# *Petrophysical Studies on Samples from Eocene Exposures West Cairo-Egypt*

by

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## ABSTRACT

The present work deals with petrophysical and petrochemical studies on 58 limestone samples of Eocene age in two localities west of Cairo (Sakkara and Giza Pyramids Plateau). The determined petrophysical properties are: effective and total porosity, grain and bulk density, gas permeability and electrical resistivity. The petrochemical properties are weight percentages of $CaCO_3$, $MgCO_3$, shale and sand.

The computational methods used for processing the obtained data include regression analyses (least square method), correlation analysis, cluster and linkage analyses. They are used to classify and correlate rock samples using their petrochemical and petrophysical parameters.

All Eocene rocks of the Giza Pyramids Plateau area were found to be more dense and less porous than those of the Sakkara area and hence the electric resistivities of rocks in the former area are higher than those of rocks in the latter area. The stratigraphic subdivisions made by conventional geologic methods for Eocene rocks are very well represented by noticeable variations in the different studied petrochemical and petrophysical properties.

# دراسات بتروفيزيائية على عينات من صخور الايوسين الموجودة حول القاهرة

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يختص هذا البحث بدراسة الخواص البتروكيميائية والبتروفيزيائية للعينات المأخوذة من مكاشف الصخور الجيرية لعصر الايوسين في منطقتي هضبة أهرام الجيزة وسقارة - أبو صير . تم جمع ٥٨ عينة من مكاشف صخور الأعضاء المختلفة لعصر الايوسين في هاتين المنطقتين .

أ - منطقة هضبة أهرام الجيزة :

تم جمع ٣٢ عينة من أعضاء الجيزاهنيسيس وحجر البناء العلوي والجيوشي (تكوين المقطم) وحيط الغراب وجيران الفول (تكوين المعادي)

ب - منطقة سقارة - ابو صير :

تم جمع ٢٦ عينة من أعضاء سقارة وجيران الفول (تكوين المعادي) .

ولقد اجريت على هذه الصخور الدراسات البتروجرافية والبتروفيزيائية المختلفة .

أولا : الدراسات البتروكيميائية : تم تعيين النسب المئوية بالوزن لكل من كربونات الكالسيوم - كربونات الماغنيزيوم - الطين - الرمل في كل عينة صخرية .

ثانيا : الدراسات البتروفيزيائية : تشمل تعيين مسامية الصخور الكلية والمؤثرة - الكثافة الكلية والوزن النوعي للصخور - معامل النفاذية - المقاومة النوعية الكهربية للصخور - معامل المقاومة الكهربية للتكوين عند ثلاث درجات تركيز مختلفة لمحلول كلوريد الصوديوم الذي شبعت به العينات (٦٠٠٠ ، ٦٠٠٠٠ ، ١٢٠٠٠٠ جزء/ مليون .)

ولقد عولجت جميع النتائج المعملية إحصائيا بواسطة الحاسب الالكتروني وتم عمل المقارنات وتوضيح العلاقات بين الخواص البتروكيميائية والبتروفيزيائية للصخور المدروسة من ناحية والعلاقات بين الخواص البتروفيزيائية المختلفة من ناحية أخرى . كما تم تصنيف العينات الى مجموعات تبعا للخواص التي درست والتي تميز كل مجموعة .

ولقد وجد تطابق بين هذا التقسيم وبين التقسيم المبني على الدراسة الاستراتجرافية . فقد وجد أن عضو الجيوشي (تكوين المقطم) يتكون من حبيبات دقيقة أقل في حجمها من حبيبات صخور عضو حجر البناء العلوي وصخور عضو الجيزاهينسيس (تكوين المقطم) كما وجد أن الحجر الجيري لعضو حيط الغراب (تكوين المعادي) أكثر ارتباطا بعضو الجيوشي (تكوين المقطم) وهذا أيضا ما أكدته الدراسات الاستراتجرافية .

## Introduction

In the last decades, intensive work has been carried out on the geology, stratigraphy and sedimentary petrology of the Eocene exposures along the Nile valley. These rocks constitute the bulk of most of the high plateau limiting the course of the river from the latitude of Qena up to the region around Cairo. The study of the petrophysical properties of these rocks has been very limited. The present work intends to introduce the use of the petrophysical properties of rocks to characterise stratigraphical units recognized in the field and in the laboratory by conventional means. Furthermore, the type of relation between the different petrophysical properties of the rocks in definite stratigraphic intervals or in some given occurrences may throw light on some genetic and diagenetic processes which have affected these rocks.

## Method of Study

To reach the proposed aims of the present investigations, the following methodological steps were undertaken:

1. Field description and sampling of the different rock units in the studied localities.
2. Laboratory treatment of samples for determination of some important petrochemical and petrophysical properties of the rocks. These include:
   a. insoluble residue analysis,
   b. chemical analysis (percentage of $CaCO_3$ and $MgCO_3$),
   c. petrophysical properties (bulk density, grain density, total and effective porosities, permeability and electrical resistivity).
3. Statistical treatment and processing of the obtained data for establishing two main types of relations:
   a. relations between the different samples based on the established physicochemical parameters. The computational classification method used in the present work is a cluster analysis as proposed by Sokal and Sneath [1].
   b. relations between the different physical and chemical properties. These are established in three different ways:
      *i)* for each type of lithology, to detect particular genetic processes for the investigated rock type (as carbonates, marls, shales).
      *ii)* for all samples, to detect general trends.
      *iii)* for each locality, to detect particular genetic processes for each investigated locality. All these statistical treatments and processing of data were done by preparing special programs and by using computer IBM 11/30 at the data processing centre of Ain Shams University.
4. The obtained results are graphically presented and discussed. The distribution of each rock type in each stratigraphical rock unit and in each locality is determined and conclusions are drawn on some aspects of the genesis of these rocks.

## Sampling

Samples were selected from two localities showing well-developed Eocene exposures at the western side of the greater Cairo area (Fig. 1):

1. The Sakkara area, to the south (Fig. 2) (26 samples).
2. The Giza Pyramids Plateau area, to the north (Fig. 3) (32 samples).

Stratigraphical studies on Sakkara area were prepared by Mohamed [2] and those for Giza Pyramids Plateau area were carried out by Zahran [3]. The relation of the stratigraphical subdivisions of the Eocene exposures in the studied areas was established by Blanckenhorn [4].

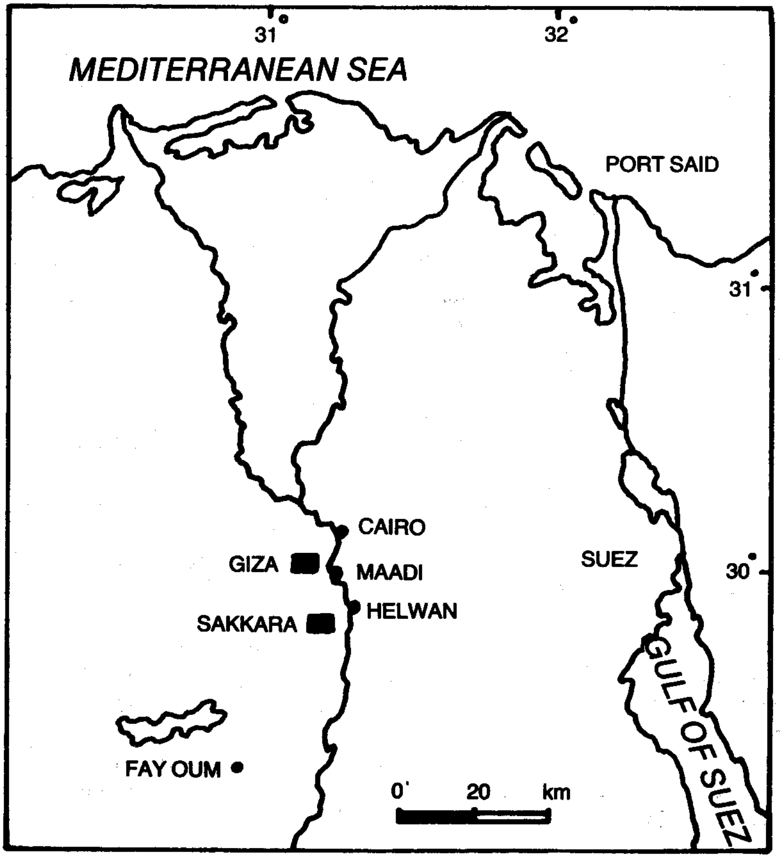


*Fig. 1:* Key map showing the location of the studied localities

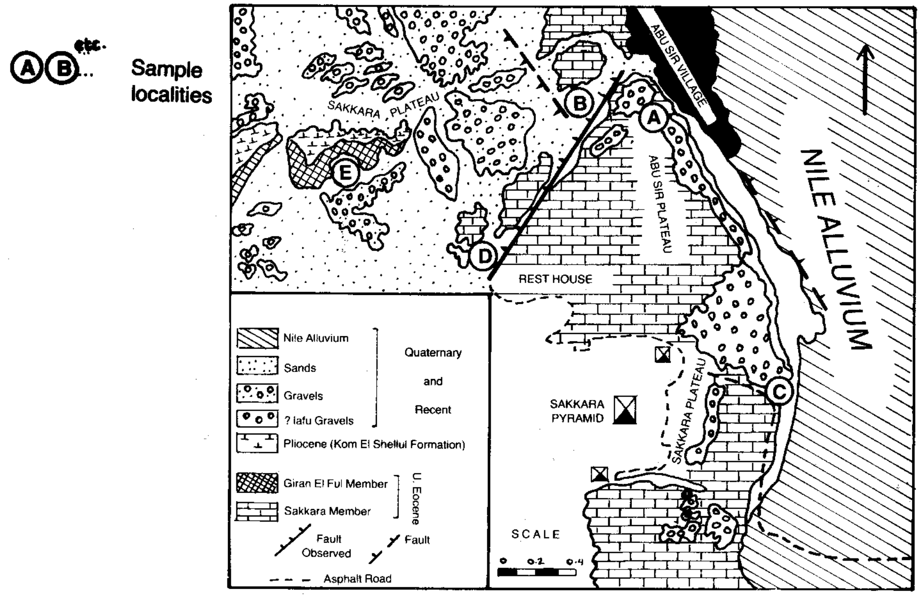


*Fig. 2:* Photo-geologic map of the Sakkara area (After Mohamed, 1977)

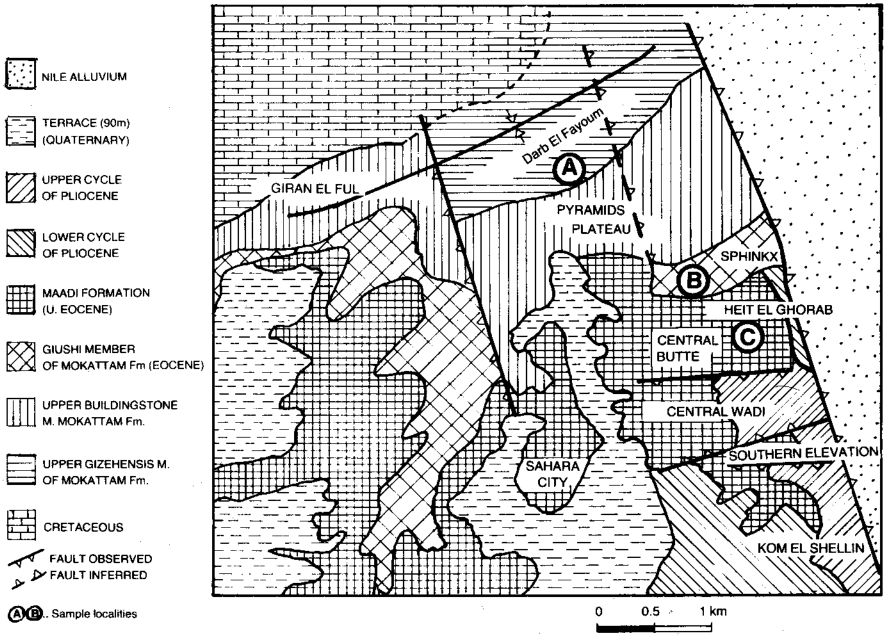


*Fig. 3:* Geologic map of the Pyramids Plateau area showing structural and stratigraphical relations. (After Zahran, in preparation).

## Laboratory Studies

Two types of analysis on rock samples were done: first, chemical analysis including insoluble residue analysis and the determination of $Ca^{++}$ and $Mg^{++}$ in rock samples. The second type of analysis dealt with the determination of petrophysical properties of rocks which can be subdivided into mass properties, storage capacity and electrical properties.

*A – Chemical Analyses*

Here, insoluble residue is defined as the material remaining after rock fragments have been digested in HCl. The method followed for insoluble residue analysis is that introduced in the geological practice in the early thirties [5, 6, 7]. On the other hand, the proportions of $CaCO_3$ and $MgCO_3$ in rock samples were determined using the method described by Shapiro and Brannock [8].

The obtained results for the chemical analysis are graphically represented in ternary diagrams (Fig. 4). These diagrams show the general aspect of the samples in each locality and for each rock unit. Figs. 5 and 6 show the vertical variations of the determined parameters for the stratigraphical subdivisions, lithologic and stratigraphic location of samples in each area.

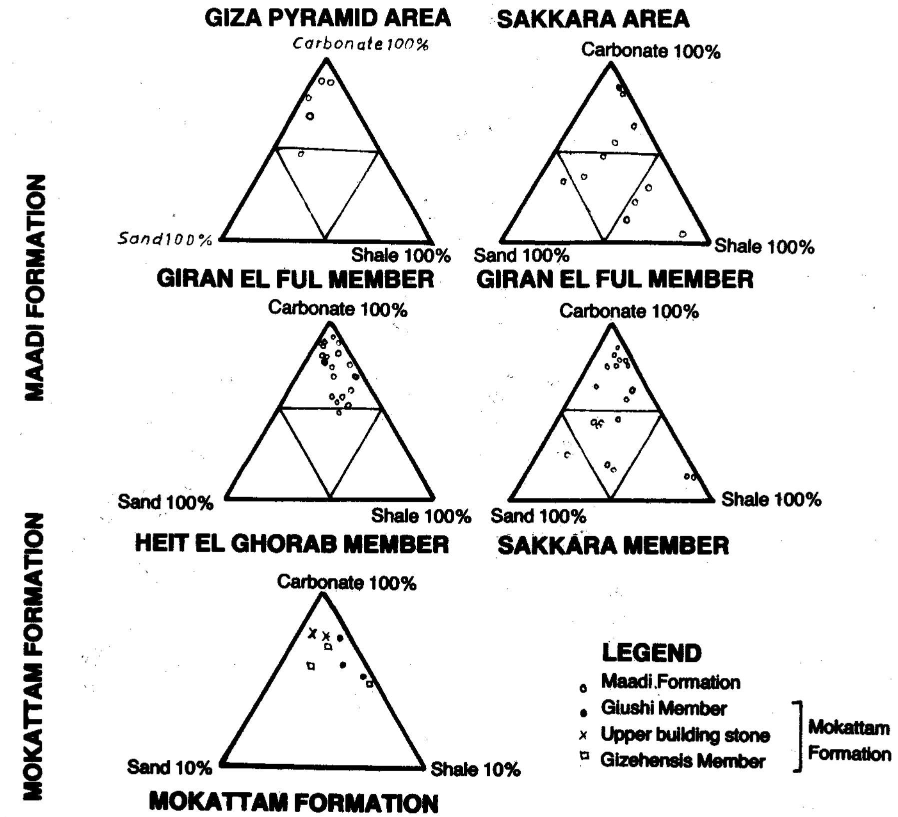


*Fig. 4:* Ternary diagrams showing the relative portion of carbonate, shale and sand in the studied samples of the different rock units in the two investigated localities.

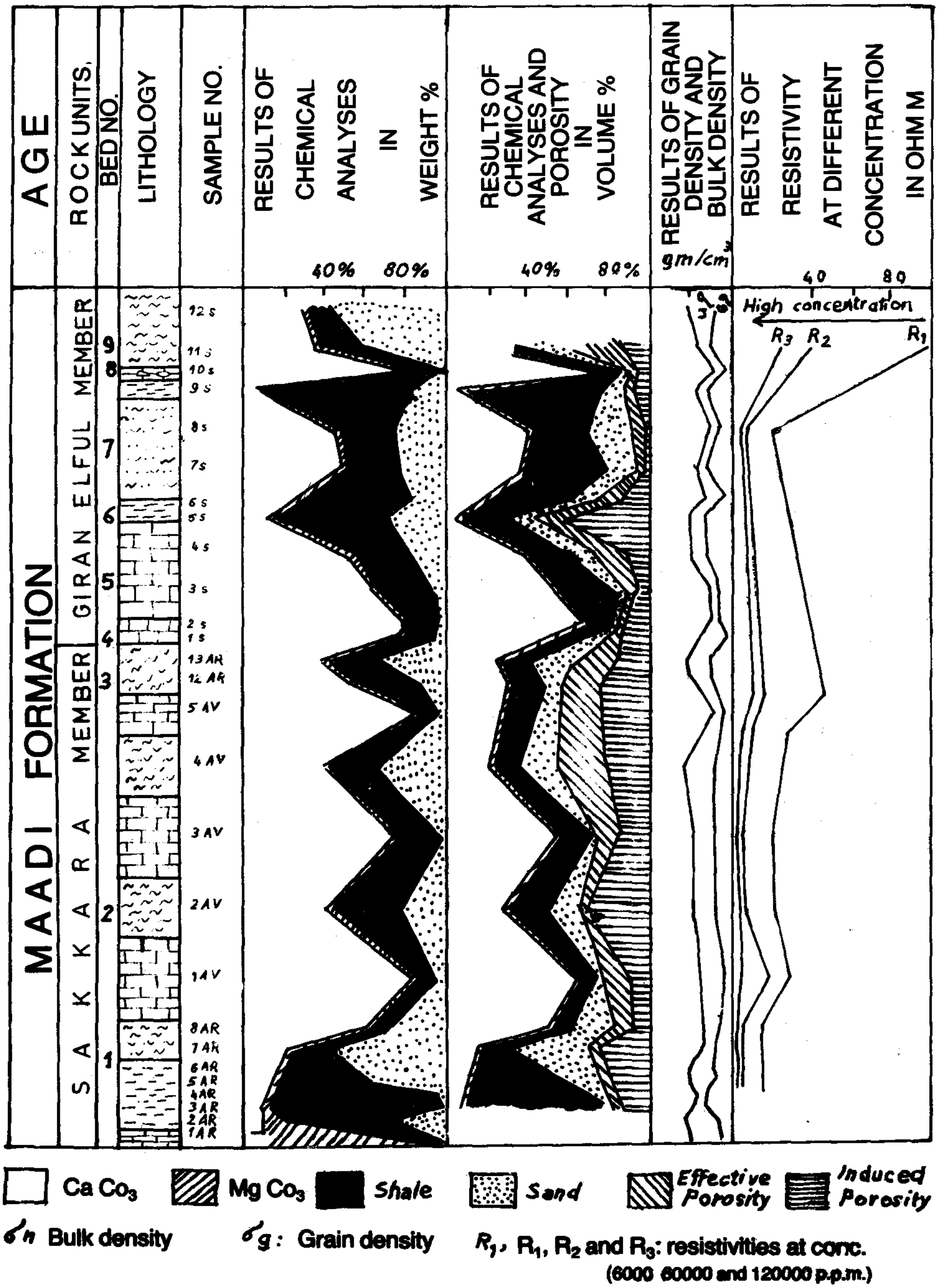


*Fig. 5:* Chart showing the stratigraphical variations of the measured petrographical and petrophysical data in the Sakkara area.

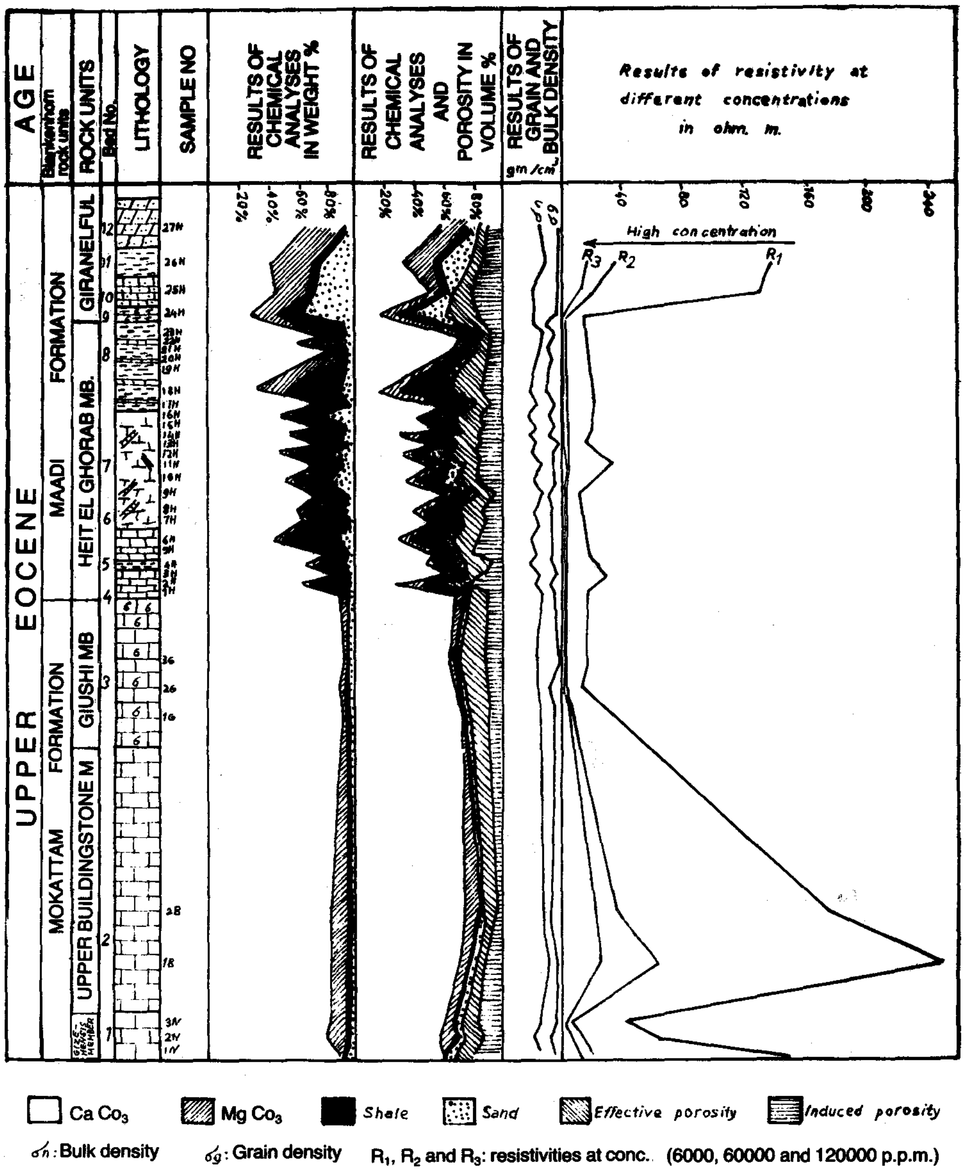


*Fig. 6:* Chart showing the stratigraphical variation of the measured petrographical and petrophysical data in the Giza Pyramids Plateau area.

*B – Basic Petrophysical Analysis*

*1. Density determinations:* The bulk density of a rock being the mass of its unit volume is controlled by the mineral composition, porosity and fluid saturation. On the other hand, the grain density of a rock is the mass of a unit volume of its solid phase (mineral skeleton) and hence it depends on the mineral composition which is controlled by the chemical composition and the structure of each mineral.

The bulk density of 58 carbonate samples is determined according to the method of Preabrojensky [9].

Grain density $\delta n$ (gm/cc) $= W_1/[W_2 - (W_3 - a)]$

Where:

$W_1$ = weight of dry sample,

$W_2$ = weight of sample saturated with kerosene,

$W_3$ = weight of sample suspended in kerosene,

a = weight of thread used for suspension.

The grain density ($\delta g$) of these samples is determined by the pycknometer method [10].

$\delta g$ (gm/cc) $= W_3 - W_1/[W_2 - W_1) = (W_4 - W_3)]$

where:

$W_1$ = weight of dry pycknometer,

$W_2$ = weight of pycknometer filled with distilled water,

$W_3$ = weight of dry pycknometer + sample,

$W_4$ = weight of pycknometer + sample + water.

The results of bulk and grain density determinations are graphically presented with the stratigraphic subdivisions in the two studied areas in Figs. 5 and 6.

*2. Porosity determinations:* The study of porosity of carbonate rocks is significant because it can give information on their genesis. Generally primary porosity is syndepositional, while secondary porosity is often post-depositional and diagenetic. Post-depositional changes in the porosity of rocks are due to:

a) Fracturing of rocks due to tectonic movements.

b) Chemical action of solutions circulating in pores.

In this study the total porosity (Øa) of rock samples is evaluated using the equation:

$$Øa, \% = (\delta g - \delta n)/(\delta g - \delta e) \times 100$$

where

$\delta g$ - grain density

$\delta n$ - bulk density

$\delta e$ - density of the fluid filling the pores of rock sample.

The effective porosity (Ø e) is also calculated applying the results of bulk density measurements in the following equation:

$$Øe, \% = \{ (W_2 - W_1)/W_2 - (W_3 - a) \} \times 100$$

The results of the total and effective porosity determinations for all the 58 studied samples are graphically presented against the stratigraphic subdivisions in the two areas in Figs. 5 and 6. The relation between the determined effective porosity, total porosity and bulk density for the studied samples are given in Figs. 7 and 8 respectively.

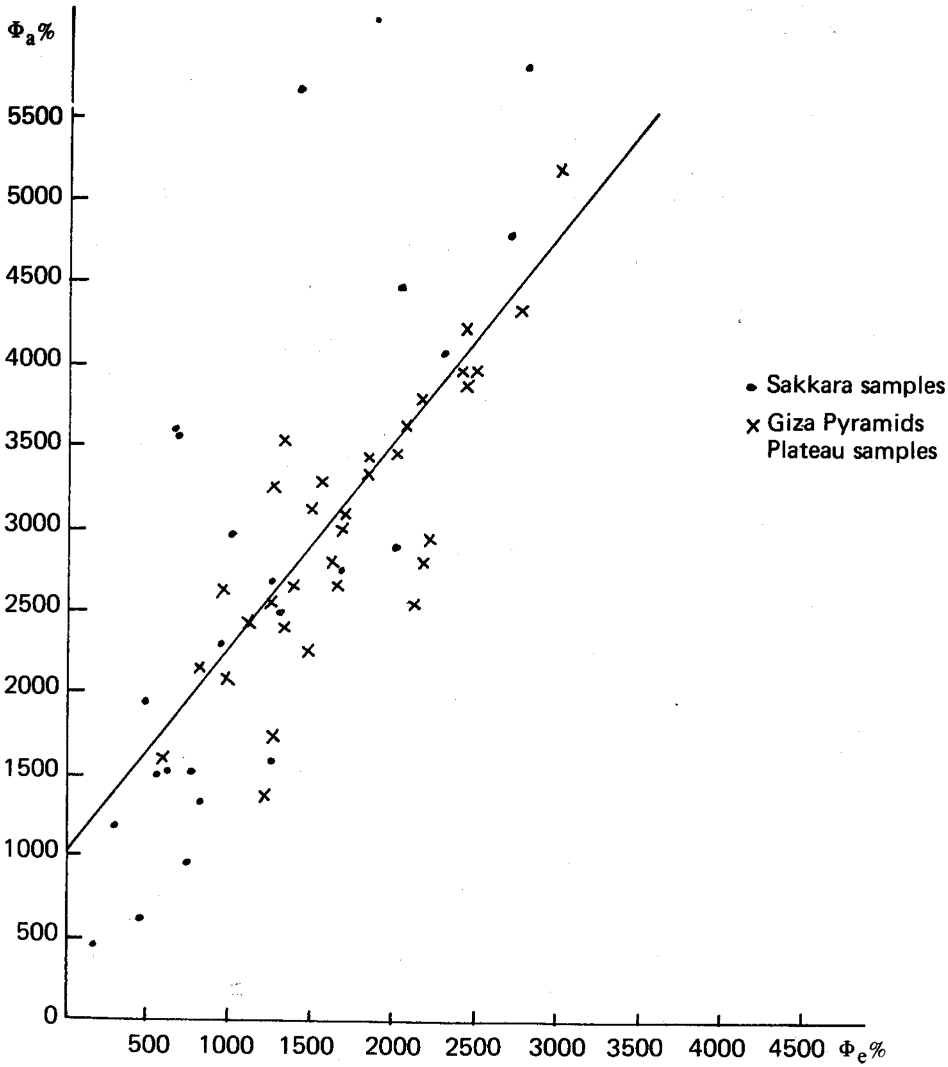


*Fig. 7:* Relationship between effective porosity ($\phi_e\%$) and total porosity ($\phi_a\%$)

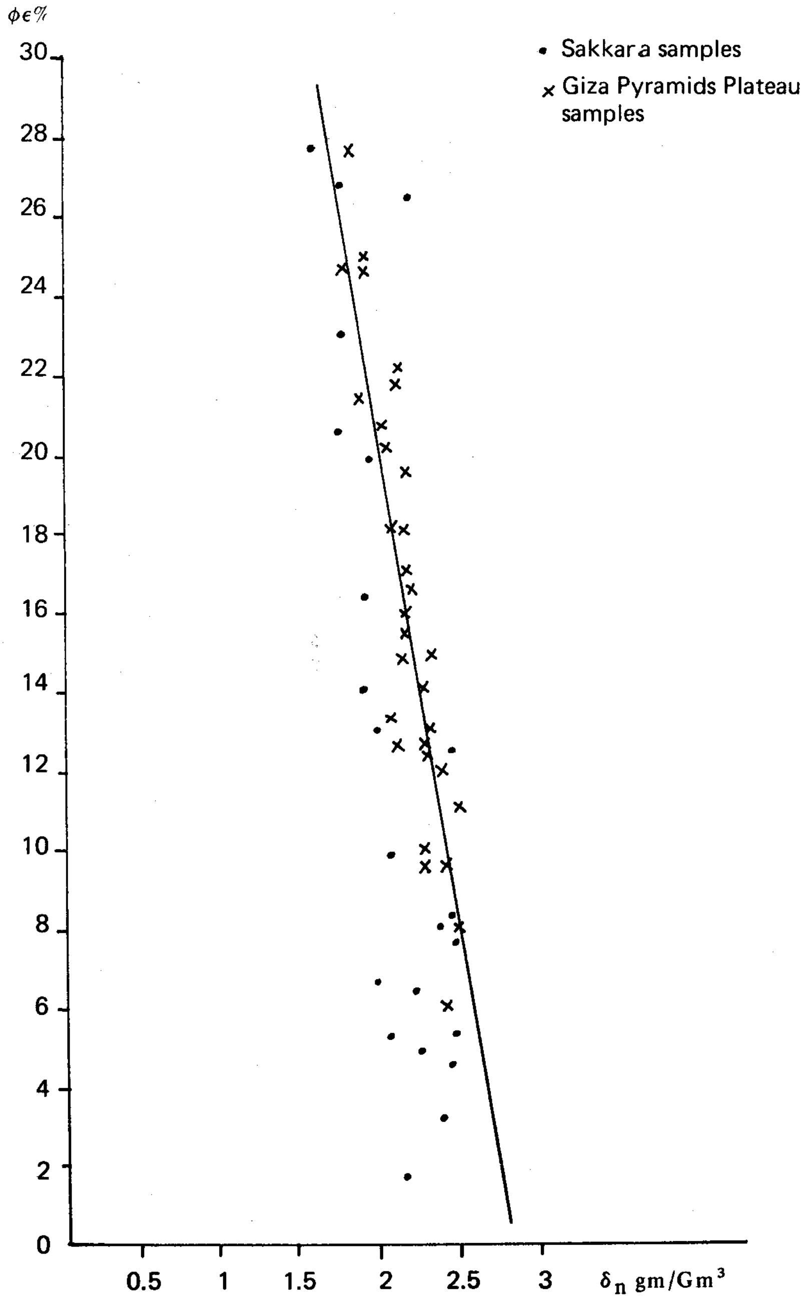


*Fig. 8:* Relationship between bulk density ($\delta_n$) and effective porosity ($\phi_e\%$)

*3. Permeability measurements:* Permeability is a measure of the ability of a porous material to conduct fluids. The permeability of a rock is controlled by its grain size, degree of cementation and compaction. According to Kobranova [10], rock samples can be classified depending on their gas permeability into three classes: Permeable rocks having permeability more than 10 millidarcies, semipermeable rocks with permeability from 0.1 to 10 md.; rock samples having permeability less than 0.1 md. are classified as non-permeable. Such samples have pores of subcapilliar size.

Gas permeabilities for 38 rock samples were measured using Ruska Gas permeameter. The permeability results are graphically presented for each stratigraphic subdivision in the two areas under investigation in Figs. 5 and 6. The relationship between the measured permeability and the effective porosity of the studied samples is given in Fig. 9.

*4. Electrical properties:* The electrical properties of rocks are considered to be a very important aid in determining many petrographical and petrophysical properties (matrix constitution, porosity, permeability and the amount and nature of fluids in rock pores). Among all the electrical properties, the electric resistivity is the most widely applicable. Therefore, to complete the petrophysical study of the Eocene carbonates, the electric resistivities of 29 samples were measured in three successive rounds. In each round, samples were saturated with NaCl solution of different concentrations (6000, 60000, 120000 ppm) respectively. These solutions have electric resistivities $R_W = 0.7$, 0.08 and 0.065 ohm.m. This was done in order to study the pore structure of samples by the variations in their calculated formation resistivity factors. The electric resistivity of samples was measured at a frequency 1000 Hz using an A.C. resistivity bridge. Corrections were made to compensate for the contact resistances between rock samples and the used electrodes according to the method described by the author [11]. The results of these resistivity measurements ($R_e$) and the corresponding formation resistivity factors ($F = R_O/R_W$) are given against the stratigraphic subdivisions in the two studied areas in Figs. 5 and 6. The relationships between the determined formation resistivity factors at different concentrations and the effective porosities of samples are given in Fig. 10.

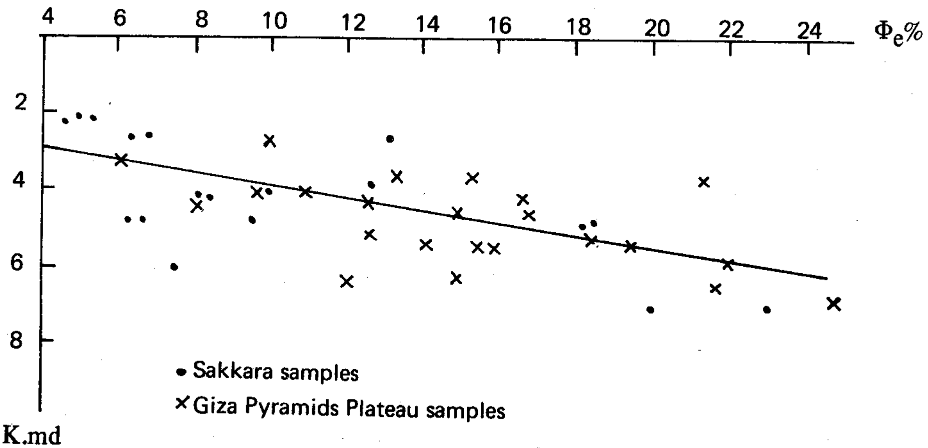


*Fig. 9:* Relationship between permeability ($\kappa$) and effective porosity ($\phi_e\%$)

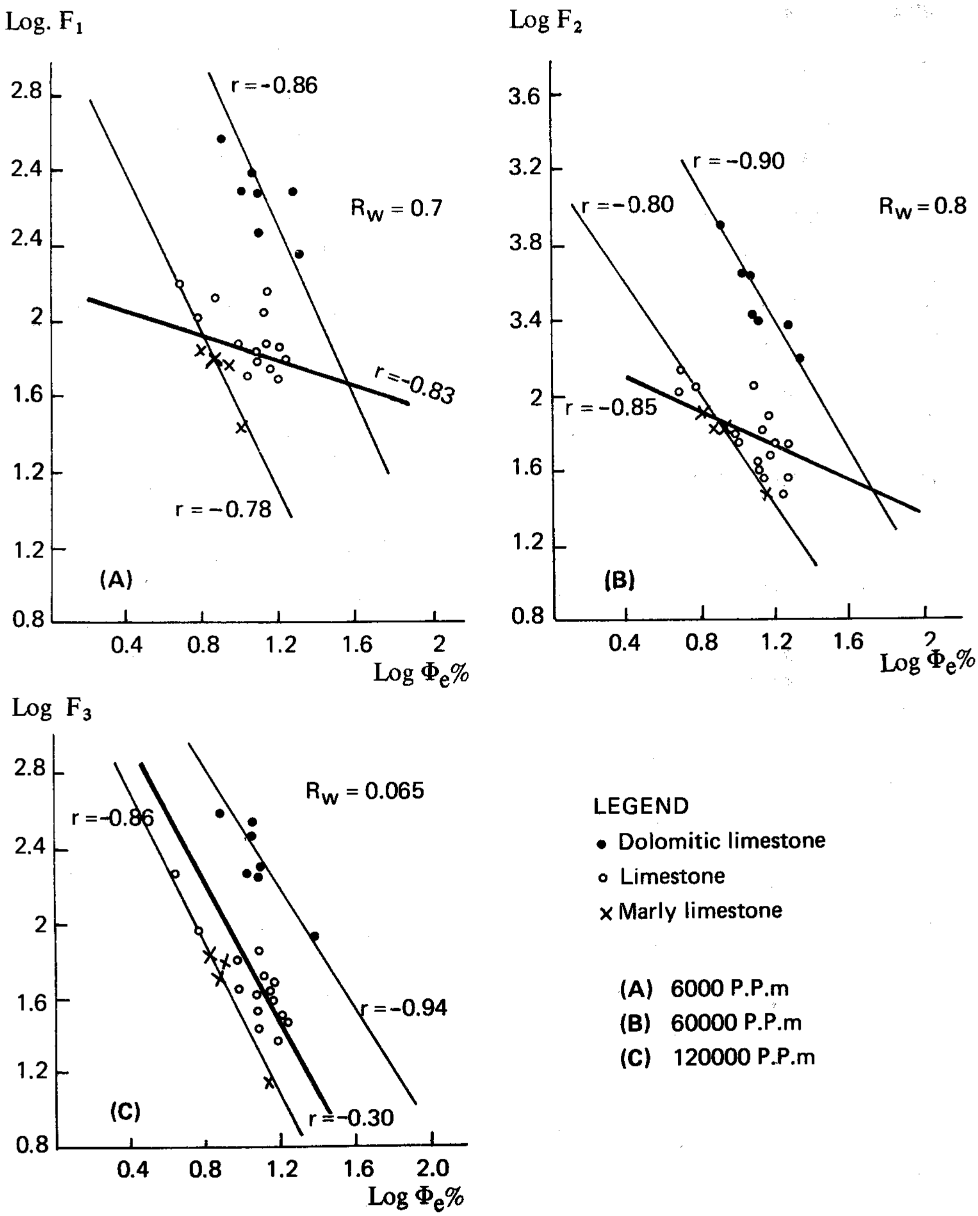


*Fig. 10:* Curves showing the relationship between determined resistivity formation factor and effective porosity at conc.

**(A) 6000 p.p.m.**
**(B) 60000 p.p.m.**
**(C) 120000 p.p.m.**

## Discussion of Results

Based on the lithographic subdivisions of the Eocene rocks exposed in the Giza Pyramids Plateau and the Sakkara areas and the results of the petrochemical and petrophysical studies for samples selected from these rocks which are presented in Figs. 4 to 10, the following results can be pointed out:

1. The members of the Maadi Formation, ranging from dolomitic limestones, limestones, sandy marly limestones to shales, show high vertical variation in their petrochemical and petrophysical properties. The members of the Mokattam Formation are more uniform in character and generally highly calcareous.
2. The Maadi formation in the Giza Pyramids Plateau is generally more dolomitic than that of Sakkara area, particularly the Giran El Ful Member.
3. The Upper Gizehensis and Upper Buildingstone Members of the Mokattam Formation in Giza are more dolomitic than the Giushi Member of the same locality.
4. The Maadi Formation in the Giza Pyramids Plateau area is generally more calcareous and contains less clastic material (sand and shale) than the same formation in the Sakkara area. This is probably the reason for the noticed higher values of grain and bulk density for Maadi Formation rocks from Giza Pyramids Plateau area than those of the same rock unit from Sakkara area.
5. The effective porosity of the sparitic (crystalline) rocks of the Mokattam Formation is higher than that of the micritic (muddy) rocks of this formation. Thus the effective porosity of the Upper Gizehensis and the Upper Buildingstone is higher than that of the predominantly micritic Giushi Member. However, the total porosity of these rocks is generally low, because of their compaction. This is also represented by their higher densities.
6. The effective porosity of the Maadi Formation is higher than that of the Mokattam Formation. The effective porosity and permeability of these rocks in the Sakkara area is higher than of the Giza Pyramids Plateau area. This may be due to the high sand content and the fissility of the shales present in the rocks of the Sakkara area.
7. Generally, the permeability of the investigated Eocene rocks is more or less uniform (semipermeable) and the variations observed are only within small limits. It may be noticed that sediments deposited under high energy conditions are generally more permeable than rocks deposited under low energy conditions.
8. Considering the results of the effective porosity and permeability determinations for the studied samples, it is interesting to notice that only for the samples of the Upper Buildingstone Member is there a distinct relationship between these two parameters. This may be due to the presence of some large-sized cavities which have been formed by dissolution.
9. The electrical resistivity and formation resistivity factor of samples of the Mokattam Formation are generally high because of their high density and high Mg $CO_3$ content and their low effective porosity. These values are lower in the Maadi Formation, because these rocks are more porous and less dense and of lesser Mg $CO_3$ content. However, the determined electrical resistivity values for this formation in the Sakkara is still lower because of the great increase of clastics (sand and shale).
10. The study of the relationships between the electric resistivity of rock samples and their petrographical and other petrophysical properties shows the following:

a. The formation resistivity factor decreases by increasing the effective porosity of the rock and hence it can be used for the evaluation of the effective porosity of rocks.

b. By using the least square method to calculate the constants C and m in Whyllie's formula [12] which has the form:

$$F = C \phi_e^{-m}$$

Three different values were found for the three different types of lithologies as follows:

For dolomitic limestones: $\log F = 0.62 - 0.25 \log \phi_e$,

For limestones: $\log F = 0.58 - 0.29 \log \phi_e$,

For marly limestones: $\log F = 0.54 - 0.30 \log \phi_e$.

These values are calculated from the resistivity measurements for samples saturated with NaCl solution of the highest concentration (120000 ppm) which has electric resistivity $R_W = 0.065$ Ohm.m.

c. The highest correlation factor for such relationships was found to be for dolomitic rocks. The constants C and m tend to decrease with increasing shale content in the rocks and increases with increasing Mg $CO_3$ content.

**Summary and Conclusions**

The petrographic (insoluble residue, $CaCO_3$ and $MgCO_3$ content) and the petrophysical (density, porosity, permeability and electric resistivity) properties of 58 rock samples from the Eocene rocks exposed in Sakkara and Giza Pyramids Plateau areas were studied. These studies lead to the following:

1. All the Eocene rocks of Giza Pyramids Plateau area are generally more dense and less porous than the rocks of the Sakkara area and hence the electric resistivities of rocks in the former area are higher than those of rocks in the latter area.

2. The stratigraphic subdivisions made by conventional geologic methods for Eocene rocks are very well represented by noticeable variations in the different studied petrographic and petrophysical properties. This throws light on the importance of the study of different petrophysical properties as a tool for identification and classification of different rocks.

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