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ELECTRICAL PROPERTIES OF THE LOWER EOCENE ROCKS IN QATAR

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ABSTRACT

Thirteen limestone samples representing the Rus Formation (Lower Eocene) are selected from four locations in Qatar Peninsula. These samples are subjected to electrical resistivity, porosity, shaliness factor and water saturation measurements.

Very reliable formation resistivity factor–porosity relations have been obtained at two successive resistivity measuring cycles of rock samples saturated with two different brine concentrations. The limestones of the Rus Formation in each studied area are distinguished by a characteristic mean value of shaliness. A resistivity index–water saturation relation has been performed at the actual formation water resistivity.

INTRODUCTION

Qatar Peninsula is situated halfway along the western coast of the Arabian Gulf, (Fig. 1). It is a wide, gentle anticlinal arch with a north–south main axis. The exposed stratigraphic succession in Qatar is composed of Tertiary limestones and dolomites with interbedded clays, shales and marls covered locally by Quaternary and Recent deposits. The regional geology and stratigraphy of the Qatar Peninsula have been investigated by many authors such as; Cavelier (1970); Purser (1973); Abu–Zeid and Khalifa (1983); Abu–Zeid and Boukhary (1984) and Hamam (1984).

The rock samples used in the present study are mainly from the upper part of the Rus Formation in the Lower Eocene. They are selected from four different

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pilot areas; Dukhan, Umm–Bab, Abu–Hasiyyah, and Rashidah (Fig. 1). The Rus Formation is considered to be the oldest exposed rocks in Qatar Peninsula. It is exposed specially at locations on the crests of anticlines. The Rus Formation is conformably overlying the unexposed Umm er Radhuma Formation of Palaeocene–Lower Eocene age (Smout, 1954). The Rus Formation is overlain, apparently conformably, by the Dammam Formation which constitutes the most widespread outcrops in Qatar. The Rus Formation is one of the main charged aquifers in Qatar Peninsula and many of the Arabian Gulf States. The stratigraphic setting of the Rus Formation is shown in Figure 2.

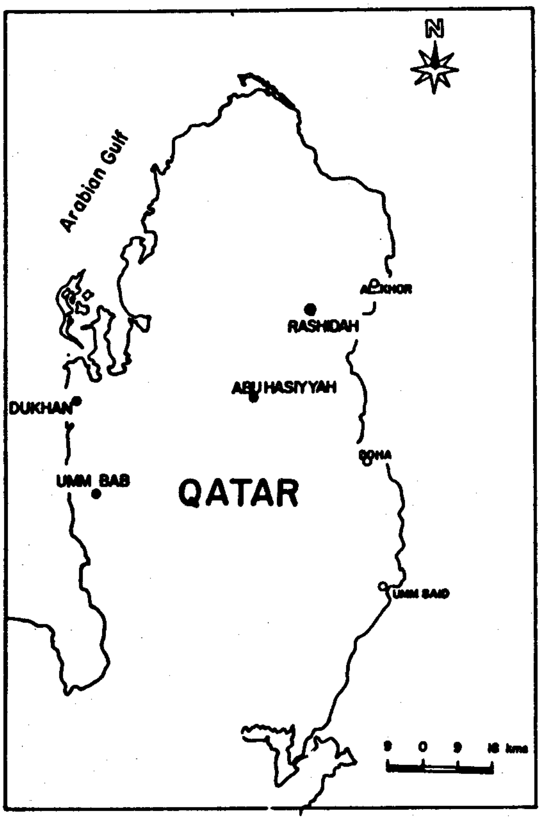

Fig. 1 : Location map of the study areas.

The study of the electrical properties of reservoir rocks is considered to be very helpful for both reservoir description and evaluation of the reservoir storage capacity with respect to both water and hydrocarbon accumulation. The prime objective of the present work is to study the electrical properties and their significances in determination of the Rus Formation characteristics.

AGE				LITHOSTRATIGRAPHIC UNITS.	
				GROUP	FORMATION
CENOZOIC	QUATERNARY.				SUPERFICIAL DEPOSITE
CENOZOIC	TERTIARY.	MIO_ PLIOCENE			HOFUF
CENOZOIC	TERTIARY.	MIO_ PLIOCENE			DAM
CENOZOIC	TERTIARY.		LUTETIAN		DAMMAM
CENOZOIC	TERTIARY.		YPRESIAN		RUS
CENOZOIC	TERTIARY.		THANETIAN MOHTIAN?		UMM ER RADHUMA
MESOZOIC	CRETACEOUS	UPPER	MAASTRICHTIAN	ARUMA	SIMSIMA
MESOZOIC	CRETACEOUS	UPPER	CAMPANIAN	ARUMA	FIQA
MESOZOIC	CRETACEOUS	UPPER	SANTONIAN	ARUMA	HALUL
MESOZOIC	CRETACEOUS	UPPER	CONIACIAN	ARUMA	LAFFAN

Fig. 2 : Stratigraphic setting of the Rus Formation (After Hamam, 1984).

MATERIALS AND TECHNIQUES

Sample Preparation

The selected rock samples representing the Rus Formation were cut into plugs of 2.5 cm diameter and 5.0 cm length, for both porosity and electrical resistivity measurements. Prior to petrophysical measurements, the limestone plugs were cleaned by use of the Soxhlet extractor. The cleanliness of the sample was determined from the colour of the organic solvent which siphons periodically from the extraction. Subsequently, ultraviolet light for fluorescence examination was used as well. The samples were dried in an electric oven at 120°C for a minimum of three hours. Then rock porosity and electrical resistivity measurements were carried out.

Porosity Measurements

Rock porosity is defined as the ratio of the volume of void space in a rock to the bulk volume of that rock multiplied by 100 to express in per cent. In the laboratory measurement of rock porosity it is necessary to determine only two of the three basic parameters. They are: pore volume (V_p), grain volume (V_{gr}) and bulk volume (V_b). The latter being the sum of the previous two parameters. In the present work, the sample porosity was measured by use of both the mercury pump–universal porosimeter (Ruska Instrument Code No. 101–1A) for bulk volume determination and Helium–porosimeter (Core Lab–code No. 7542–005) for grain volume determination. Hence, porosity (∅) is calculated as:

$$\varnothing = 1.0 - \frac{V_{gr}}{V_b} \cdot 100 \qquad (1)$$

Where : ∅ = Rock porosity per cent.

The determined rock porosity for the studied samples are given in Table (1).

Table 1

Porosity Measurements

Sample Number *	Volume Steel Disks Out	Gauge Reading	Dead Volume	Grain Volume	Bulk Volume	Pore Volume	Porosity (∅,%)
R–1A	24.022	12.90	5.36	16.48	20.77	4.29	20.66
R–2A	17.619	9.23	5.36	13.74	17.10	3.35	19.59
R–3U	25.603	10.32	5.36	20.64	23.58	2.93	12.45
R–4U	24.022	11.88	5.36	17.50	20.54	3.03	14.79
R–5D	17.619	8.55	5.36	14.42	17.53	3.10	17.68
R–6D	17.619	13.52	5.36	9.45	14.94	5.48	36.68
R–7D	17.619	11.65	5.36	11.32	17.33	6.01	34.70
R–8D	17.619	9.69	5.36	13.28	16.83	3.54	21.03
A–7U	14.396	7.39	5.36	12.36	13.67	1.30	9.53
A–1A	17.619	9.36	5.36	13.61	14.93	1.31	8.77
Ra7R	19.200	10.18	5.36	14.38	17.93	3.54	19.79
Ra7′R	19.200	9.80	5.36	14.76	17.57	2.80	15.99
Ra9R	14.397	8.85	5.36	10.90	13.96	3.05	21.87

* Sample No. ending by letter – A : Abu Hasiyyah, U : Umm Bab, D : Dukhan and R : Rashidah.

Electrical Resistivity

The electrical resistivity of limestone core samples was measured by use of core Lab Inc. A–C bridge (cat. No. 100A). The measuring techniques are outlined by Hassan and El-Sayed (1983). The electrical resistivity of samples fully saturated with brine solution (R_o) was measured twice for two different successive brine concentrations (R_w = 0.126 and 0.054 ohm m^2/m) to study the effect of conductive solids on both the multiplier (a) and the cementaion exponent (m) in Wyllie's equation;

$$F = a \cdot \varnothing^{-m} \qquad (2)$$

Where : (F) = Formation resistivity factor.

RESULTS AND DISCUSSION

Out of the studied core samples, eight were selected for resistivity index (I) measurements. The selected samples not only vary in porosity (from 12.45% to 36.67%) but also they cover all pilot locations. According to Archie (1942), the resistivity index (I) is the ratio of the resistivity of a partially water saturated rock sample (R_t) to the resistivity of the 100 per–cent brine saturated sample (R_o). It is used as a guide to possible production of either water or hydrocarbons. The water saturation was experimentally varied using the high speed centrifuge method described by Slobod *et al.*, (1951). The resistivity index (I) is calculated for the true formation water resistivity (R_w = 0.054 ohm.m^2/m) as follows:

$$I = R_t / R_o \qquad (3)$$

Substituting for $R_o = F.R_w$

Therefore, $$R_t = F \cdot R_w \cdot C. S_w{}^{-n} \qquad (4)$$

Where: C = Multiplier,

S_w = Water saturation, fraction,

n = Saturation exponent.

Formation Factor – Porosity Relation

The laboratory measured data (Table 2) were used for formation resistivity factor calculation according to Archie's equation:

$$F = R_o / R_w \qquad (5)$$

Table 2
Resistivity Measurements

Sample No.	Pilot Area	Porosity (Ø %)	R_w=0.126 ohm m²/m		R_w=0.054 ohm m²/m	
			R_o	F	R_o	F
R–1A	Abu–Hasiyyah	20.66	09.01	071.50	04.64	085.95
R–2A	Abu–Hasiyyah	19.59	07.42	058.95	04.57	084.74
R–3U	Umm–Bab	12.45	16.71	132.68	06.25	115.79
R–4U	Umm–Bab	14.79	04.96	039.39	02.40	044.59
R–5D	Dukhan	17.68	04.07	032.35	02.01	037.26
R–6D	Dukhan	36.68	03.89	010.17	00.54	010.50
R–7D	Dukhan	34.70	02.44	011.38	00.65	012.00
R–8D	Dukhan	21.03	03.83	030.46	02.15	039.93
A–7U	Umm–Bab	09.53	13.61	108.05	05.95	110.30
A–1A	Abu Hasiyyah	08.77	79.32	629.53	43.36	803.01
Ra7R	Rashidah	19.79	20.15	159.94	06.67	123.67
Ra7'R	Rashidah	15.87	13.00	103.17	11.02	204.15
Ra9R	Rashidah	21.87	06.61	52.52	03.15	058.48

Figures (3A and B) exhibit the formation resistivity factor porosity relations for the limestone samples of the Rus Formation at the two different brine concentrations. The regression line equation, the coefficient of correlation (r), the probability of existence (phi), the multiplier (a), and the cementation exponent (m) of the general equation ($F=a.\varnothing^{-m}$) have been calculated for each brine concentration. The analysis of the calculated formulae shows that formation factor–porosity relations (Figs. 3A & B) are reliable with a good fit. That is confirmed by the consistently high values of both probability of existence (phi) and coefficient of correlation (r) for the two formation factor–porosity relations deduced for the two measuring cycles.

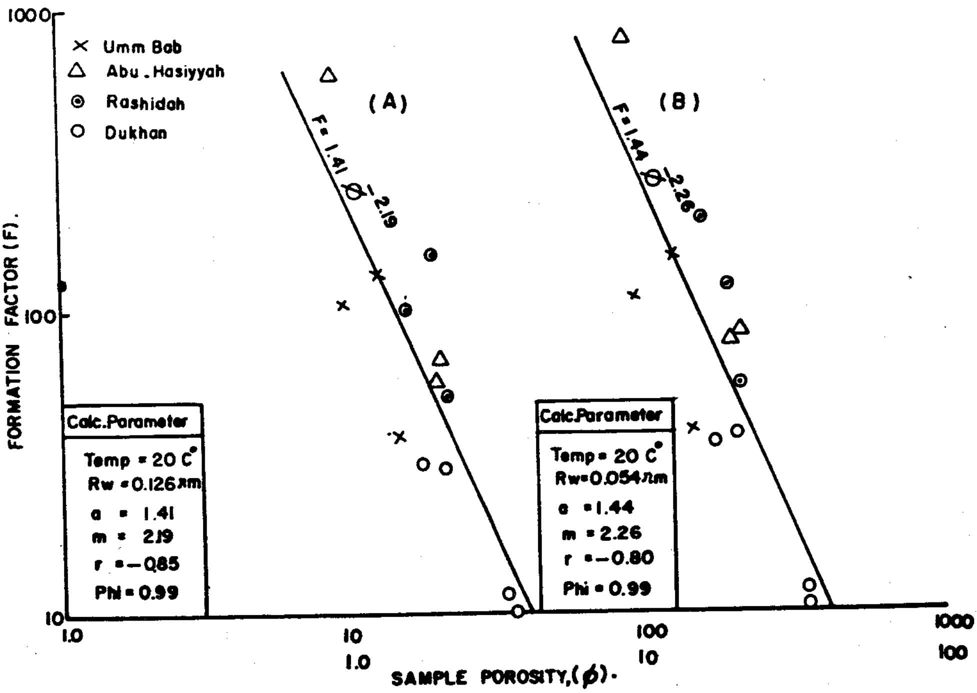

Figure 3 : Formation factor–porosity relations.
(A) at R_W = 0.126 ohm m²/m (B) at Rw = 0.054 ohm m²/m.

The cementation exponent (m) is found to vary from 2.19 to 2.27. It increases slightly with the vigorous increase of the brine concentration. The multiplier (a) of the general equation ($F = a \,.\, \emptyset^{-m}$) varies from 1.41 to 1.44. The noticed variation in values of both the cementation exponent (m) and the multiplier (a) for the studied limestone samples is considered to be limited compared with the range of variation of these constants for shaley sandstones. These limited variations reveal merits for existence of small quantities of conductive solids in the rock pore spaces. The conductive solids in the limestone samples of the Rus Formation are mainly authigenic clays and iron oxides (El–Sayed, 1986).

If the average formation water resistivity (R_W) of the Rus Formation is 0.054 ohm m²/m. then, the most reliable formation resistivity factor– porosity relation which can be used for evaluation of the porosity and for refining resistivity logs for conductive solids is:

$$F = 1.44\, \emptyset^{-2.27} \qquad (6)$$

In addition, the cementation exponent (m) is calculated when the multiplier is put as a constant value (a = 1.0) as:

$$F = 1.0 \, \varnothing^{-2.47} \quad \text{(Archie's Formula)} \tag{7}$$

True Formation Factor — Porosity Relation

The formation factor (F_{lim}) for the limestone samples of the Rus Formation is calculated at a hypothetical saturating brine resistivity (R_W = 1.0 ohm cm²/cm). It is considered to be corrected for the conductive clays (Hill and Millburn, 1956). Fig. 4, reveals the relationship between the calculated true formation resistivity factor and the fractional porosity. It is characterized by a high value of coefficient of correlation (r = – 0.78). This relation is controlled by the equation:

$$F_{lim} = 1.68 \, \varnothing^{-2.31} \tag{8}$$

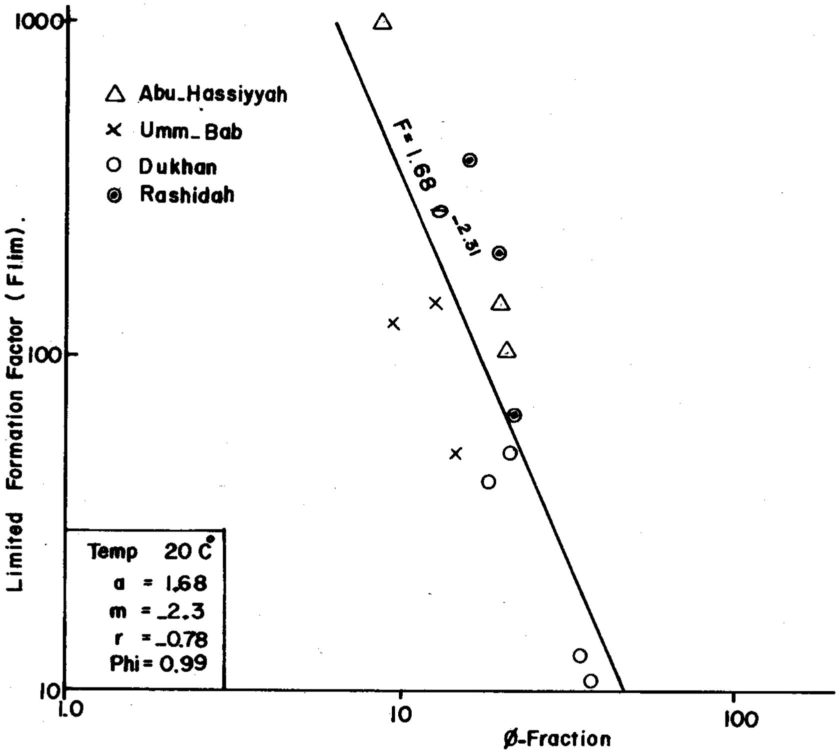

Figure 4 : Limited Formation factor versus porosity fraction (∅).

Shaliness Factor

Shaliness factor (b) is a function of clay content in the argillaceous rocks (Hill and Millburn, 1956). The shaliness factor (b) is calculated for the limestone samples of the Rus Formation by use of the following equation (Hill and Millburn, 1956):

$$F_a = F_{lim} \, (100 \, R_w)^{b \log (100 \, Rw)} \qquad (9)$$

Where : F_a = Apparent formation factor.

Figure 5, presents a plot of the average of the ratio of ($\log F_a / \log F_{lim}$) versus (R_w) for different samples selected from each study area (Fig. 1). Using this plot it is easy to differentiate between the types of the studied carbonate rocks. Each study area is distinguished by a characteristic average value of shaliness factor (b). The limestone samples obtained from Rashidah are characterized by a distinctive high value of shaliness (b = −0.35). It may indicate a rapid muddy environment of sedimentation. The samples from Abu−Hasiyyah have a medium value of shaliness factor (b = −0.24). Samples of both Dukhan and Umm−Bab are represented by distinctive low values of shaliness factor. The calculated shaliness factor (b) for these samples are found to be −0.12 and −0.10 respectively. These low values indicate that this limestone type is the cleanest one among the studied rocks. It may indicate stable shelf sedimentation in calm clear water.

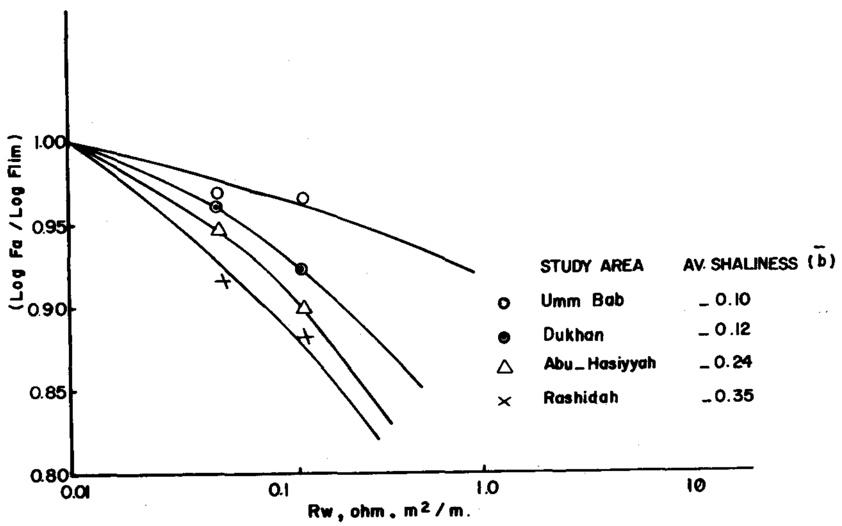

Figure 5 : Experimental to Extrapolated Formation Factor ($\log F_a / \log F_{lim}$) versus Water Resistivity (R_w).

Resistivity Index

Figure 6, represents the resistivity index measured values for eight cylinderical limestone samples at different water saturation controlled by a fixed centrifuge regime at the true formation water resistivity (R_w = 0.054 ohm m^2/m). This relation is characterized by a high value of coefficient of correlation (r = −0.85). The calculated saturation exponent of the general Archie's equation ($I = c. S_w^{-n}$) is slightly low (n = 1.79). It implies that these samples are entirely water – wet, while they have a small quantity of conductive clay in their pore structures. If the resistivity index (I) is accurately estimated from the resistivity logs, therefore the plot in Fig. 6, may be used to determine the average water saturation of the Rus Formation. When water reserve estimates are being made it is required to determine water saturation (S_w) using the Archie's formula:

$$S_w = \sqrt[n]{\frac{c.\, a\, R_w}{\varnothing^{m} .\, R_t}} \qquad (10)$$

Where : n, c, a, and m are laboratory estimated. However, $\varnothing$, R_w , and R_t can be calculated from well logs.

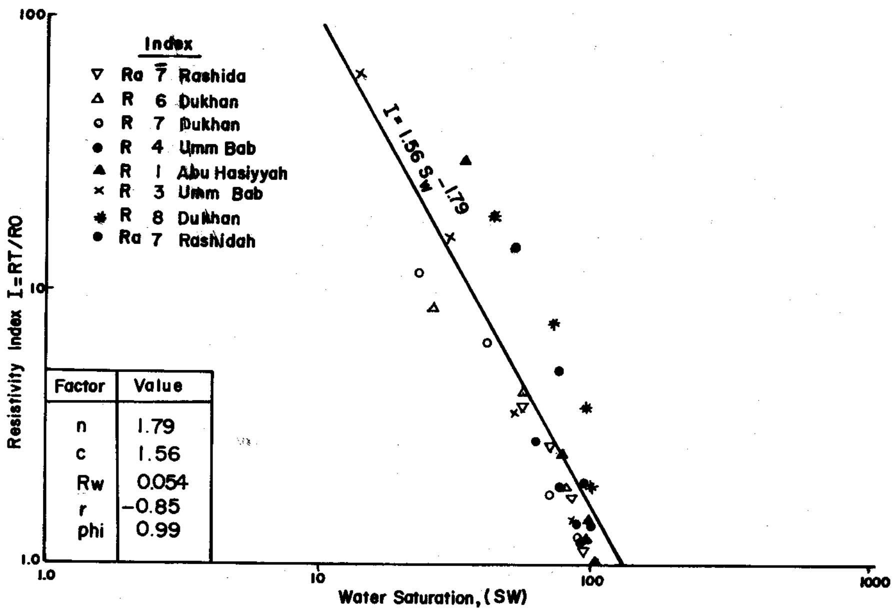

Figure 6 : Resistivity Index (I) – Water Saturation (S_w) Relation.

CONCLUSIONS

1. Reliable formation factor–porosity relations was obtained.
2. The studied limestone samples of the Rus Formation are distinguished by characteristic value of shaliness (b) in each study area:
3. The studied samples are entirely water - wet, so that the calculated petrophysical parameters may be used for water reserve estimation.

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الخواص الكهربائية لصخور الأيوسين الأسفل في قطر

عبدالمقتدر عبدالعزيز السيد

تم قياس المقـاومـة الكهربائية النوعية لعينات صخرية جُمعت من متكون الرس التابع للأيوسين الأسفل في عدة أماكن في دولة قطر وذلك عندما كانت العينـات مشبعـة (١٠٠٪) بمحلول كلوريد الصـوديوم عنـد تركيزات مختلفة ومقاومة كهربائية = ٠,١٢٦ ، ٠,٠٥٤ ، ٠ أوم متر٢ /متر. وقد دُرست العلاقة بين معامل التكوين ومعامل مسامية الصخر عند كل تركيز ملحي وعُولجت إحصائياً لتعين كل من معادلة الانحدار الخطي والثوابت المميزة لهذه الصخور والتي يمكن استخدامها في تفسير التسجيلات الكهربائية لهذه الصخور.

ولقد استخدمت القياسات الكهربائية وكذلك قياسات المسامية في حساب كل من معـامل الطفلة ومعامل التكوين الحقيقي (عند مقاومة كهربائية نوعيه للمحلول = ٠,٠١٠ أوم متر٢ /مـتر) للعينات قيد الدراسة. وأمكن باستخدام مُعامل الطفلة التمييز بين العينات التابعة لكل موقع موضع الدراسة.

ولقد دُرست العلاقة بين دليل المقاومة الكهربائية ودرجة تشبع الصخور بمياه التكـوين ، وتم تعيين الثـوابت المميزة لهذه الصخـور والتي تحدد مقدرتها على التشبـع بالمياه . وتميزت هذه العـلاقـة بمعـامـل ارتباط عالي مما يتيح إمكانية إستخـدامها في حساب مقدار الإحتياطي المخزون من المياه الجوفية في متكون الرس في دولة قطر.