

The procedure for running SPSS requires time to understand and the steps to operate discriminant analysis are shown below.

3.4.1 Open SPSS Software

The software after installation is run using windows 7 computer with high processing speed by double clicking the SPSS icon.

3.4.2 Data editor

The log data available is loaded into the data editor where in the data view, each colum represents a variable or characteristic that is being measured. In this case, the log readings represents the variables at its respective depth. (Refer fig 2.6 and 2.7)

3.4.3 Discriminant analysis

After the values are inserted into the data box and saved. From the menus choose:

Analyze

Classify

Discriminant...

A Window that pops up will ask to define the following as shown in figure 3.3 :

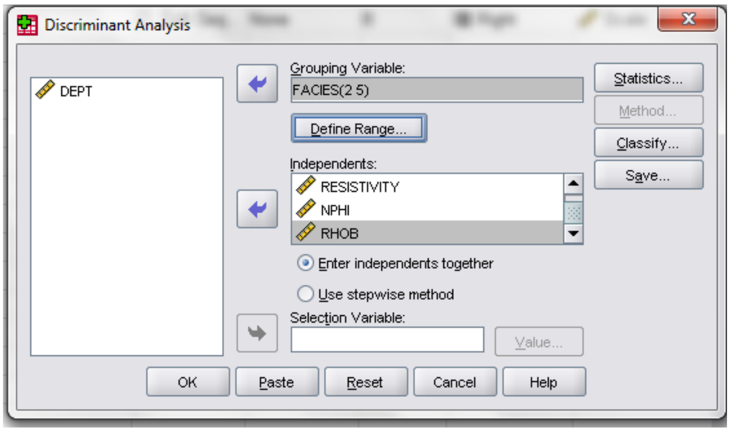


Fig 3.3 Discriminant Analysis dialog box

- In grouping variables, the member variables is selected and the “define ranges” options is clicked and the ranged are specified (fig 3.3). For Kalhur formation ranges are from 2 to 5, and for Pabdeh formation is 6 to 12.
- The log data which are Gamma ray, density porosity and resistivity are inserted into the “independents” box.
- Enter independents together. Simultaneously enters all independent variables that satisfy.

3.4.4 Discriminant analysis define range

Specify the minimum and maximum value of the grouping variable for the analysis as shown in fig 3.4. Cases with values outside of this range are not used in the discriminant analysis but are classified into one of the existing groups based on the results of the analysis. The minimum and maximum values must be integers.

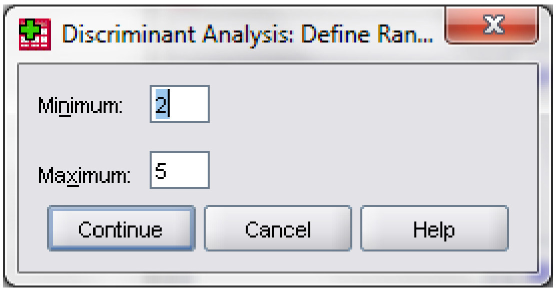


Fig 3.4 Ranges for Kalhur formation

3.4.5 Discriminant analysis statistics

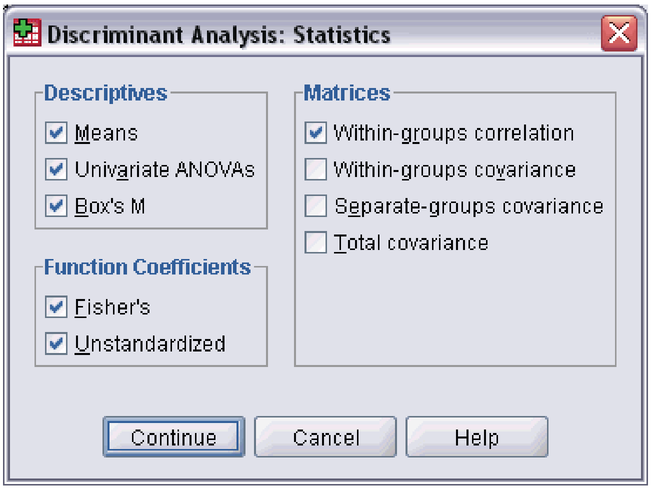


Fig 3.5 Discriminant Analysis Statistics dialog box

The following boxes are checked as shown in the fig 3.5 in the dialog box and the "continue" option is clicked.

3.4.6 Discriminant analysis classification

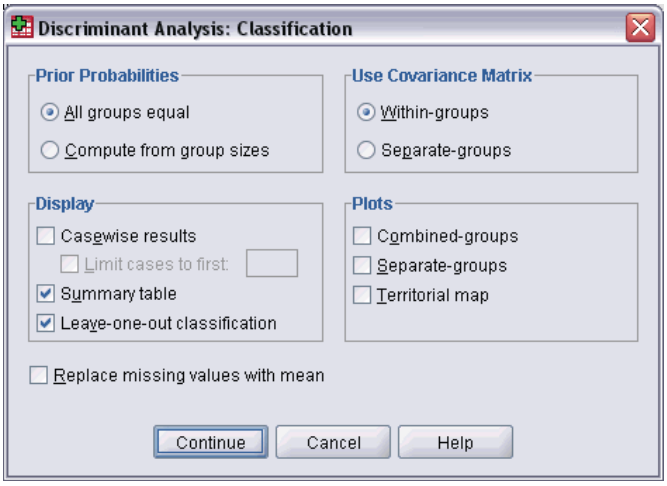


Fig 3.6 Discriminant Analysis Classify dialog box

In the classify dialog box, the following classification options are marked as shown in fig 3.6 and then the continue option is clicked.

3.5 Improving the quality of classification result

The classification results are analyzed and is improved by assigning the same members number for similar cases

In kalhur formation, the following changes are made due to unsatisfactory classification results as shown in Table 3.2. This is done by assigning the same members numbering for the members which have very weak discrimination and which were classified under a different member.

Table 3.2 Separation based on similar case (Kalhur formation)

Depth	Members Number	Members description	Formation
(2888.5-3001m)	2	Salt Sequence	Kalhur Formation
(3001-3038m)	3	Massive Anhydrite	Kalhur Formation
(3038-3068.5m)	4	Operculina Limestone	Kalhur Formation
(3068.5-3077m)	3	Massive Anhydrite	Kalhur Formation

Basalt anhydrite is replaced by massive anhydrite as they are classified as the same group. Similarly in Pabdeh Formation as shown in Table 3.3, the same method is adopted.

Table 3.3 Separation based on similar case (Pabdeh formation)

(3077-3210m)	6	Green marl member	Pabdeh Formation
(3210-3260m)	7	Platy limestone member	Pabdeh Formation
(3260-3355.5m)	8	Brown bituminous shale and marl member	Pabdeh Formation
(3355.5-3385m)	9	Marly limestone member	Pabdeh Formation
(3385-3460m)	10	Cherty limestone member	Pabdeh Formation
(3460-3476m)	11	Grey marl and shale member	Pabdeh Formation
(3476-3514m)	11	Grey marl and shale member	Pabdeh Formation

Purple shale member is replaced by Grey marl and shale member as they cannot be discriminated by SPSS as shown in results in the next section. After the changes have been made, discriminant analysis is run following the same procedure for both the formations as shown in Step 3 to improve the classification results.

3.6 Including the unknown formation data to the data set

The “unknown member” data is then clubbed along with the known set of log data as shown in Figure 3.7.

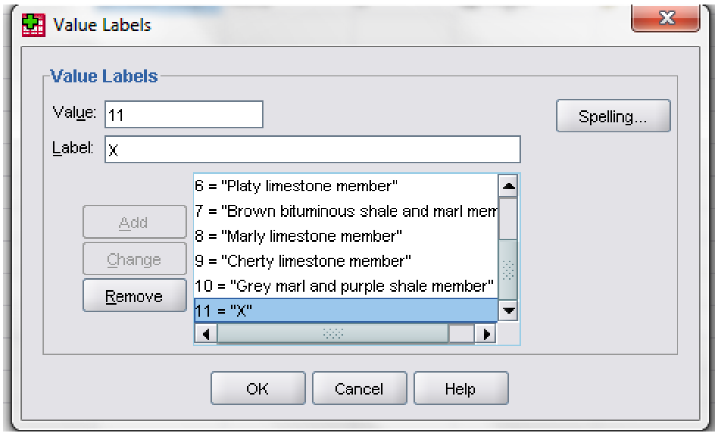


Fig 3.7 Including the Unknown member in to the data set

3.7 Running Discriminant analysis with Unknown formation

Further, the discriminant analaysis is run by making the following changes.

From the menus choose:

Analyze

Classify

Discriminant...

In the define ranges option, the “unknown member” is data is excluded from the remaining known member as shown below in Figure 3.8.

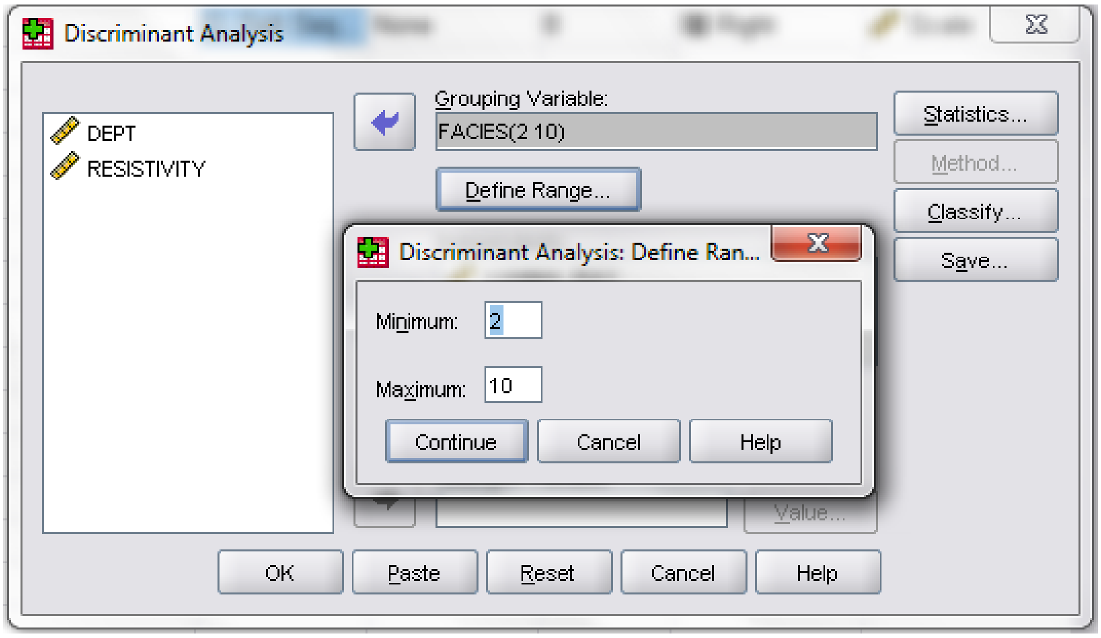


Figure 3.8 Unknown data excluded from grouping variables.

Remaining steps are followed as per protocol and hence the results of the unclassified (unknown groups) can be generated.

3.8 Verification of the unknown member using cross plots.

Using the data available for the unknown member which includes the density and neutron porosities, the lithology's can be identified.

The separations between the quartz, limestone, and dolomite lines indicate good resolution for these lithologies. Also, the most common evaporites (rock salt, anhydrite) are easily identified.

In the example shown on Figure 3.9, $\varphi Ds = 15$ and $\varphi N = 21$. This defines Point P, lying between the limestone and dolomite curves and falling near a line connecting the 18% porosity graduations on the two curves. Assuming a matrix of limestone and dolomite and proportioning the distance between the two curves, the point corresponds to a volumetric proportion of about 40% dolomite and 60% limestone; porosity is 18%.

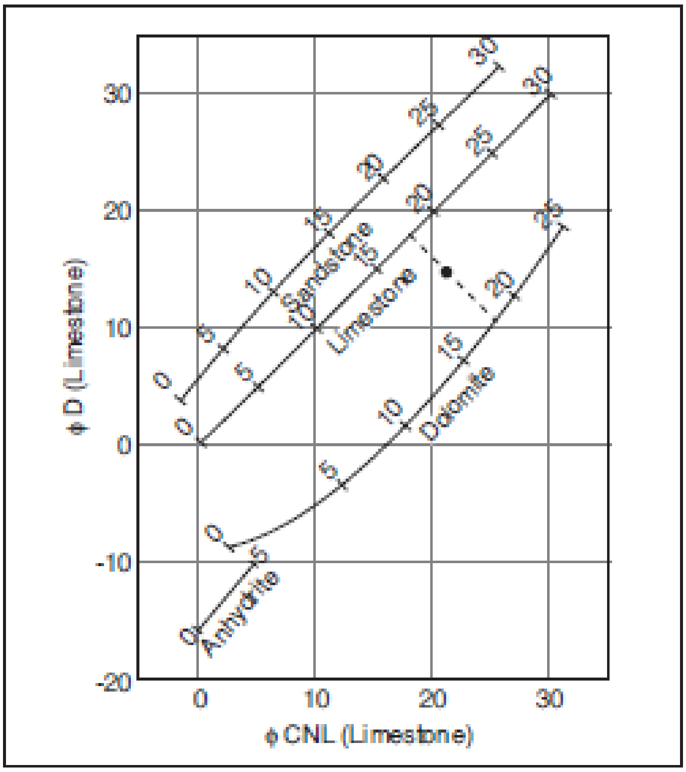


Fig 3.9 Porosity and lithology determination from FDC density and CNL neutron logs

An error in choosing the matrix pair does not result in large error in the porosity value found, as long as the choice is restricted to quartz (sandstone or chert), limestone, dolomite, and anhydrite; shaliness and gypsum are excluded. For instance, in the above example, if the lithology were sandstone and dolomite instead of limestone and dolomite, the porosity found would be 18.3%; the mineral proportions would, however, be about 40% sandstone and 60% dolomite.

In fact, the plotted Point P of figure 3.9 could correspond to various mixtures of sandstone, limestone, and dolomite. In all cases, the porosity would be in the 18% range. Thus, although the rock volumetric fractions estimated from the neutron-density data could be considerably in error, the porosity value will always be essentially correct if only sandstone, limestone, and/or dolomite are present. This feature of the neutron-density combination, coupled with its use as a gas-finder, has made it a very popular log combination.

3.9 Project planning

The table 3.4 presented below shows the Gantt chart for this project.

Table 3.4 Gantt chart

Phase		March				April				May			
	Week	1	2	3	4	5	6	7	8	9	10	11	12
Phase 1	Field data gathering for the single borehole well												
	Study the data given and understand the necessary well log interpretations												
Phase 2	Familiarizing the basic application and utilization of SPSS software												
	Classification of zones based on discriminant analysis												
	Improvements in classification based on discriminant analysis												
	Result validation												
Phase 3	Application of SPSS to determine the lithology of the unknown zone												
	Apply density porosity cross plot for result validation												
Phase 4	Estimate the petrophysical properties of the zone based on the given limited data.												
	Result finalization												

CHAPTER 4
RESULT AND DISCUSSION

4.1 Core data available

The core data available is described below along with the geological information for various members.

4.1.1 Kalhur Formation (2845.5-3077 m)

It consists of anhydrite, dolomite, limestone, claystone and minor marl in upper part and salt with trace of anhydrite, marl and limestone in middle part and massive anhydrite with two dolomite / limestone beds in lower part. The Operculina limestone and Basal Anhydrite makes up the lower most part of Kalhur Member. Based on cutting samples and wire line logging data, the Kalhur Member can be divided into 5 different sub members:

- **Upper Kalhur (2845.5-2888.5m)**

It consists of pale yellowish brown, light olive grey, olive grey and dark yellowish brown argillaceous limestone, pale yellowish brown, medium grey to medium dark grey dolomite, dark green grey to olive grey claystone and white-off white microcrystalline to crystalline anhydrite

- **Salt Sequence (2888.5-3001m)**

It's mainly comprised of coarse crystalline transparent-milky anhydritic salt with trace of anhydrite, limestone and marl. Good to week oil shows reported in some of limestone cutting chips in this sub member. A well defined repeated section of the Salt and Massive anhydrite sequence is seen in the well.

- **Massive Anhydrite (3001-3038m)**

This part of Kalhur Member is a thick anhydrite / gypsum layer with a few thin limestone / dolomite beds. Limestone with olive grey, brownish grey, medium dark grey colors are mainly argillaceous and anhydritic. Dark yellowish brown-brown grey dolomite generally is slight argillaceous and highly anhydritic.

- **Operculina Limestone (3038-3068.5m)**

It consists of dark green grey, med dark grey to pale brown marl alternating with limestone. Limestone with a color of buff, light grey and pale yellowish brown is fossiliferous and contain Operculina sp., Echinoid debris, Ostracods and globigerina sp. The fractured limestones are the origin of the high pressure water flow observed while drilling the 12 ½ " section.

- **Basal Anhydrite (3068.5-3077m)**

This part of sequence is entirely comprised of anhydrite and is a regional marker both in Western Iran and in Iraq.

4.1.2 Pabdeh Formation (3077-3514 m)

It comprises of dark green grey, medium dark grey and olive grey marl and marly limestone mostly with basinal pelagic fauna in upper part of the formation. Slightly silty to silty pale brown, dark yellowish brown and brown grey marl/claystone with rare disseminated micro pyrite, minor buff to yellowish grey limestone and dark green grey to dark grey shale at the middle of section. Toward the base carbonate percentage increases, carbonates are mostly yellowish grey, pale yellowish brown, buff to off white, moderate hard to hard, generally argillaceous, glauconitic, cherty and rarely pyritic limestone. Two distinctive moderate brown Marl layers recognized as key beds in upper part of Pabdeh Formation. This Formation can informally be divided into seven different members based on outcrop studies as follows:

- **Green marl member (3077-3210m)**

This member is upper most part of Pabdeh Formation and overlain by Asamri Formation (Basal Anhydrite). It mainly consists of dark green grey, green grey and olive grey marl that is generally slightly silty, in partly pyritic and locally highly calcareous grading to argillaceous limestone and light grey, medium light grey to pale yellowish brown limestone which is mainly chalky, argillaceous and contain pelagic facies. Two distinctive brown marl layers reported at 3107m and 3124m depth and could be consider as key marker beds. These key beds are about 37m and 54m below the top of the formation respectively.

- **Platy limestone member (3210-3260m)**

This member with very light grey, light grey to light olive grey color separates Brown bituminous member from Green marl member.

- **Brown bituminous shale and marl member (3260-3355.5m)**

It consists of pale brown, dark brown and dark yellowish brown marl which in partly contain disseminated micro pyrite and locally grading to claystone with trace of buff to light yellowish argillaceous limestone and dark grey to medium dark grey shale. Higher drilling gas values were observed when drilling this unit and may indicate some source rock potential.

- **Marly limestone member (3355.5-3385m)**

This member is mainly comprised of light olive grey, yellowish grey, light grey argillaceous limestone with trace of pale yellowish brown to yellowish grey marl. A two meters thick dark brown to brownish grey claystone with emerald glauconite laid in lower most part of member and can be consider as key bed in next wells.

- **Cherty limestone member (3385-3460m)**

Is mainly consists of light grey, pale yellowish brown and rarely off white moderate hard to hard limestone with chert nodules and minor dark yellowish brown to brownish grey marl and rare dark green grey shale. Toward the base of member, marl percentage increases and color changes to medium grey to greenish grey.

- **Grey marl and shale member (3460-3476m)**

Consists of glauconitic light grey, medium grey to greenish grey marl interbedded with thin bedded very light grey to off white argillaceous limestone. This member separates thin laminated Cherty limestone from Purple shale member.

- **Purple shale member (3476-3514m)**

This unit is lower most member of Pabdeh Formation that separates Pabdeh Formation from underlying

4.2 Basic data table

The well log data for the depth 2962 meters to 3554 meters which is available on LAS format is viewed in LAS viewer. In this study, the data set comprises of a suite of logs including Gamma ray, deep resistivity and density neutron porosity logs. The two formations namely Kalhur and Pabdeh have 4 and 7 different members respectively at different depths as per the data from the core analysis. They are numbered as shown below in table 4.1.

Table 4.1 Member based classification table.

Depth	Member No	Members description	Formation
(2888.5-3001m)	**2**	Salt Sequence	Kalhur Formation
(3001-3038m)	**3**	Massive Anhydrite	Kalhur Formation
(3038-3068.5m)	**4**	Operculina Limestone	Kalhur Formation
(3068.5-3077m)	**5**	Basal Anhydrite	Kalhur Formation
(3077-3210m)	**6**	Green marl member	Pabdeh Formation
(3210-3260m)	**7**	Platy limestone member	Pabdeh Formation
(3260-3355.5m)	**8**	Brown bituminous shale and marl member	Pabdeh Formation
(3355.5-3385m)	**9**	Marly limestone member	Pabdeh Formation
(3385-3460m)	**10**	Cherty limestone member	Pabdeh Formation
(3460-3476m)	**11**	Grey marl and shale member	Pabdeh Formation
(3476-3514m)	**12**	Purple shale member	Pabdeh Formation

4.3 Training data set classification for Kalhur formation

Table 4.2 Training data set classification result Kalhur formation.

			member				
			salt sequence	Massive Anhydrite	Operculina Limestone	Basal Anhydrite	total
Original	Count	Salt Sequence	249		6		255
		Massive Anhydrite	39	200	3	1	243
		Operculina Limestone			200		200
		Basal Anhydrite		35	2	20	57
	%	Salt Sequence	97.6	.0	2.4	.0	100.0
		Massive Anhydrite	16.0	82.3	1.2	.4	100.0
		Operculina Limestone	.0	.0	100.0	.0	100.0
		Basal Anhydrite	.0	61.4	3.5	35.1	100.0
Cross-validateda	Count	Salt Sequence	249		6		255
		Massive Anhydrite	39	200	3	1	243
		Operculina Limestone			200		200
		Basal Anhydrite		35	2	20	57
	%	Salt Sequence	97.6	.0	2.4	.0	100.0
		Massive Anhydrite	16.0	82.3	1.2	.4	100.0
		Operculina Limestone	.0	.0	100.0	.0	100.0
		Basal Anhydrite	.0	61.4	3.5	35.1	100.0

RESULTS

a. Table 4.2 shows 88.6% of original grouped cases correctly classified.
b. Table 4.2 shows 88.6% of cross-validated grouped cases correctly classified.

4.3.1 Canonical distribution for the member in Kalhur formation

Fig 4.1 represents the canonical discriminant functions for the member together in Kalhur formation

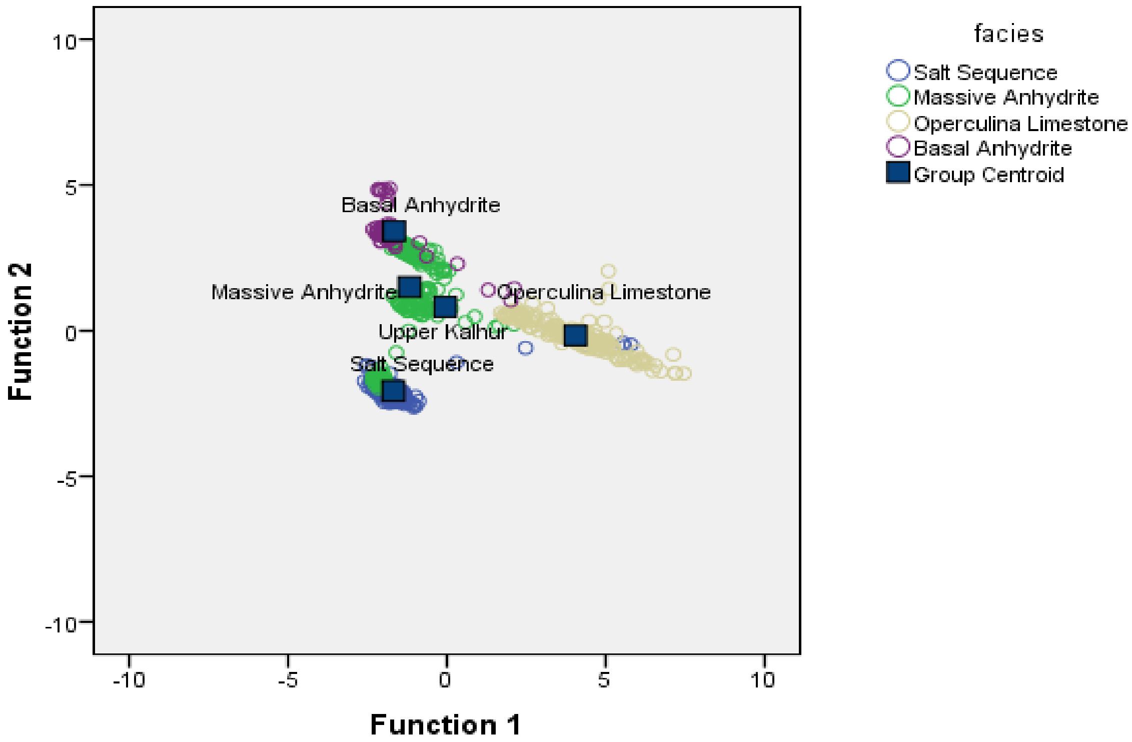


Fig 4.1 Canonical distribution plot for the member of Kalhur formation

4.4 Testing data set classification for Kalhur formation

Table 4.3 Testing data set classification result second stage Kalhur formation

		MEMBER	Predicted Group Membership			
			Salt Sequence	Massive Anhydrite	Operculina Limestone	Total
Original	Count	Salt Sequence	249		6	255
		Massive Anhydrite	39	256	5	300
		Operculina Limestone			200	200
	%	Salt Sequence	97.6	.0	2.4	100.0
		Massive Anhydrite	13.0	85.3	1.7	100.0
		Operculina Limestone	.0	.0	100.0	100.0
Cross-Validated[a]	Count	Salt Sequence	249		6	255
		Massive Anhydrite	39	256	5	300
		Operculina Limestone			200	200
	%	Salt Sequence	97.6	.0	2.4	100.0
		Massive Anhydrite	13.0	85.3	1.7	100.0
		Operculina Limestone	.0	.0	100.0	100.0

RESULTS

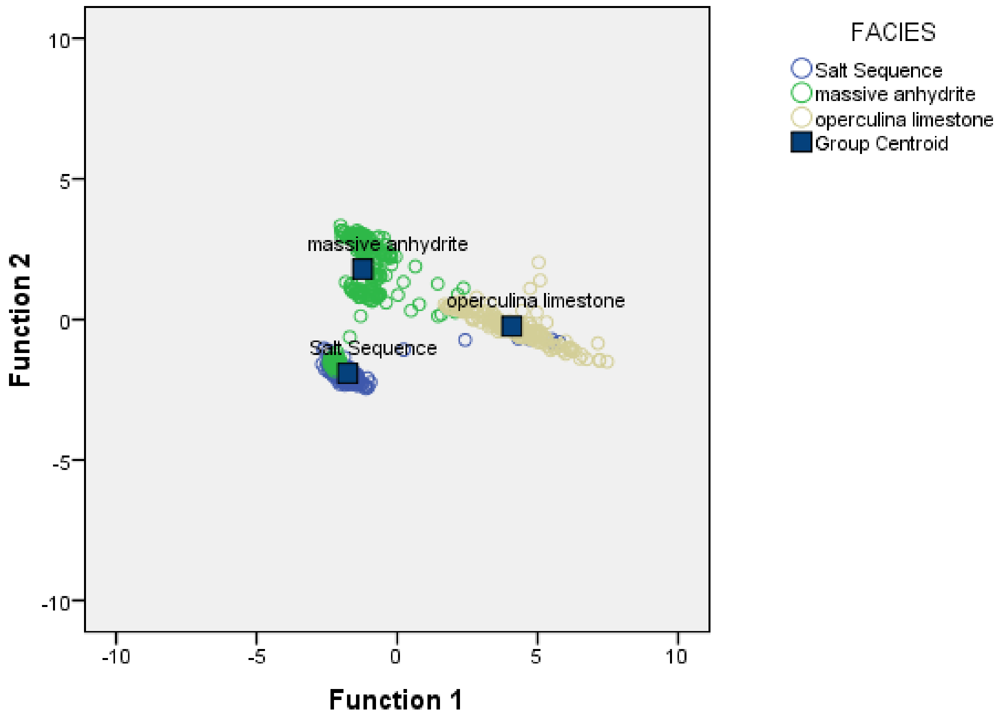
a. Table 4.3 shows 93.4% of original grouped cases correctly classified.

b. Table 4.3 shows 93.4% of cross-validated grouped cases correctly classified

4.4.1 Canonical distribution for the member in Kalhur formation

The Fig 4.2 represents the canonical discriminant functions for total member after second stage classification.

Fig 4.2 Canonical distribution plot for member of Kalhur formation



4.5 Training data set classification for Pabdeh formation

Table 4.4 Training data set classification for Pabdeh formation

		Member	Predicted Group Membership							
			GMM	PLM	BBS &MM	MLS M	CLMM	GMSM	PSM	Total
Original	COUNT	Green marl member	779	49	4	21	17	1		871
		Platy limestone member	80	233		15			1	329
		Brown bituminous shale and marl member	3	3	614	6				626
		Marly limestone member	12	47	21	112	2			194
		Cherty limestone member	5	36	32	72	335	3	9	492
		Grey marl and shale member					12	11	82	105
		Purple shale member	29	3			4	1	213	250
	%	Green marl member	89.4	5.6	.5	2.4	2.0	.1	.0	100.0
		Platy limestone member	24.3	70.8	.0	4.6	.0	.0	.3	100.0
		Brown bituminous shale and marl member	.5	.5	98.1	1.0	.0	.0	.0	100.0
		Marly limestone member	6.2	24.2	10.8	57.7	1.0	.0	.0	100.0
		Cherty limestone member	1.0	7.3	6.5	14.6	68.1	.6	1.8	100.0
		Grey marl and shale member	.0	.0	.0	.0	11.4	10.5	78.1	100.0
		Purple shale member	11.6	1.2	.0	.0	1.6	.4	85.2	100.0

RESULTS

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.
b. Table 4.4 shows 78.1% of original grouped cases correctly classified.

4.5.1 Canonical distribution for the member in Pabdeh formation

The Fig 4.3 represents the canonical discriminant functions for all the member together in Pabdeh Formation

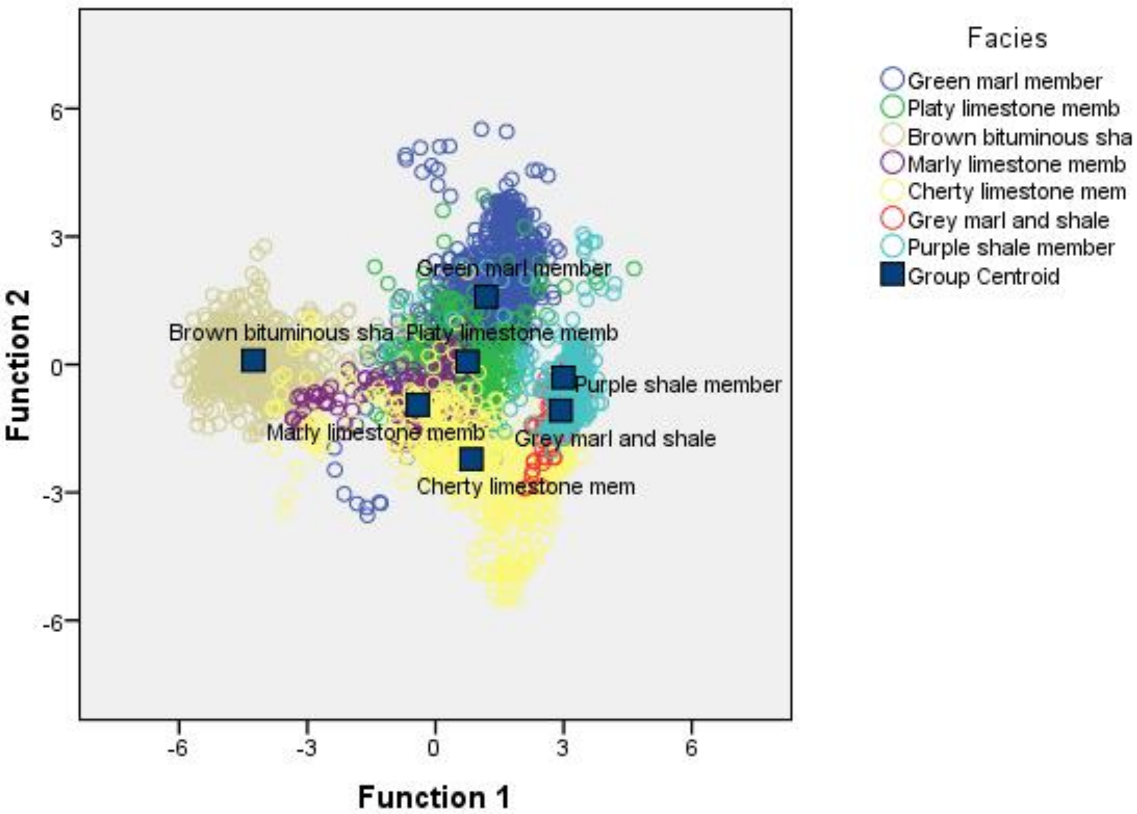


Fig 4.3 Canonical distribution plot for member of Pabdeh formation

4.6 Testing data set classification for Pabdeh formation

Table 4.5 Testing data set classification for Pabdeh formation

		MEMBER	Predicted Group Membership: Green Marl Member	Platy Limestone Member	Brown Bituminous Shale& Marl Member	Marly Limestone	Cherty Limestone	Grey Marl And Shale Member	Total
Original	Count	Green Marl Member	778	50	4	21	18		871
		Platy Limestone Member	80	233		15		1	329
		Brown Bituminous Shale& Marl Member	3	3	614	6			626
		Marly Limestone	12	50	21	109	2		194
		Cherty Limestone	6	36	32	72	324	22	492
		Grey Marl And Shale Member	27	3			13	312	355
	%	Green Marl Member	89.3	5.7	.5	2.4	2.1	.0	100.0
		Platy Limestone Member	24.3	70.8	.0	4.6	.0	.3	100.0
		Brown Bituminous Shale& Marl Member	.5	.5	98.1	1.0	.0	.0	100.0
		Marly Limestone	6.2	25.8	10.8	56.2	1.0	.0	100.0
		Cherty Limestone	1.2	7.3	6.5	14.6	65.9	4.5	100.0
		Grey Marl And Shale Member	7.6	.8	.0	.0	3.7	87.9	100.0

RESULTS

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.
b. Table 4.5 shows 82.7% of original grouped cases correctly classified.

4.6.1 Canonical distribution for the member in Pabdeh formation

The Fig 4.4 represents the canonical discriminant functions for all member after second stage classification in Pabdeh Formation

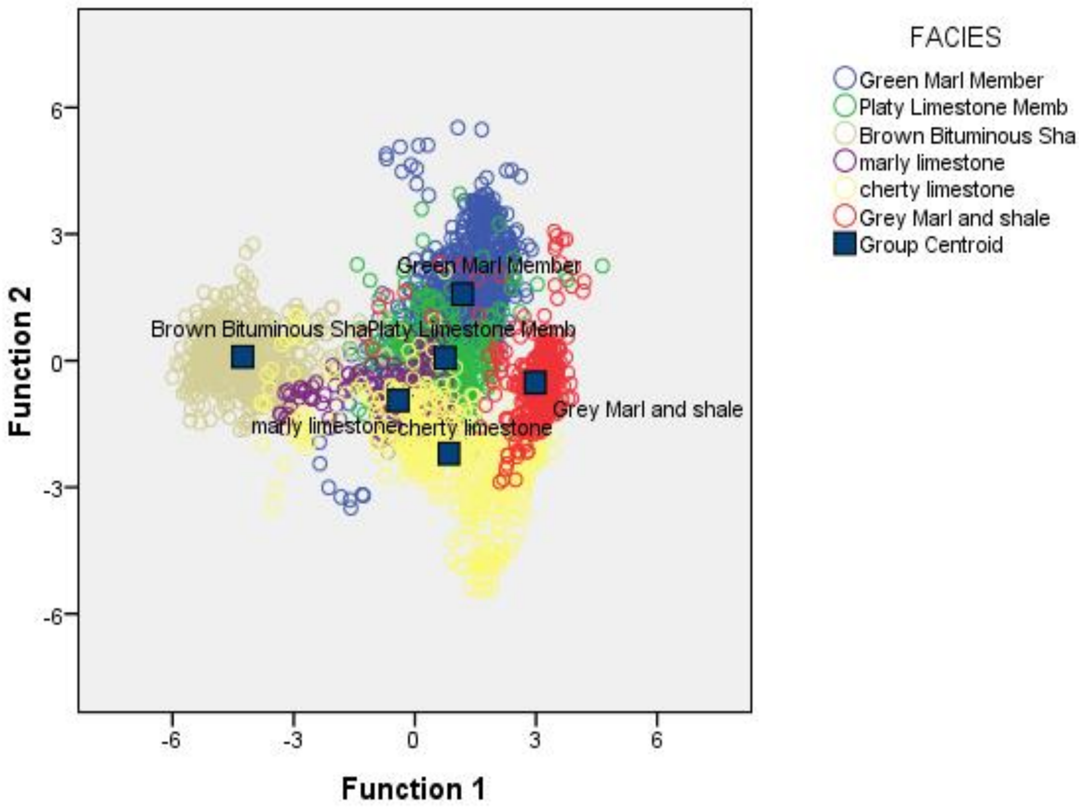


Fig 4.4 Canonical distribution plot for member of Pabdeh formation

4.7 Result presentation and analysis for Unknown formation

Table 4.6 Classification result (Unknown formation)

		MEMBER	Predicted Group Membership									
			SS	MA	OLS	GMM	PLSM	BBS&SM	MLSM	CLSM	GM& PSM	Total
Original	Count	SS	248					6	1			255
		MA	39	238					2	19	2	300
		OLS			1	148	18	8	23	1	1	200
		GMM			4	778	54	9	20	4	2	871
		PLSM				103	86	4	4	121	11	329
		BBS&SM				5	2	618	1			626
		MLSM				19	26	32	26	90	1	194
		CLSM				5	22	25	26	373	41	492
		GM&PSM				38	4			85	228	355
		Ungrouped cases	31	214					2	16	2	265
	%	SS	97.3	0	0	0	0	2.4	0.4	0	0	100
		MA	13	79.3	0	0	0	0	0.7	6.3	0.7	100
		OLS	0	0	0.5	74	9	4	11.5	0.5	0.5	100
		GMM	0	0	0.5	89.3	6.2	1	2.3	0.5	0.2	100
		PLSM	0	0	0	31.3	26.1	1.2	1.2	36.8	3.3	100
		BBS&SM	0	0	0	0.8	0.3	98.7	0.2	0	0	100
		MLSM	0	0	0	9.8	13.4	16.5	13.4	46.4	0.5	100
		CLSM	0	0	0	1	4.5	5.1	5.3	75.8	8.3	100
		GM&PSM	0	0	0	10.7	1.1	0	0	23.9	64.2	100
		Ungrouped cases	11.7	80.8	0	0	0	0	0.8	6	0.8	100

RESULTS

a. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

b. Table 4.6 shows **72.1** % of original grouped cases correctly classified.

4.7.1 Canonical distribution for the memberS in total formation

The Fig 4.5 represents the canonical discriminant functions for all member in both formation after the classification of unknown formation

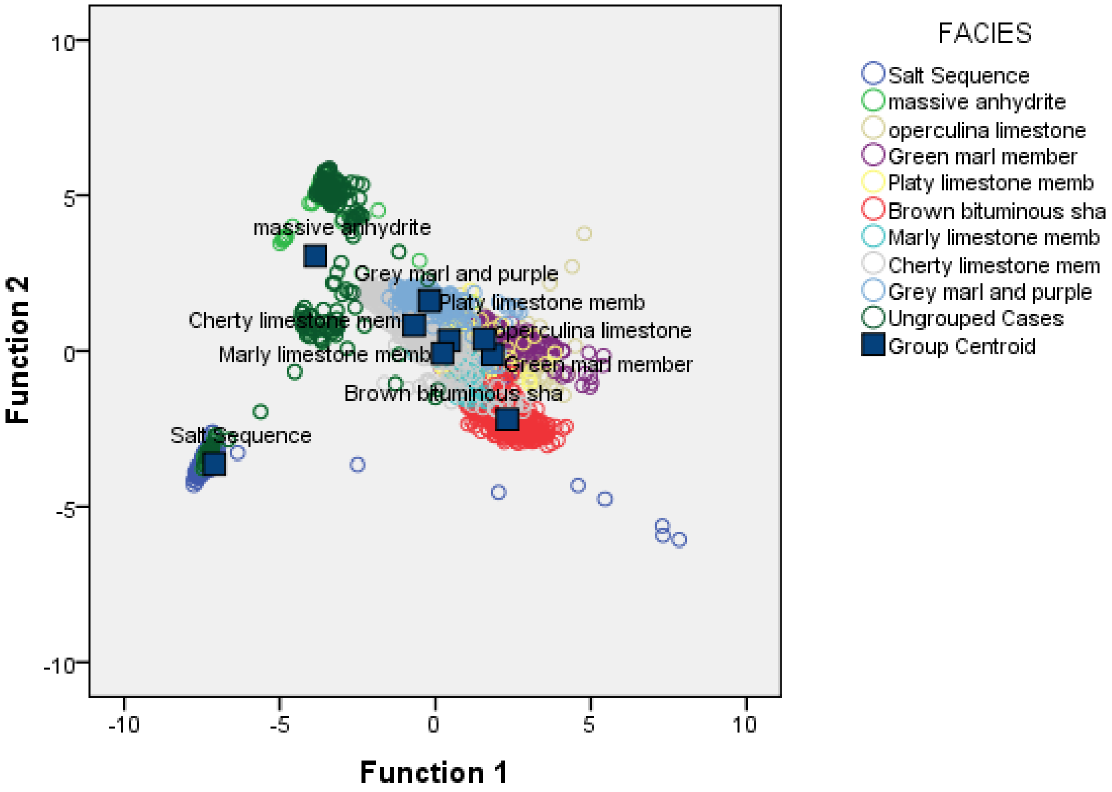


Fig 4.5 Canonical distribution plot for the area under study

4.8 Lithology validation using density neutron cross plot.

Accurate lithlogy determination is more difficult when the matrix lithology is unknown or consists of two or more minerals in unknown proportions. Cross plots are a convenient way to demonstrate how various combinations of logs respond to lithology and porosity. They also provide visual insight into the type of mixtures that the combination is most useful in unravelling.

The porosity values are for various depths for the unknown zone are plotted on the cross plot chart and are seen to lie within the vicinity of anhydrite.

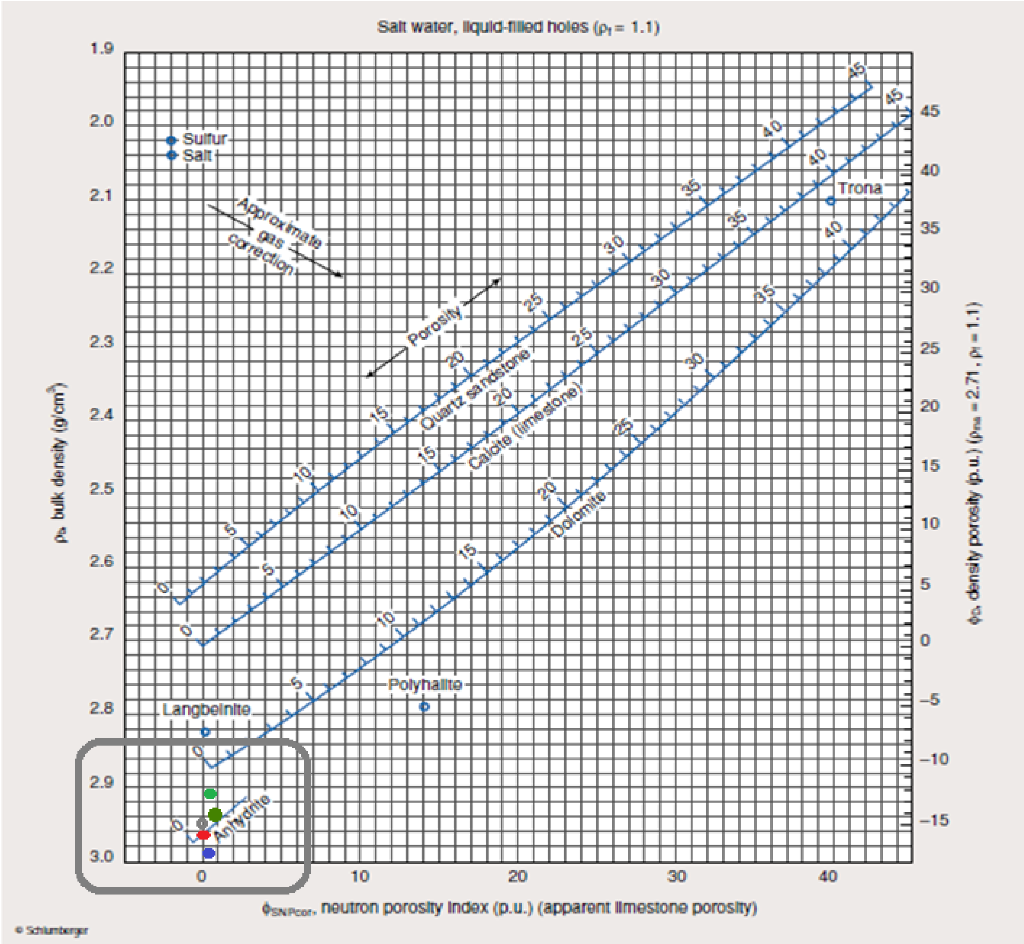


Fig 4.6 cross plot

4.9 Petrophysical properties of the unknown formation.

4.9.1 Porosity

The porosity can be determined using the formula

$$(\rho_{ma} - \rho_b) / (\rho_{ma} - \rho_f) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where ρ_{ma} is the matrix density for anhydrite (2.98)

ρ_b is the bulk density (from log data)

ρ_f is the fluid density (Fluid density is 1.1 as it is assumed to be saline)

The porosity from the neutron and densities are averaged and the unknown formation is separated into 4 zones based on the porosity values calculated (Table 4.7) using equation 4.

Table 4.7 Porosity estimation for the unknown zone

Depth	Porosity Averaged
3514.1916 to 3521.202	0.68
3521.3544 to 3535.2228	21.68
3535.3752 to 3537.6612	4.84
3537.8136 to 3554.4252	1.357

4.9.2 Permeability

The permeability can be estimated by taking the core data available for depth **Massive Anhydrite (3001-3038m)** as the unknown lower shows much similarity and is grouped with the anhydrite formation when classification was performed. The figure 4.7 shows the relationship of poro perm from the core data given.

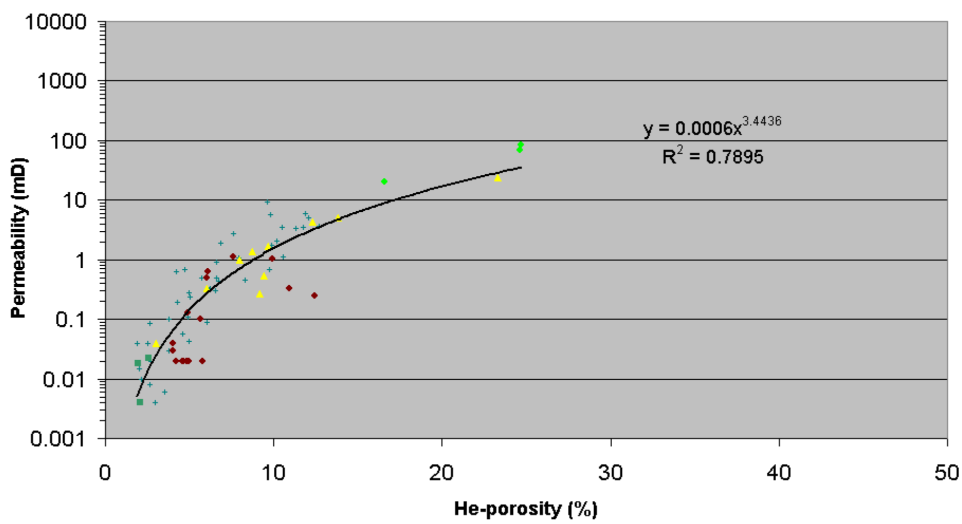


Fig 4.7 Permeablility v/s porosity for Massive Anhydrite

Carbonates can exhibit highly varying properties (e.g., porosity, permeability, flow mechanisms) within small sections of the reservoir, making them difficult to characterize. A focused approach is needed to better understand the heterogeneous nature of the rock containing the fluids and the flow properties within the porous and often fractured formations. This involves detailed understanding of the fluids saturation, pore-size distribution, permeability, rock texture, reservoir rock type, and natural fracture systems at different scales.

Fracture corridors often exist that range from tens to hundreds of meters in width and height and have areal extents in the order of kilometres, representing primary pathways for hydrocarbon migration. Such fracture corridors can have a permeability of a thousand times greater or more than the surrounding rock matrix and have a considerable impact on oil, gas, and water production, including issues related to the drilling process. The permeability can be estimated by using the equation $y=0.0006x^{3.4436}$ which is obtained from figure 4.7 the values of permeability are estimated as follows as shown in table 4.8.

Table 4.8 Permeability estimation for the unknown zone

Depth	**Porosity Averaged (%)**	**Permeability (Md)**
3514.1916 to 3521.202	0.68	1.58E-04
3521.3544 to 3535.2228	21.68	23.933
3535.3752 to 3537.6612	4.84	0.136
3537.8136 to 3554.4252	1.357	1.71E-03

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In the member recognition process, discriminant analysis proved to be a very effective technique. The best results were achieved when discriminant analysis was applied to the data when the classification results proved that some members can be clubbed. This made it easy to understand the lithology of the unknown formation confirming 80% classified as Anhydrite. The unclassified 20% is due to the complex mineralogy which exist within the formation. There can be possibility that the unknown formation may contain interbedded traces of limestone, gypsum or dolomite which may make it hard to estimate porosity for the formation. Also for in the same case only 72.1 % of original grouped cases are classified correctly. This can be due to the fact that the discrimination among the different limestone members in successive members are weak and thus produces weaker classification.

In this case study, the time consumption is low and the extracted knowledge can be integrated with other prediction techniques in order to build a more intelligent and reliable data interpretation model. It can be suggested that the incorporation of other techniques, such as neural networks, may improve the quality of the lithology determination process. But in this particular case where there is limited data available, discriminant analysis can be applied to member in non-cored wells of the area under study. The immediate application is found in formation evaluation where distinct models, parameters, to estimate porosities and if similar members are available from cores, can also help to estimate permeability. Better discrimination results can be obtained with the availability of data such as pressure for each member.

The improved data, obtained through the methods described above, allowed better facies maps to be constructed and the stratigraphic sections to be prepared automatically. These can be effective tools in planning the development and production strategy of the field under study. They can equally well be employed in exploratory studies to aid in the characterization of depositional systems and environments.

References

1. Darwin V. Ellis, Julian M. Well Logging for Earth Scientists ,edited by Singer
2. Chikhi S, Batouche M, Shout H (2005). Hybrid Neural Network Methods for Lithology Identification in the Algerian Sahara. Int. J. Comput. Intell, 1: 6 - 12.
3. Chang HC, Kopaska - Merkel DC, Chen HC (2002). Identification of lithofacies using Kohonen self organizing maps. Comput. Geosci. 28: 223-229
4. Milliman, J. D., 1974, Marine Carbonates. Part1, Recent Sedimentary Carbonates: New York, Springer-Verlag, 375 p.
5. Lees, A, 1975, possible influence of salinity and temperature on modem shelf carbonate sedimentation: Marine Geology, v. 19, p. 159-198.
6. Philip W. Choquette and Lloyd C. Pray Geologic nomenclature and classification of porosity in sedimentary carbonates. The American Association of Petroleum Geologists Bulletin V. 54, No. 2 {February, 1970), P. 207-250,
7. Lucia, F. J., 1995, Chapter 14, Lower Paleozoic cavern development, collapse, and dolomitization, Franklin Mountains, El Paso, Texas, in Budd, D. A., Saller, A. H., and Harris, P. M., eds., Unconformities and porosity in carbonate strata: American Association of Petroleum Geologists, AAPG Memoir 63, p. 279–300.
8. Lucia, F. J., and Conti, R. D., 1987, Rock fabric, permeability, and log relationships in an upward-shoaling, vuggy carbonate sequence: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 87-5, 22 p.
9. Harari Z,Wang St,Saner S.1995 , Pore compressibility study of arabain carbonate reservoir rocks,SPE Num 27625
10. Davis, J.C. Statistics and Data Analysis in Geology. John Wiley & Sons, New York, 1986
11. Wong, P. M., Taggart, I. J. and Jian, F. X. A Critical Comparison of Neural Networks and Discriminant Analysis in Lithofacies, Porosity, and Permeability Predictions, Journal of Petroleum Geology, vol. 18(2), April (1995), pp. 191-206.

12. Condert, L., Frappa, M. and Arias, R. A Statistical Method for Lithofacies Identification, Journal of Applied Geophysics, vol 32, (1994), pp. 257-267.
13. Fung, C. C., Wong, K. W. Eren, H. and Charlebois, Lithology Classification using Self-Organising Map,. Proceedings of IEEE International Conference on Neural Networks, Perth, Western Australia, December (1995), pp. 526-531.
14. Wong, P.M., Gedeon, T.D, and Taggart, I.J.: Fuzzy ARTMAP: A New Tool for Lithofacies Recognition. AI Applications, Vol. 10, No. 2 (1996), pp. 29-39.
15. Rogers, S. J., Fang, J. H., Karr, C. L. and Stanley, D.A. .Determination of Lithology from Well Logs Using a Neural Network,The AAPG Bulletin, vol. 76(5), (1992), pp. 731-739.

APPENDIX

Appendix A

Discriminant analysis statistics options.

Descriptives. Available options are means (including standard deviations), univariate ANOVAs, and Box's M test.

- **Means**. Displays total and group means, as well as standard deviations for the independent variables.
- **Univariate ANOVAs**. Performs a one-way analysis-of-variance test for equality of group means for each independent variable.
- **Box's M**. A test for the equality of the group covariance matrices. For sufficiently large samples, a nonsignificant p value means there is insufficient evidence that the matrices differ. The test is sensitive to departures from multivariate normality.

Function Coefficients. Available options are Fisher's classification coefficients and unstandardized coefficients.

- **Fisher's**. Displays Fisher's classification function coefficients that can be used directly for classification. A separate set of classification function coefficients is obtained for each group, and a case is assigned to the group for which it has the largest discriminant score (classification function value).
- **Unstandardized.** Displays the unstandardized discriminant function coefficients.

Matrices. Available matrices of coefficients for independent variables are within-groups correlation matrix, within-groups covariance matrix, separate-groups covariance matrix, and total covariance matrix.

- **Within-groups correlation**. Displays a pooled within-groups correlation matrix that is obtained by averaging the separate covariance matrices for all groups before computing the correlations.
- **Within-groups covariance**. Displays a pooled within-groups covariance matrix, which may differ from the total covariance matrix. The matrix is obtained by averaging the separate covariance matrices for all groups.

- **Separate-groups covariance**. Displays separate covariance matrices for each group.
- **Total covariance**. Displays a covariance matrix from all cases as if they were from a single sample.

Discriminant analysis classification option

Prior Probabilities. This option determines whether the classification coefficients are adjusted for a priori knowledge of group membership.

- **All groups equal**. Equal prior probabilities are assumed for all groups; this has no effect on the coefficients.
- **Compute from group sizes**. The observed group sizes in the sample is used to determine the prior probabilities of group membership. For example, if 50% of the observations included in the analysis fall into the first group, 25% in the second, and 25% in the third, the classification coefficients are adjusted to increase the likelihood of membership in the first group relative to the other two.

Display. Available display options are case wise results, summary table, and leave-one-out classification.

- **Casewise results**. Codes for actual group, predicted group, posterior probabilities, and discriminant scores are displayed for each case.
- **Summary table**. The number of cases correctly and incorrectly assigned to each of the groups based on the discriminant analysis. Sometimes called the "Confusion Matrix."
- **Leave-one-out classification**. Each case in the analysis is classified by the functions derived from all cases other than that case. It is also known as the "U-method."

Replace missing values with mean. Select this option to substitute the mean of an independent variable for a missing value during the classification phase only.

Use Covariance Matrix. Can be chosen to classify cases using a within-groups covariance matrix or a separate-groups covariance matrix.

- **Within-groups**. The pooled within-groups covariance matrix is used to classify cases.

- **Separate-groups**. Separate-groups covariance matrices are used for classification. Because classification is based on the discriminant functions (not based on the original variables), this option is not always equivalent to quadratic discrimination.

Plots. Available plot options are combined-groups, separate-groups, and territorial map.

- **Combined-groups**. Creates an all-groups scatterplot of the first two discriminant function values. If there is only one function, a histogram is displayed instead.
- **Separate-groups**. Creates separate-group scatterplots of the first two discriminant function values. If there is only one function, histograms are displayed instead.
- **Territorial map**. A plot of the boundaries used to classify cases into groups based on function values. The numbers correspond to groups into which cases are classified. The mean for each group is indicated by an asterisk within its boundaries. The map is not displayed if there is only one discriminant function.

Appendix B

Porosity permeability calculation

Depth	Porosity%	Permeabilty (Md)
3514.192	17.5813	11.63078
3514.344	12.482	3.575324
3514.496	6.1837	0.318342
3514.649	0.5329	6.87E-05
3515.106	0.6815	0.00016
3515.258	1.0051	0.000611
3515.411	0.2804	7.53E-06
3515.868	0.3301	1.32E-05
3516.63	0.2139	2.96E-06
3516.782	1.0378	0.000682
3516.935	1.7221	0.0039
3517.087	0.9961	0.000592
3517.24	0.1589	1.06E-06
3519.221	0.4627	4.22E-05
3519.373	0.4093	2.77E-05
3519.526	0.5929	9.92E-05
3519.678	0.1132	3.31E-07
3519.83	0.481	4.83E-05
3519.983	0.5985	0.000102
3520.135	0.956	0.000514
3520.288	0.6061	0.000107
3520.44	0.7012	0.000177
3520.592	0.4877	5.06E-05
3520.745	0.7995	0.000278
3520.897	0.5241	6.49E-05
3521.05	0.4305	3.29E-05
3521.202	0.5477	7.55E-05
3521.354	27.3413	53.20859
3521.507	26.6329	48.60962
3521.659	26.8414	49.93266
3521.812	27.7632	56.08967
3521.964	28.0067	57.80195
3522.116	29.0506	65.56502
3522.269	29.4291	68.55382
3522.421	29.0326	65.42523
3522.574	28.0512	58.11883

.....CONT

3522.726	29.0641	65.67
3522.878	29.7748	71.36695
3523.031	30.2029	74.96297
3523.183	29.4713	68.89293
3523.336	28.7811	63.49411
3523.488	28.7544	63.2915
3523.64	28.2102	59.26113
3523.793	27.9068	57.09504
3523.945	28.1812	59.05161
3524.098	28.2962	59.88557
3524.25	28.1396	58.75197
3524.402	27.9007	57.05207
3524.555	28.1852	59.08048
3524.707	28.9503	64.78877
3524.86	28.9144	64.51253
3525.012	28.64	62.42859
3525.164	27.7544	56.02847
3525.317	28.017	57.87518
3525.469	28.6847	62.76476
3525.622	28.604	62.15878
3525.774	27.8993	57.04221
3525.926	25.9652	44.54002
3526.079	22.6087	27.65252
3526.231	18.9448	15.04236
3526.384	17.5252	11.50348
3526.536	16.1748	8.727884
3526.688	14.873	6.53767
3526.841	15.2338	7.100186
3526.993	15.4967	7.531111
3527.146	16.6399	9.622897
3527.298	17.2027	10.79075
3527.45	16.9904	10.33904
3527.603	16.8236	9.993686
3527.755	16.1766	8.731229
3527.908	16.2465	8.861837
3528.06	16.9959	10.35057
3528.212	16.2893	8.942489
3528.365	16.2406	8.850759
3528.517	16.2078	8.789356
3528.67	17.047	10.45813
3528.822	18.1072	12.87324
3528.974	17.9013	12.37612

.....CONT

3529.127	18.5337	13.9478
3529.279	17.8343	12.21734
3529.432	17.9206	12.42213
3529.584	17.7488	12.01682
3529.736	19.3664	16.2268
3529.889	19.5566	16.78221
3530.041	22.3943	26.75991
3530.194	29.3548	67.95964
3530.346	33.1846	103.6689
3530.498	32.2803	94.26026
3530.651	25.8003	43.57348
3530.803	20.3321	19.18702
3530.956	17.4959	11.43738
3531.108	15.5187	7.567992
3531.26	15.2891	7.189337
3531.413	14.7648	6.375339
3531.565	15.1181	6.916205
3531.718	16.9097	10.17092
3531.87	17.9856	12.57798
3532.022	18.7738	14.57993
3532.175	18.7794	14.59492
3532.327	19.2526	15.9008
3532.48	20.0533	18.2961
3532.632	19.1771	15.6871
3532.784	19.1943	15.7356
3532.937	18.8878	14.88708
3533.089	18.6359	14.21444
3533.242	18.5926	14.10103
3533.394	18.1344	12.93996
3533.546	17.9083	12.39279
3533.699	18.8214	14.70763
3533.851	19.029	15.27383
3534.004	20.2515	18.92637
3534.156	19.962	18.01084
3534.308	19.7432	17.34008
3534.461	18.4117	13.63417
3534.613	16.0983	8.586554
3534.766	13.2305	4.369294
3534.918	13.3116	4.462216
3535.07	12.0633	3.178982
3535.223	10.9707	2.292462
3535.375	8.1748	0.832449

.....CONT

3535.528	7.5038	0.619826
3535.68	6.6384	0.406452
3535.832	5.8466	0.262458
3535.985	5.7431	0.246801
3536.137	5.7226	0.243781
3536.29	5.8618	0.264815
3536.442	5.5195	0.215257
3536.594	5.9436	0.277759
3536.747	5.9189	0.273804
3536.899	5.0332	0.156683
3537.052	3.6885	0.053722
3537.204	2.0867	0.007555
3537.356	1.6269	0.003206
3537.509	1.2061	0.001144
3537.661	1.0156	0.000633
3537.814	0.7204	0.000194
3537.966	0.4634	4.24E-05
3538.118	0.2921	8.66E-06
3538.423	0.7715	0.000246
3538.576	1.5457	0.002688
3538.728	1.7294	0.003957
3538.88	1.4363	0.002088
3539.033	1.7693	0.00428
3539.185	2.8732	0.022729
3539.338	2.9905	0.026087
3539.49	2.6936	0.018199
3539.642	2.2157	0.009289
3539.795	2.1846	0.008847
3539.947	1.9301	0.005775
3540.1	1.7159	0.003852
3540.252	1.5328	0.002611
3540.404	1.3219	0.001569
3540.557	0.5044	5.68E-05
3540.709	0.4266	3.19E-05
3540.862	0.7768	0.000251
3541.014	1.6635	0.003462
3541.166	1.5977	0.003012
3541.319	1.948	0.005962
3541.471	2.4518	0.013164
3541.624	3.0615	0.028282
3541.776	2.665	0.017542
3541.928	1.8562	0.005049

.....CONT

3542.081	0.7391	0.000212
3542.233	0.7629	0.000236
3542.386	0.5319	6.82E-05
3542.538	0.6472	0.000134
3542.69	0.046	1.49E-08
3542.843	0.1938	2.11E-06
3542.995	0.2285	3.72E-06
3543.148	0.2229	3.41E-06
3543.3	0.4129	2.85E-05
3543.452	0.6984	0.000174
3543.605	1.2278	0.001216
3543.757	1.0504	0.000711
3543.91	0.7264	0.0002
3544.062	0.9712	0.000543
3544.214	1.053	0.000717
3544.367	1.2752	0.001386
3544.519	1.2065	0.001145
3544.672	1.6091	0.003087
3544.824	1.109	0.000857
3544.976	0.7137	0.000188
3545.129	0.4382	3.5E-05
3545.281	0.675	0.000155
3545.434	1.0641	0.000743
3545.586	1.0419	0.000691
3545.738	1.8679	0.005159
3545.891	2.6678	0.017606
3546.043	5.4871	0.210937
3546.196	6.2343	0.327403
3546.348	5.6516	0.233523
3546.5	3.3291	0.037743
3546.653	1.9452	0.005932
3546.805	1.6573	0.003417
3546.958	1.1653	0.001016
3547.11	1.2989	0.001477
3547.262	1.1433	0.000952
3547.415	1.2061	0.001144
3547.567	1.1635	0.001011
3547.72	1.1269	0.000905
3547.872	1.0236	0.00065
3548.024	0.8538	0.000348
3548.177	0.9647	0.00053
3548.329	1.2888	0.001437

.....CONT

3548.482	1.7406	0.004046
3548.634	2.167	0.008604
3548.786	2.1788	0.008767
3548.939	2.1036	0.007768
3549.091	1.5602	0.002776
3549.244	1.4735	0.00228
3549.396	1.1978	0.001117
3549.548	1.4588	0.002202
3549.701	0.8061	0.000286
3549.853	0.5105	5.92E-05
3550.006	0.4553	3.99E-05
3550.158	0.5011	5.56E-05
3550.31	0.2173	3.13E-06
3550.615	0.0747	7.91E-08
3550.768	0.2724	6.81E-06
3550.92	0.6993	0.000175
3551.072	1.0936	0.000817
3551.225	0.8849	0.000394
3551.377	0.4345	3.4E-05
3551.53	0.6379	0.000128
3551.682	0.6271	0.00012
3551.834	0.4004	2.57E-05
3551.987	0.412	2.83E-05
3552.139	0.7971	0.000275
3552.292	1.1906	0.001094
3552.444	0.838	0.000326
3552.596	0.5602	8.16E-05
3552.749	0.752	0.000225
3552.901	0.4383	3.5E-05
3553.054	0.4854	4.98E-05
3553.206	0.4066	2.71E-05
3553.358	0.8657	0.000365
3553.511	1.1166	0.000877
3553.663	1.3618	0.001738
3553.816	1.5091	0.002475
3553.968	2.3528	0.011422
3554.12	2.7912	0.020572
3554.273	3.4964	0.044685
3554.425	3.367	0.039243