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SOME PETROPHYSICAL CHARACTERISTICS OF THE MIOCENE CARBONATE RESRVOIR IN ZEIT BAY OIL FIELD, GULF OF SUEZ, EGYPT

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بعض الخصائص البتروفيزيائية لخزان الكربونات الميوسينى بحقل خليج الزيت– خليج السويس– مصر

الخلاصة: يعتبر خزان الكربونات (سحنة كريم – روديس) من عصر الميوسين المبكر هو الخزان الرئيسى فى المنحدر الغربى لحقل خليج الزيت لإحتوائه على ٥٠% من المخزون الأصلى. وقد ترسبت هذه الكربونات وتطورت على كتل الصدوع المتدرجة الناشئة من الشد الخارجى والتى تقع على الحافة الغربية للخسف. وتهدف هذه الدراسة إلى وصف خواص خزان الكربونات الميوسينى إعتماداً على تحليل العينات الإسطوانية و المشاهدات البتروجرافية و كذلك بعض الحسابات البتروفيزيائية.

و قد تبين من الدراسات البتروفيزيائية و البتروجرافية، التى تمت باستخدام المعلومات المتاحة من التسجيلات الكهربائية و العينات الأسطوانية أن خزان الكربونات يمكن أن ينقسم إلى عدة نطق حيث يمثل الجزء العلوى طبقة الحجر الجيرى و التى تشكلت على هيئة طبقة منفصلة على المنحدر الغربي. و تلى طبقة الحجر الجيرى طبقة الدولوميت الناشئة عن عملية الإحلال الكيميائية لطبقة الحجر الجيرى. و تنقسم طبقة الدولوميت إلى نطاقين، حيث يتميز النطاق العلوى بوجود طبقة الأنهيدريت ذات الإشعاع القليل من أشعة جاما. ويتميز النطاق السفلى يتميز بوجود أشعة جاما بكمية عالية ناتجة عن تغلغل اليورانيوم داخل بلورات الدولوميت و وجود الحجر الرملى الناتج من عملية التعرية لمتكون الحجر الرملى النوبى.

ABSTRACT: *The Kareem/Rudeis Carbonate reservoir of Lower Miocene time represents the main reservoir in the western flank in Zeit Bay Oil Field, containing approximately 50% of the total hydrocarbon reserves. The carbonate platform developed upon the extensional tilted fault blocks located on the western rift margin.*

This study aims to evaluate the reservoir characteristics of the Kareem/Rudeis carbonate reservoir based on core analysis, petrographic observations and petrophysical determinations.

Petrographic analysis and petrophysical investigations of these carbonates, using the available electric logs and core data, show that the carbonate facies can be distinguished into several litho-facies. The upper part is a limestone body which is developed as separate mound along the western flank. The dolomite facies which underlies the limestone and is considered as a secondary dolomite derived by the diagenetic dolomitization processes on the originally deposited limestone. This dolomite facies can be subdivided into two zones according to the log response and cuttings description. The upper one is characterized by the presence of an anhydrite content with low gamma ray. The lower dolomite is characterized by a relatively high gamma ray which is caused by incorporation of uranium into dolomite crystal lattice reflecting somewhat different chemistry of the dolomitized fluids than the overlying low-gamma dolomite, and presence of sand which was reworked from the underlying Nubia Sandstone Formation.

INTRODUCTION

The purpose of this study is to evaluate the reservoir characteristics of Kareem/Rudeis carbonates reservoir in Zeit Bay oil field, based on core analysis, petrographic observations and petrophysical determinations.

The Zeit Bay oil Field is located in the south western margin of the Gulf of Suez, some 65 km north of Hurgada, and 100 km south of Ras Gharib (fig. 1).

It is situated generally in shallow water (about 20 meter depth), while a part of it extends to the Ras Bahar peninsula.

The field consists of a heterogeneous multiple reservoirs where it has oil contribution from different reservoir units ranging in age from Pre-Cambrian fractured Basement rocks to middle Miocene Hammam Faraun carbonates. The field contained oil reserves estimated, in 1984, at in excess of 600 million barrels in place. The reservoir layers consist of different reservoir rock types which are hydraulically communicated. The Kareem/Rudeis carbonate reservoir is volumetrically the largest reservoir unit in the field, containing approximately 50% of the total reserves, (Sultan et al., 1985).

The sub-surface Miocene in the Gulf of Suez region is generally subdivided into two main depositional phases. An early clastic and carbonate phase (includes Nukhul, Rudeis and Kareem Formations), overlain by predominantly evaporite phase (includes Belayim, South Gharib and Zeit formations). The stratigraphic sequence of the field, (fig. 2) ranges in age from Pre-Cambrian Basement complex to Recent sediments.

The Kareem Formation is generally attributed to the Gharandal Group of the Middle Miocene age. In the Zeit Bay oil field, the Kareem Formation is overlain by the Belayim evaporites and is underlain by the Basal Sandstone (of Lower Miocene and Pre-Miocene age) and Basement rocks (weathered and / or fractured).

Fig. 1 Zeit Bay Oil Field Location Map

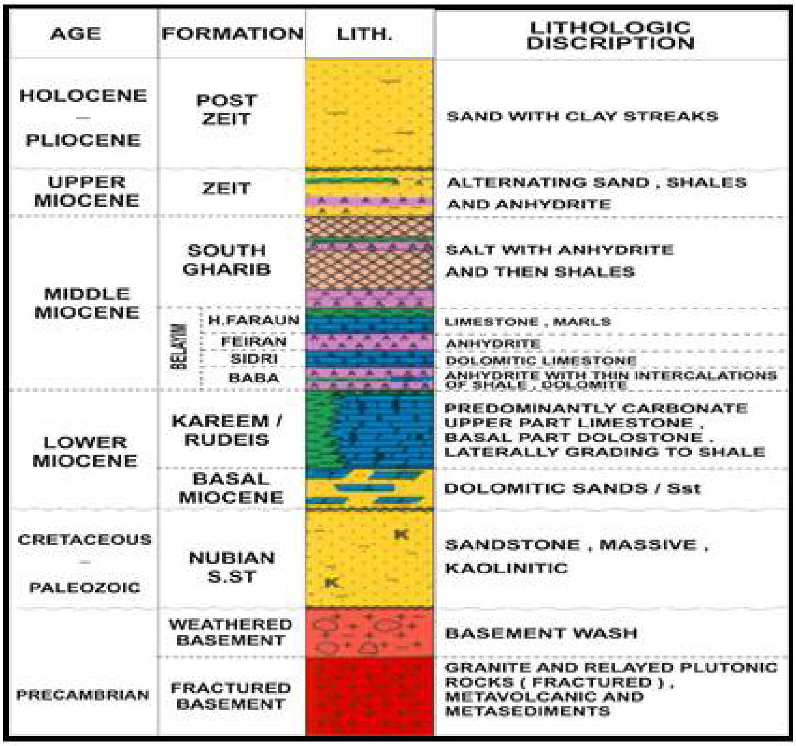


Fig. 2 Stratigraphic Column, Zeit Bay Oil Field

The field structure is a NW-trending horst-like anticline with a faulted margin. In map view, (fig. 3), it plunges toward the northwest and the southeast, (Chawdhary, L. R., Said, T., 1988).

In cross section view, (fig. 4), it represents a SW-tilted block of Lower Miocene older rocks.

RESERVOIR DESCRIPTION OF KAREEM/RUDEIS CARBONATES

El Hilaly, H.; and Darwish, M., 1986, examined the core samples from some selected wells covering the complete section of the Kareem/Rudeis carbonates in the studied area where they concluded that these carbonates include a wide variety of lithofacies groups, (fig. 5), starting from top to bottom as follows;

1- Packstone (fossiliferous limestone), represents the main limestone group recorded in several wells drilled in the studied area.
2- Wackstone (algal dolostone),
3- Anhydritic wackstone (anhydritic algal dolostone)
4- Anhydritic sandy wackstone (anhydritic sandy algal dolostone).

The depositional environment of these carbonate facies is interpreted as open marine water due to the presence of corals, molluscs and coral algal specially in the lower part of the section, (Harms and Brady, 1986). The dissolving of these faunal remains assemblage had led to the concentration of uranium minerals in the lower part.

The early diagenetic stages (pen-contemporaneous compaction, pressure solution and cementation) affect to a great extent in reducing the available pore space. On the other hand, the late diagenetic and epigenetic stages (ex.: dolomitization) are responsible for increasing the reservoir quality (both porosity and permeability parameters). Filling processes by anhydrite, calcite and/or silica may reduce the reservoir quality especially before hydrocarbon migration and filling.

The log response for the above mentioned lithofacies can be seen in figure 6. The lower part of Kareem/Rudeis carbonate sequence in the southwestern part of the Zeit Bay field, (Zone IV), is characterized by a relatively high gamma ray which is caused by incorporation of uranium into dolomite crystal lattice reflecting somewhat different chemistry of the dolomitized fluids than for the overlying low gamma dolomite. This part is characterized also by high density and low porosity due to the filling process by anhydrite. Permeability, as shown in (fig. 6) on the core permeability track, is relatively lower than the upper dolomite zone ranging from 1 to 70 millidarcies. The dolomite facies is considered as a secondary dolomite derived by dolomitization processes from the originally deposited limestone. The original limestone body was exposed to dolomitization processes which interpreted due to geochemical hypothesis by ground water effect, (Hanshaw, et al., 1971).

The upper part of the dolomite section, (zone III), is characterized by a low gamma content, low density and high porosity. The permeability as indicated from core data is relatively higher than the lower dolomite zone ranging from 100 to more than 400 millidarcies. This zone has the best reservoir quality comparing with the other carbonate zones.

Zone II is considered as the transition zone where is it subjected to the least degree of dolomitization process, and described as dolomitic limestone. As indicated from the log, (fig. 6), it has a relatively higher gamma ray, low porosity and low permeability.

Porosity/Density cross plots allowed identification for the above mentioned lithofacies, (fig. 7). The uppermost zone (Zone I) is low porosity limestone described in the thin section as Wackstone-Packstone foraminifera limestone. Zone II is identified on the cross plot as dolomitic limestone of better reservoir parameters than Zone I. This zone is described as algal dolostone. Reservoir Zone III is clearly identified on the porosity/density cross plot as anhydrite dolomite and described on the sedimentological cross section as anhydritic algal dolostone. The fourth reservoir sub zone is the most porous, high gamma ray dolomite and described as anhydritic sandy algal dolostone in the sedimentological thin sections.

PETROPHYSICAL EVALUATION

The purpose of log analysis is to obtain an accurate description of the subsurface formations from the log measurements. Various empirical methods have been used in the past. Several interpretation programs were used over the last 30 years, but they could not resolve the complex lithology recorded and the log data to be interpreted through the use of constraints, reflecting geological and local knowledge. With the advent of modern logs and greater number of measurements available, empirical methods can no longer be used.

A more systematic approach is necessary, such as the used in the ELAN program. This program gives a quantitative determination of porosity, hydrocarbon saturation and mineral volume fractions. It is based on the minimization of the differences of the actual and reconstructed log readings for the mineral/ fluid model chosen. Both linear and non-linear tool response equations for the various tools are built into the evaluation package. Hydrocarbon corrections to the density and neutron tools including the neutron excavation effect are handled automatically. All the log data in this program can be used simultaneously; any number of minerals can be incorporated into the model and statistical measurement errors of the logging tools can be accounted for, (Schlumberger, 1997).

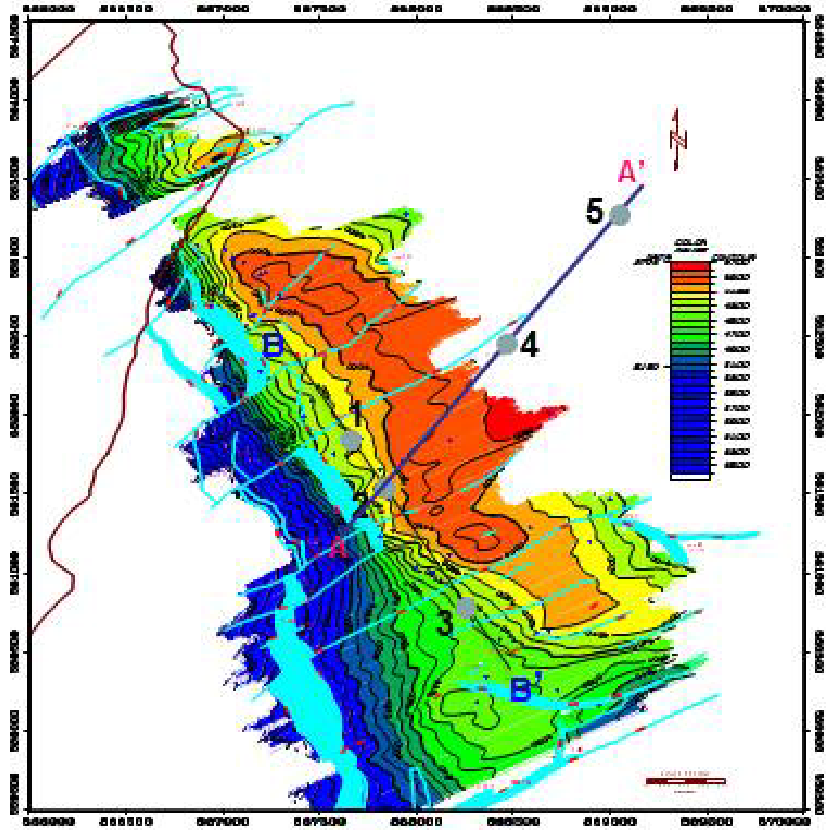


Fig. 3 Structure Contour Map on Top Kareem Carbonates
(*After Suez Oil Company, 2002*)

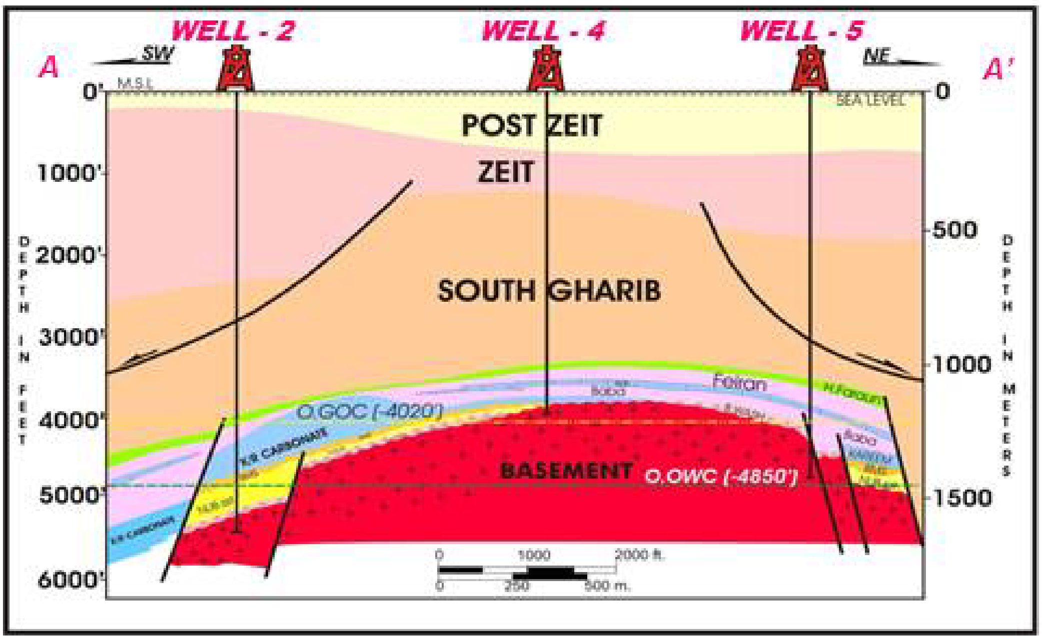
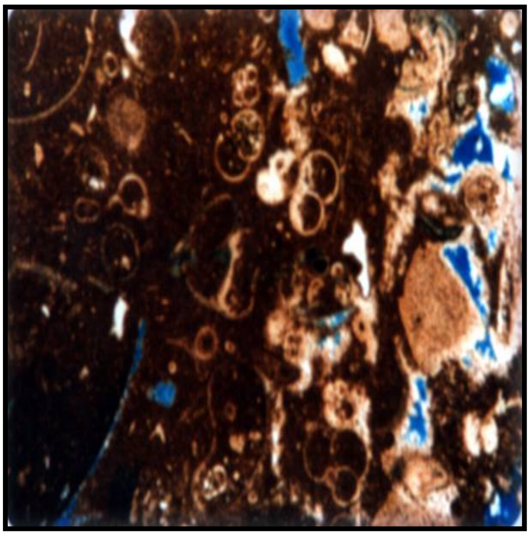
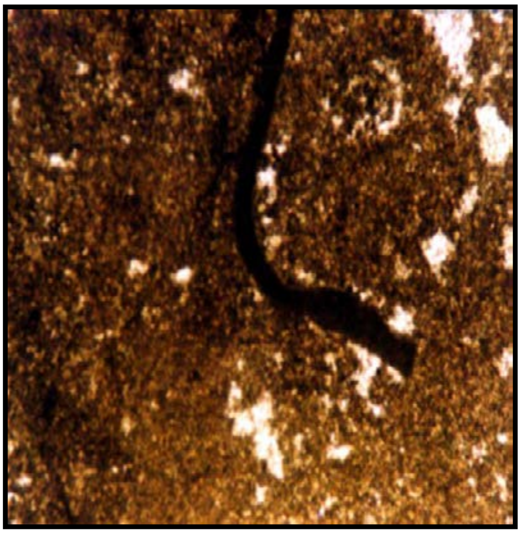


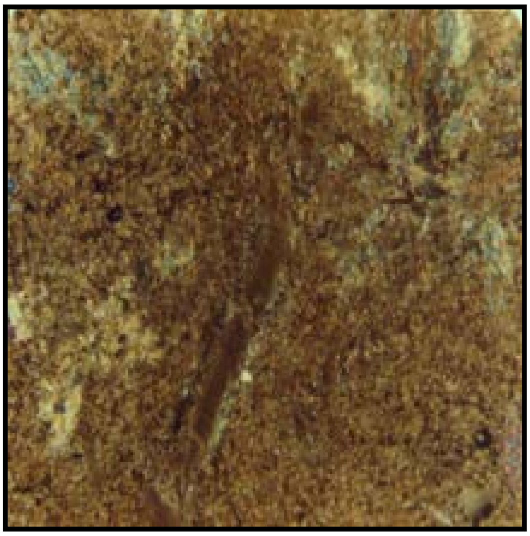
Fig. 4 Structure Cross Section Along SW-NE Direction
(*After Suez Oil Company, 2002*)



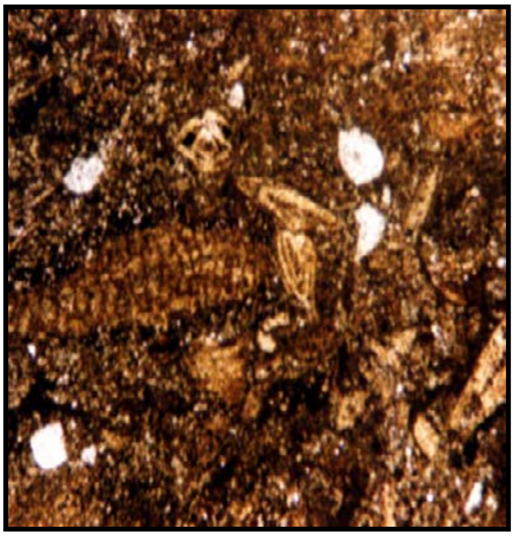
A- Wackstone-Packstone (Foraminiferal Limestone)



B- Wackstone (Algal Dolostone)



C- Anhydritic Wackstone - Algal Dolostone (Low Gamma Ray)



D- Sandy Wackstone – Algal Dolostone (High Gamma Ray)

Fig. 5 Thin Section Photographic Characters of Kareem/Rudeis Carbonates (*After H.El Hilaly & M. Darwish, 1985*)

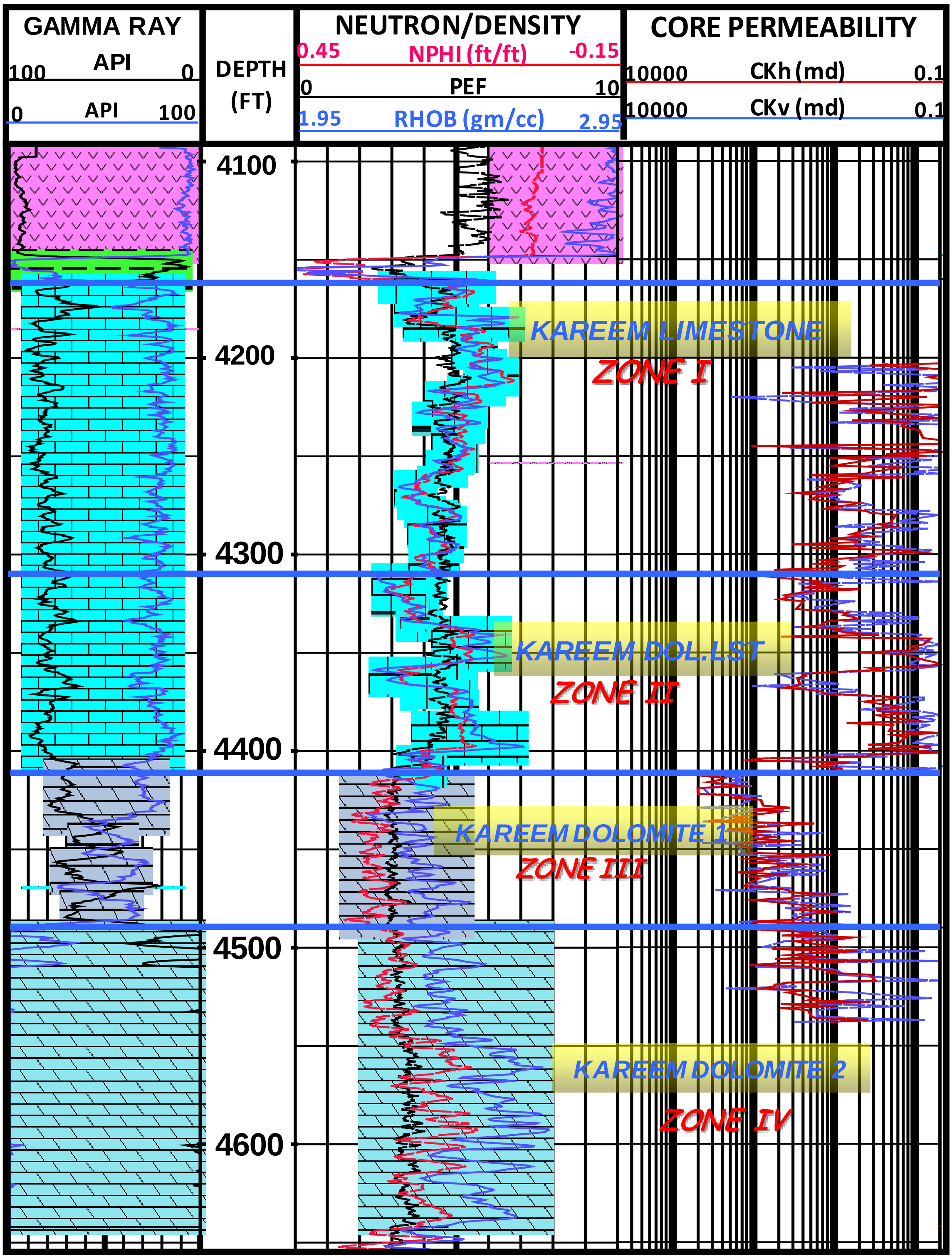


Fig. 6 Log Response & Core Permeability For Kareem Carbonate Facies, Well # 3, Zeit Bay Oil Field.

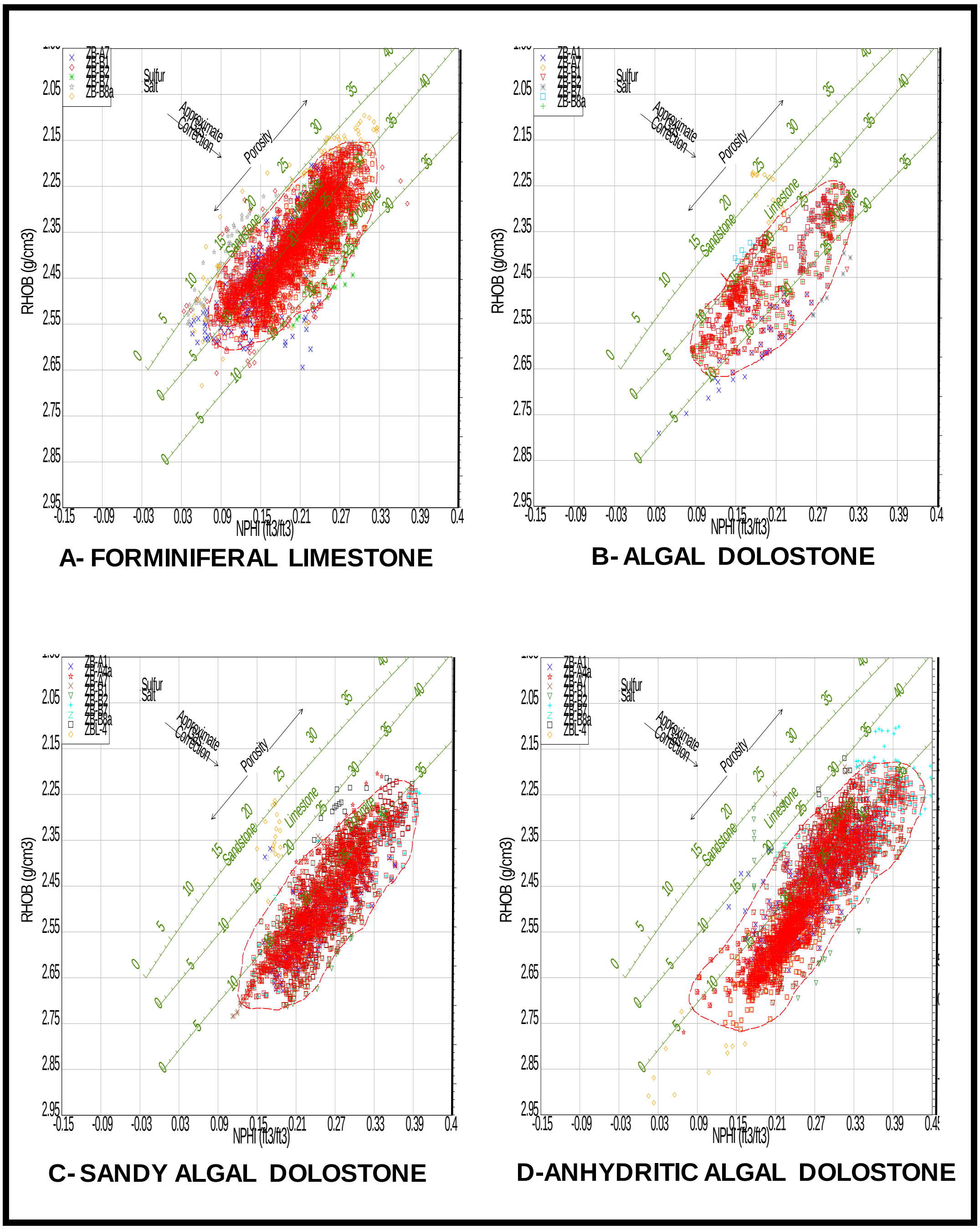


Fig. 7 Neutron-Density Cross plot For the Kareem Carbonates In Zeit Bay Oil Field

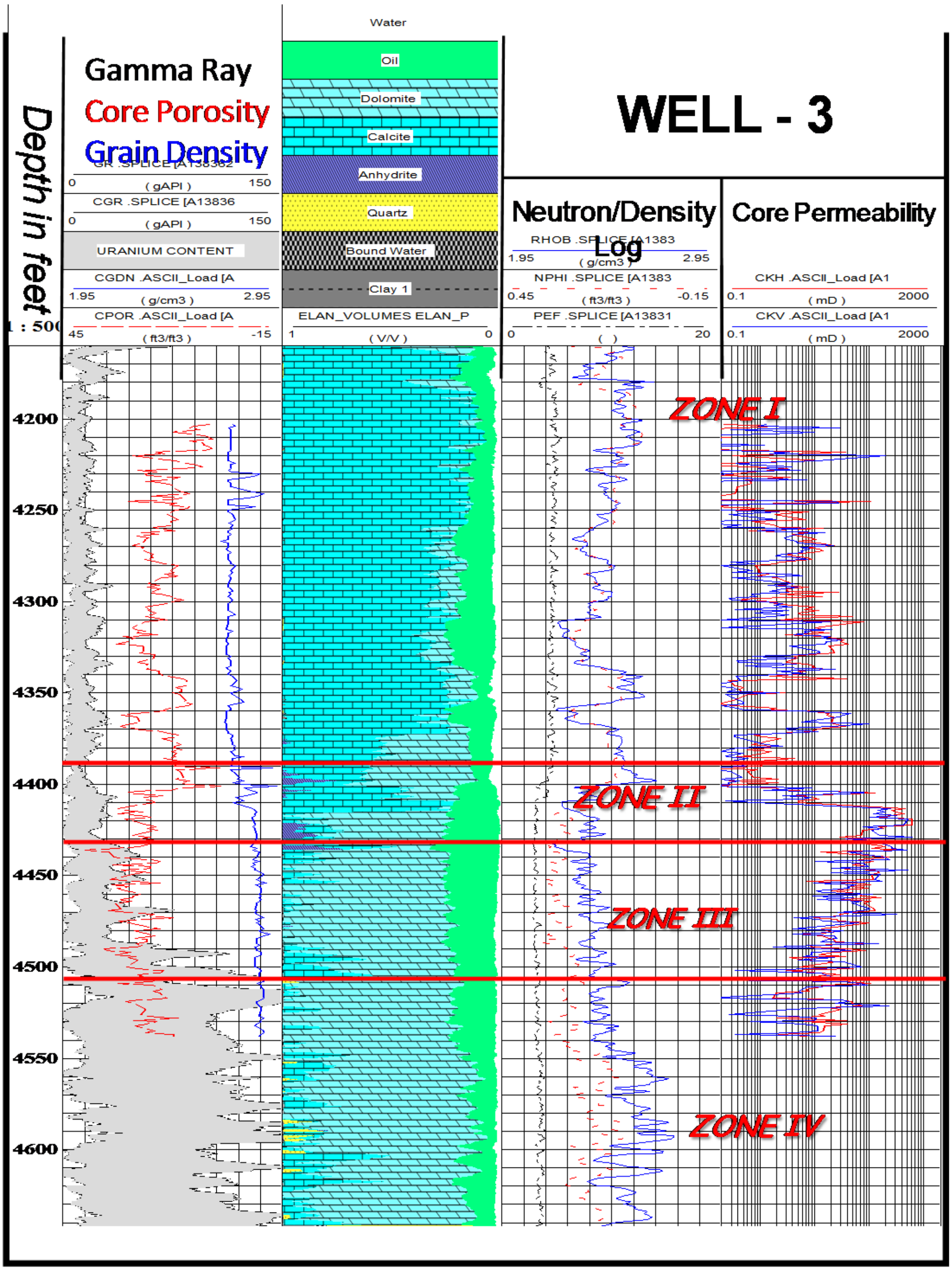


Fig. 8 ELAN Interpretation within Kareem Carbonate Reservoir in Zeit Bay Field

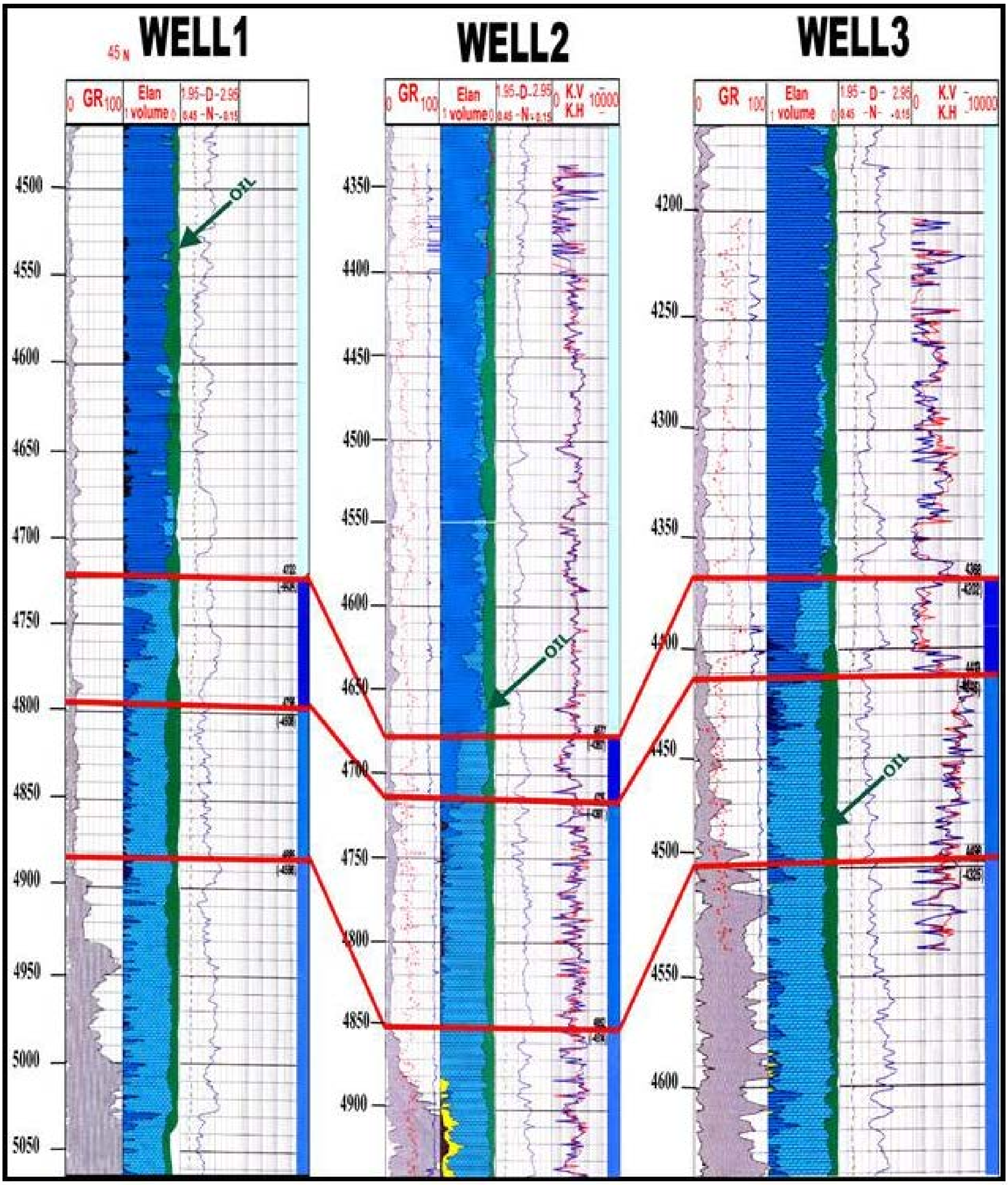


Fig. 9 ELAN Interpretation with Log Correlation For Some Wells within Kareem Carbonate Reservoir in Zeit Bay Field

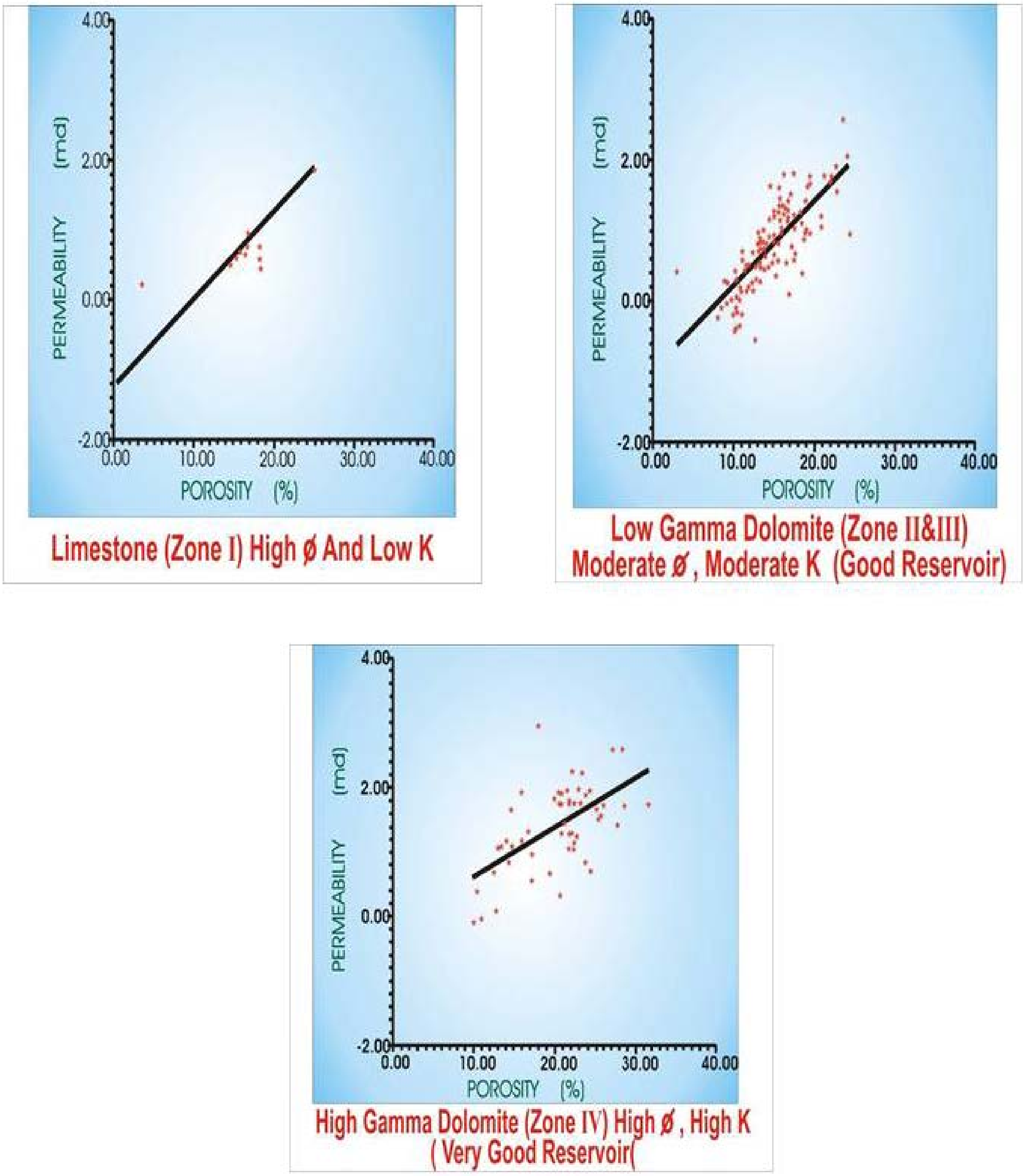


Fig. 10 Core Porosity & Core Permeability cross plot For Kareem Carbonate Facies in Zeit Bay Field

The output of ELAN software is included in the log presentation, (figure 8). The first track in this presentation, from the right, represents the core permeability curves, (both horizontal and vertical). The second track is the neutron density curves. The third track is the total formation volume derived from ELAN, including the lithology, (minerals), and fluid content, (water, gas and hydrocarbon). The fourth track represents the gamma ray with the uranium content as well as both core porosity and core grain density in the section.

The total formation volumes derived from ELAN software for several wells in the studied area were constructed and correlated together with the available log data and core permeability data (both horizontal and vertical permeability), (fig. 9). This reveals the lateral extension of the different zones along the line of correlation. Porosity, permeability and hence the fluid distribution are varied laterally depending on the degree of dolomitization and the anhydrite content.

Computation of Water Saturation:

Besides porosity and mineral fractions computation, the main objective of log analysis is to calculate water (and hence hydrocarbon) saturation. This is usually done from Resistivity measurements. *Archie, (1942)*, was the first to put forward an empirical equation relating the formation factor, derived from resistivity, to porosity and saturation, expressed by the well-known equation;

$$S_w = \{F.R_w / R_t\}^{1/n} \qquad (1)$$

where;

S_w is the water saturation,

R_w is the water resistivity,

R_t is the true resistivity

n is the index of saturation and

F is the formation factor which is a function of porosity $Ø$, usually written as:

$$F = a / Ø^m \qquad (2)$$

where;

$Ø$ is the porosity,

a is fraction multiplier = 1

m is the cementation factor.

For *Archie*, a =1, and m varies as a function of grain size and distribution or as function of the complexity of the channels linking the pores. For carbonates with good porosity, as in the Zeit Bay carbonate reservoir, the values of both a and m are generally taken to be 1 and 2, respectively.

The values of a and m can be determined by crossplots of the true formation resistivity, in water bearing zones where S_w = 1, versus the formation porosity based on *Archie* equation.

The availability of extensive core data has allowed better determination of porosity exponent "m", which is sometimes referred as "cementation exponent, depending on the type of porosity, usually ranging between 1.5 and 2.2, respectively.

RESERVOIR POTENTIAL

Dolomitization occurred in the lower part of the carbonate section in the field improved reservoir permeability simply because of the larger pore size, and the effectiveness of their connection. Permeability varies with depth (< 1 to > 400 mD). Small scale heterogeneities in texture inevitably mean that permeability will also change rapidly away from the sample point. The cross plot of porosity-permeability data of this part, (fig. 10), shows a very broad scatter of porosity values for any given permeability.

Porosity of the dolomite is mainly secondary. Harms and Brady, 1986, stated that early selective dolomitization of the mud and coralline algae resulted in the development of intercrystalline pore space which may be too fine to have enough permeability to be effective. They added that in some places, particularly in the high-gamma dolomite, the crystal size is up to 50 microns and the intercrystalline pore space greatly enhances the reservoir properties. Although they mentioned that the high-gamma dolomite is more porous than the overlying low-gamma dolomite, this observation is not clear on the neutron-density log, (fig. 7) and in ELAN interpretation, (figs. 8 & 9), where the porosity in the lower part, indicated from the neutron curve, seems to be lower than the upper part.

CONCLUSION

Kareem/Rudeis carbonate reservoir in the Zeit Bay oil field was investigated petrophysically and petrographically using the available core data and wire-line logs. This reservoir can be subdivided into several lithofacies from bottom to top; a lower high-gamma ray dolomite, an overlying low-gamma ray dolomite and a limestone unit along the western margin of the field.

Reservoir properties of the Kareem/Rudeis dolomite, as indicated petrographically and petro-physically are very good. The porosity ranges from 15-30% and permeability generally in the range from 1.0-400 millidarcies.

Kareem/Rudeis limestones are poor reservoir due to early shallow marine and vadose cementation and internal sedimentation.

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