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DENSITY EFFECTS ON SEISMIC REFLECTIVITY OF THE UPPER CRETACEOUS ROCK UNITS IN THE NORTH OF QARUN LAKE, NORTHEAST WESTERN DESERT, EGYPT

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تأثير الكثافة على الانعكاسية السيزمية لصخور الكريتاوى العلوى فى شمال بحيرة قارون بشمال شرق الصحراء الغربية، مصر

الخلاصة: تعتبر كثافة الصخور أحد أهم البارامترات الفيزيائية فى الدراسات الجيوفيزيائية. وتهتم الدراسة الحالية برسم عدد من العلاقات بين السيزمية الانعكاسية وبعض الخواص الفيزيائية كالمسامية والكثافة والتركيب الصخرى لصخور الكريتاوى العلوى والممثلة بتكوين أبو رواش وتكوين البحرية لأربع آبار فى منطقة الدراسة. وقد استخدمت تسجيلات الآبار المختلفة لحساب مكونات الصخور والخواص البتروفيزيائية للوحدات الصخرية المدروسة. كما تم تفسير بيانات السرعة والكثافة لتعريف الانعكاسية السيزمية عند الحدود الفاصلة بين الوحدات الصخرية، وقد أثبتت النتائج أن القيمة المحسوبة لمعامل الانعكاس تكون مرتفعة عند الحدود الفاصلة بين الصخور الفتاتية وغير الفتاتية.

ABSTRACT: *The density of rocks is a significant physical parameter in geophysical studies, particularly in gravity and seismic interpretation, as the anomaly sources is due to local variation in density. Formation density compensated logs are useful tools to study the density distribution within the thickness range of the sedimentary section.*

The present study is concerned to set some relationships between seismic reflectivity and the physical properties (porosity and density) and the lithologic composition of the Upper Cretaceous rock units (Abu Roash and Bahariya Formations) in the area located to the north of Qarun lake, northeast Western Desert, Egypt. The available well logging data are used to determine the lithologic components, porosity and density of the studied rock units in four wells (Qarun G-1X, East Qarun-1X, N.B.Q.-2X and Gindi Deep-1X).

The velocity and density data are interpreted in order to define the seismic reflectivity at the interface of the rock units. The results proved that the reflection coefficient estimated from velocity and density is maximum at the boundaries between clastic and non-clastic rocks.

INTRODUCTION:

PURPOSE AND SCOPE

The purpose of this study is to provide a geological and geophysical framework for delineating the physical properties and rock composition of the Upper Cretaceous rock units in the north of Qarun Lake, northern Western Desert, Egypt. The study is concerned primarily with the relation between P-wave velocity, density and porosity of the studied rock units. From a geophysical point of view, porosity and velocity data are of the most interesting parameters and numerous studies have investigated the relationship between P-wave velocity, porosity and burial depth (e.g., Japsen, 1998). The youngest sediments have high porosity and low sonic velocity (Mayer, 1979). Deeper layers are more consolidated and have lower porosity and higher sonic velocity (Wilkens et al., 1992). Sonic velocity (logging data) of the unconsolidated part of the sediment is a function of lithology, porosity and stress (e.g., Urmos et al., 1993). After core retrieval, the velocity goes down, whereas the porosity remains practically unchanged (Fabricius, 2000). Vertical velocities tend to be lower than horizontal. This may be an effect of horizontal microfracturing in unconsolidated sediments upon core retrieval (Bassinot et al., 1993). Regarding the rock density, it was found that it increases with depth due to compaction. Many papers in this field were carried out (e.g., Hedberg, 1926and 1936, and Athy, 1939). The variation of density with rock type and depth was discussed by Ricken and Chilingarian, (1974) and Maxant, (1975 and 1980).

SETTING AND DATA BASE

The investigated area is located in the eastern part of the north Western Desert of Egypt, between latitudes 29° 30\ and 29° 50\ to the north, and longitudes 30° 20\ and 31° 00\ to the east (Fig. 1). It is bordered by Wadi El-Natrun to the north, Qarun Lake and Wadi El-Raiyan to the south, the Qattara Depression to the west and the River Nile to the east. The study area slopes from the north to the south towards Qarun Lake and is covered mainly by the Lower Miocene "Moghra Formation" (Tammam, 1996). This area is in the unstable shelf zone of Egypt and is divided into two main basins, the southern one, where the Paleocene-Eocene rocks "Apollonia Formation" attains its greatest thickness, and the northern one, where the Upper Cretaceous rocks "Abu Roash and Khoman Formations" reach their maximum thickness (Abd El-Aziz et al., 1998).

The database used in this study comprises well-log and well seismic measurements, for the studied wells (Qarun G-1X, East Qarun-1X, N.B.Q.-2X and Gindi Deep-1X). The porosity logs (sonic, density and neutron) are used to determine the porosity and the lithologic components of the studied formations. Sonic logs and well seismic measurements are utilized to obtain the velocity of compressional waves.

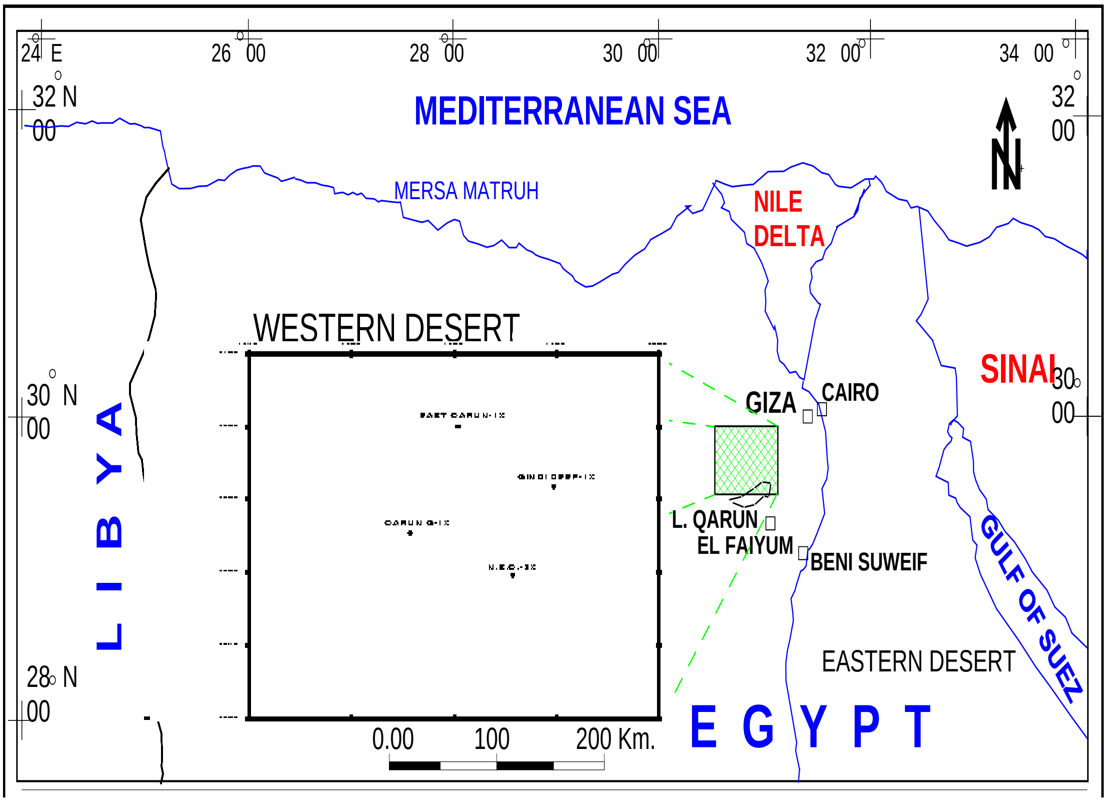

Fig. (1): Location map showing the study Area

STRATIGRAPHIC AND FACIES FRAMEWORK

The general stratigraphic succession of the Northern Western Desert of Egypt includes different sequences ranging in age from the Cambrian to the Recent (Fig. 2). Drill hole information indicates that, the average thickness of the comparable sedimentary cover increases northwards.

Accordingly the generalized stratigraphic succession that rests over the Basement Complex consists of Paleozoic, Mesozoic and Cenozoic rock units. The majority of the studied wells are bottomed in the Mesozoic rocks (Bahariya Formation), except for Gindi Deep-1X well that reaches the Basement.

The lithofacies analysis of the investigated area shows that Bahariya Formation consists mainly of argillaceous sandstone. Lithofacies analysis of Abu Roash Formation, on the other hand, shows a change in composition from one member to another. The Abu Roash "G" Member consists mainly of shale and sandy shale rocks, while the Abu Roash "F" Member is formed of limestone that is graded into argillaceous limestone and calcareous shale. The Abu Roash "E" Member consists of argillaceous sandstone. The Abu Roash "D" Member is formed of shaly and argillaceous limestone, limestone, sandy limestone and calcareous sandstone. Regarding Abu Roash "C" Member, it consists of shale, calcareous shale and argillaceous limestone. The Abu Roash "B" Member is composed mainly of limestone and argillaceous limestone. Finally, the Abu Roash "A" Member consists of calcareous sandstone, sandy limestone, and argillaceous sandstone.

METHODS

The relationship between the rock properties and velocity requires the identification of porosity and density of the studied rocks.

Density: Density of rocks depends directly upon the density of the minerals making up the rock. Density variations play a significant role in velocity variations, where, high density usually corresponds to high velocities (Sheriff and Geldart, 1983). Density is determined from the density logs that measure the bulk density of the rocks. The measured density consists of the combined effect of the matrix density, shale density and fluid density. Density log readings must be corrected to give the density of the virgin zone because the invasion process affects density measurements, thus density log readings should be recalculated by using Schlumberger, (1986) equation:

$$(\rho_b)_{corr.} = \Phi S_w\ \rho_w + \Phi_h\ \rho_h + (1-\Phi)\ \rho_{ma}.$$

Porosity: Formation porosity can be determined from porosity logs (sonic, density and neutron). Good results are obtained by combining the readings of two porosity logs. In this study the combination of density and neutron readings are used in clean and shaly formations.

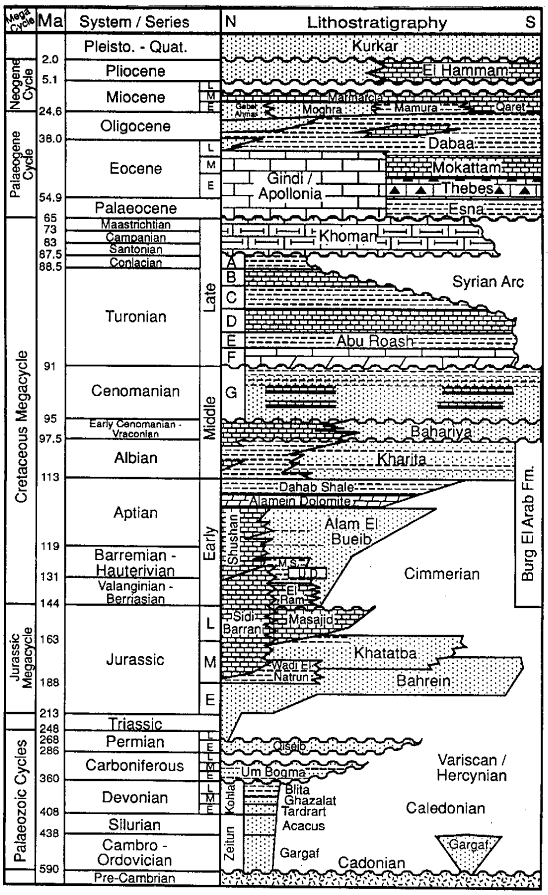

Fig.(2). Stratigraphic column of the northern Western Desert (Schlumberger, 1984).

From density log: porosity in clean and shaly formations is determined by using Wyllie equation, (1963);

$$\Phi D = \frac{\rho ma - \rho b}{\rho ma - \rho f} \qquad \text{(clean formations)}$$

$$\Phi D = \frac{\rho ma - \rho b}{\rho ma - \rho f} - Vsh \frac{\rho ma - \rho sh}{\rho ma - \rho f} \qquad \text{(shaly formations)}$$

From neutron log: porosity for clean and shaly formations is determined by using Allen, et al., (1965) equation;

$$\Phi N = \Phi Nlog \qquad \text{(clean formations)}$$

$$\Phi N = \Phi Nlog - Vsh\ \Phi Nsh \qquad \text{(shaly formations)}$$

Lithology: it is the most obvious factor affecting velocity, the ranges of velocity of different rock types overlap so much that it does not provide a good basis for distinction by itself. Identification of rock constituents in this study takes place by using the four simultaneous equations introduced by Burke et al., (1969) and Harris and McCammon, (1969) in which the normal rock constituents (porosity, shale, silica and carbonate volumes) can be determined using data derived from porosity logs.

Velocity determination: the most direct method for determining velocity is by using well surveys that include the conventional method of shooting a well and sonic logging (or continuous velocity survey).

Reflectivity: the ratio of the amplitude of the reflected wave compared to the amplitude of the incident wave, is known as the reflection coefficient or reflectivity (Sheriff, 1980). The product of density and velocity (ρV) is known as the acoustic impedance (AI). The reflection coefficient (Rc) for vertical incidence is calculated at each boundary from;

$$Rc = AI2 - AI1 / AI2 + AI1$$

The reflection coefficient is a measure of the contrast of the properties between two layers, where the quantities on which reflection coefficient depends directly on the lithology, porosity and fluid content of the rocks on either sides of the interface. The algebraic sign associated with the reflection coefficient depends upon the relative values of the acoustic impedance at the media adjacent to the interface. When the incident wave is propagating from a medium of low acoustic impedance into another one of higher acoustic impedance, the corresponding reflection coefficient is positive. On the other hand, when the wave travels from a medium of higher acoustic impedance into one of low acoustic impedance, the reflection coefficient will be negative (Peterson et al., 1955).

RESULTS AND DISSCUTION

A number of plots (continuous logs) were drawn to show the vertical changes of the different lithologic components (shale, sandstone and carbonate volumes) for the Upper Cretaceous rocks (Abu Roash and Bahariya Formations) in the four studied wells. Moreover, the rock porosity (Φ%), density (ρb gm/cc) and velocity ($V\mu sec/Ft$) are plotted in the form of crossplots to reveal their vertical changes with depth. The factors affecting the velocity are illustrated by some crossplots relating velocity-density, velocity-porosity and porosity-density. Also, the reflectivity of the studied wells has been constructed by using the density and the estimated velocity.

Presentation of Lithology vs. Depth, Porosity vs. Depth, Density vs. Depth and velocity vs. Depth:

1- Qarun G-1X well: The vertical distribution of the lithologic constituents of the Upper Cretaceous rocks in this well (Fig. 3) shows that, the sandstone matrix is abundant in the Abu Roash "G" Member and Bahariya Formation, while it decreases in the other members.

Carbonate volume is higher than sandstone in the Abu Roash "D" Member. The shale content in this well increases in the Abu Roash "G" Member and is considerable in Abu Roash "C", "E" Members and Bahariya Formation. Fig. (4) reveals the relationship between depth and the recorded parameters (Φ, ρb and V) in Qarun G-1X well. Porosity is high in the Abu Roash clastic members (E and G) due to the enrichment in sandstone. The density is increased in the Abu Roash "D" Member where it reaches 2.7 gm/cc. The velocity is also increased at the Abu Roash "D" Member, and decreased in the other members and in Bahariya Formation. The matching between the increase in velocity and density in the Abu Roash "D" Member proves that velocity depends mainly on the density of the rock.

2- East Qarun-1X well: Fig. (5) shows the prevalence of argillaceous and carbonate matrix with considerable quantities of sandstone. In the Abu Roash clastic members (C, E and G) and Bahariya Formation, sandstone and shale are the predominant lithology. Carbonates are abundant in the Abu Roash "D" and "F" Members. The argillaceous matter content is increased in this well. On the other hand, Fig. (6) illustrates the relationship between the formation depth and the recorded parameters (Φ, ρb and V). Porosity is high at the Abu Roash clastic members. Density increases in the Abu Roash "D" and "F" members and velocity shows a considerable concordance with density.

3- N.B.Q.-2X well: The lithologic components of the studied rock units in N.B.Q.-2X well are represented in Fig. (7). It is composed essentially of calcareous matrix with considerable amounts of shale and sandstone. On the other hand, Fig. (8) reveals the relationships of depth versus porosity, density and velocity. The porosity is generally high in this well, but it is intermediate in the Bahariya Formation. The density is high at the Abu Roash "G" Member and Bahariya Formation due to the calcareous nature of rocks in this well.

4- Gindi Deep-1X well: Fig. (9) shows the predominance of sandstone and shale in the Abu Roash clastic Members and Bahariya Formation. Carbonates are predominant in Abu Roash "D" and "F" Members. Fig. (10) illustrates the change of the recorded parameters with depth.

Porosity is high in the clastic rocks, while density and velocity are high in the zones of low porosity.

From the above discussion it is clear that variations of rock lithologies are strongly affecting the velocity of the seismic wave. So, increase of velocity is proportional to increase in the limestone percentage of the rock. Also, a decrease in velocity is proportional to an increase in the clay content in the sandstone and/or limestone. Moreover, low velocity and low density characterize the high porosity rocks, while, density and velocity tend to increase at low porosity rocks.

Velocity, Density and Porosity Crossplots:

1-Velocity-Density Crossplots: Fig. (11) represents the relationships between velocity and density of the Upper Cretaceous rocks in the study area. This relation shows that velocity increases with increasing density. Moreover, the relation between velocity and density of sandstone (Fig. 12) and carbonates (Fig. 13) shows that, generally, the density of sandstone is lower than that of carbonate. As a result of this the velocity of carbonate is higher than that of sandstone. This reflects the dependence of velocity on the mineral composition and the granular nature of the rock matrix.

2- Velocity-Porosity Crossplots: The relationship between velocity and porosity for the studied wells is represented in Fig. (14). This relation reveals that, in general, an increase in the porosity of a rock leads to a decrease in its velocity. On the other hand, the velocity-porosity relationship for sandstone (Fig. 15) and carbonate (Fig. 16) illustrates the high velocities in carbonates than that in sandstone. Moreover, the porosity in sandstone, as expected, is higher than that in carbonates. The scattered points which show a random distribution on the crossplot is due to the presence of many factors affecting the velocity (Dominico, 1984).

3- Density-Porosity Crossplots: This relation is illustrated in Fig. (17). Such relation shows that, an increase in the density of the rock leads to a decrease in its porosity. The relationship between density-porosity in sandstone (Fig.18) and carbonate (Fig. 19) reveals that the density of carbonate is higher than that of sandstone, consequently, the porosity is low in carbonates, this is due to the fact that, the porosity of a rock depends on the mineral composition, fluid content and clay content.

3- Reflectivity Logs: Fig. (20) represents the reflectivity logs for the studied wells. In Qarun G-1X well, the reflection coefficient along Abu Roash "B"- Abu Roash "C" Members has the largest positive value, and along Abu Roash "E"- Abu Roash "G" Members is the largest negative value. On the other hand, the reflectivity log of East Qarun-1X well shows the greatest positive value along Abu Roash "B"- Abu Roash "C" Members, while the largest negative value is along Abu Roash "E"- Abu Roash "F" Members. The reflectivity log of N.B.Q.-2X well reveals that the largest negative value is along Abu Roash "E"- Abu Roash "F" Members while the smallest value is along Abu Roash "D"- Abu Roash "E" Members. Finally, the reflectivity log of Gindi Deep-1X shows that the largest positive reflectivity is noticed along Abu Roash "C"- Abu Roash "D" Members and the largest negative value is along Abu Roash "E"- Abu Roash "F" Members. Generally, the variation of reflectivity is due to the variation of the rock types from clastic to non-clastic.

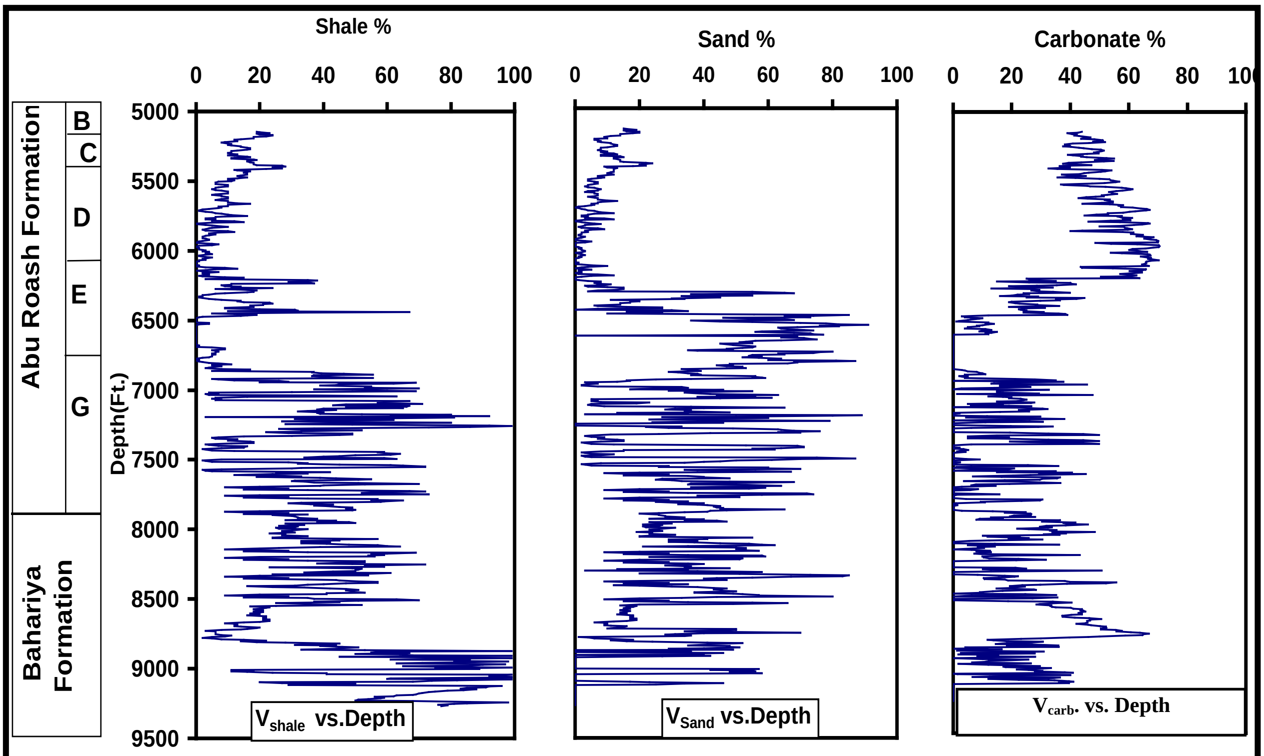

Fig.(3). Distribution of lithologies versus Depth of Upper Cretaceous Formations In Qarun G-1X Well

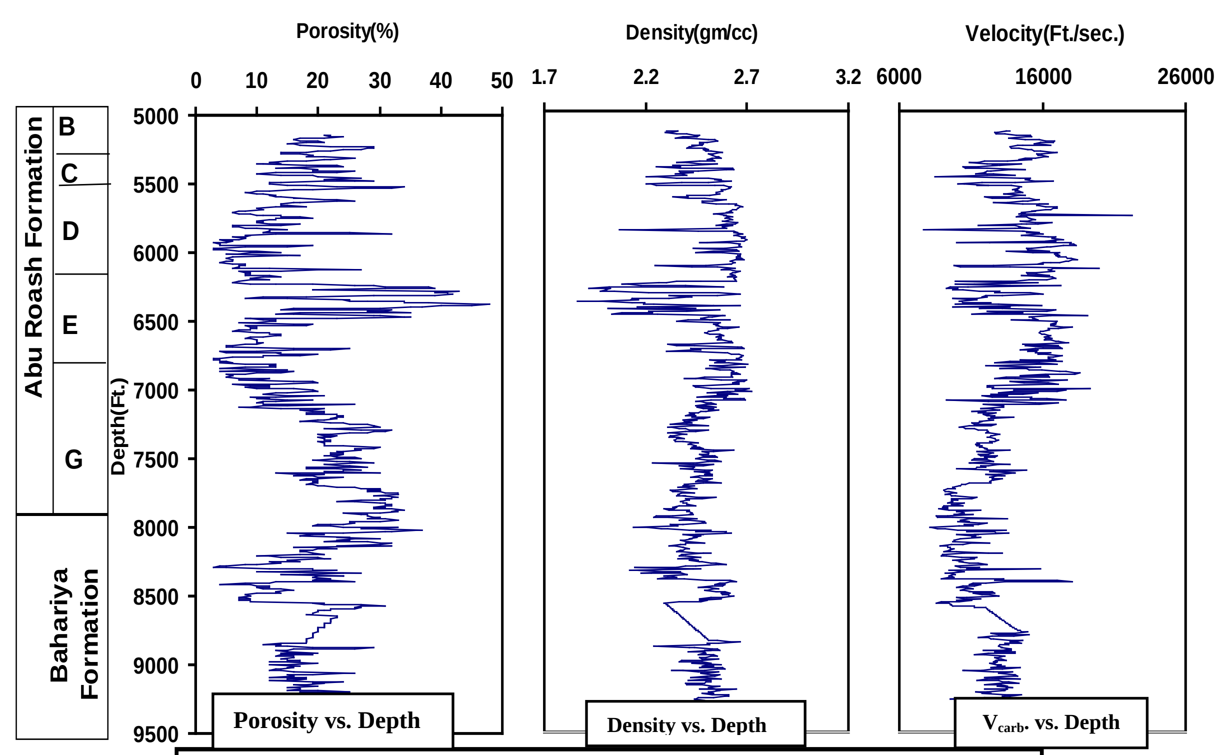

Fig.(4). Porosity,Density and Velocity versus Depth of Upper Cretaceous Formations In Qarun G-1X Well

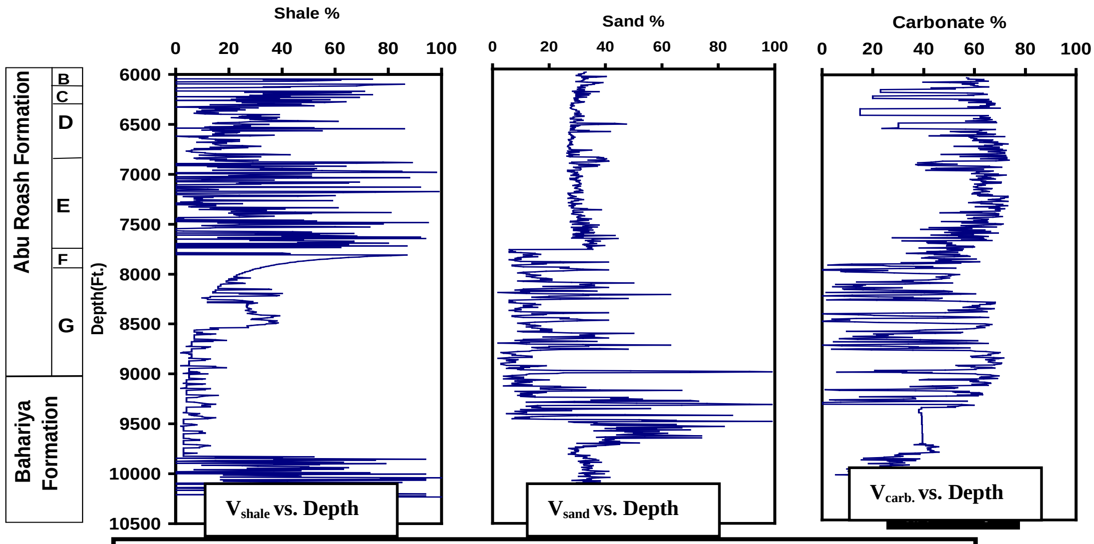

Fig.(5). Distribution of lithologies versus Depth of Upper Cretaceous Formations In East Qarun-1X Well

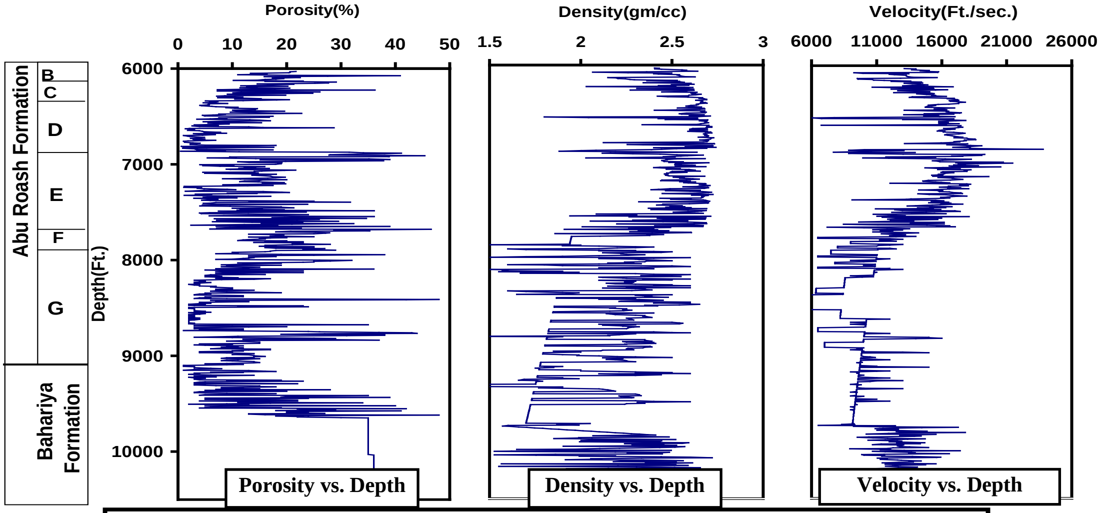

Fig.(6). Porosity, Density and Velocity versus Depth of Upper Cretaceous Formations In East Qarun-1X Well

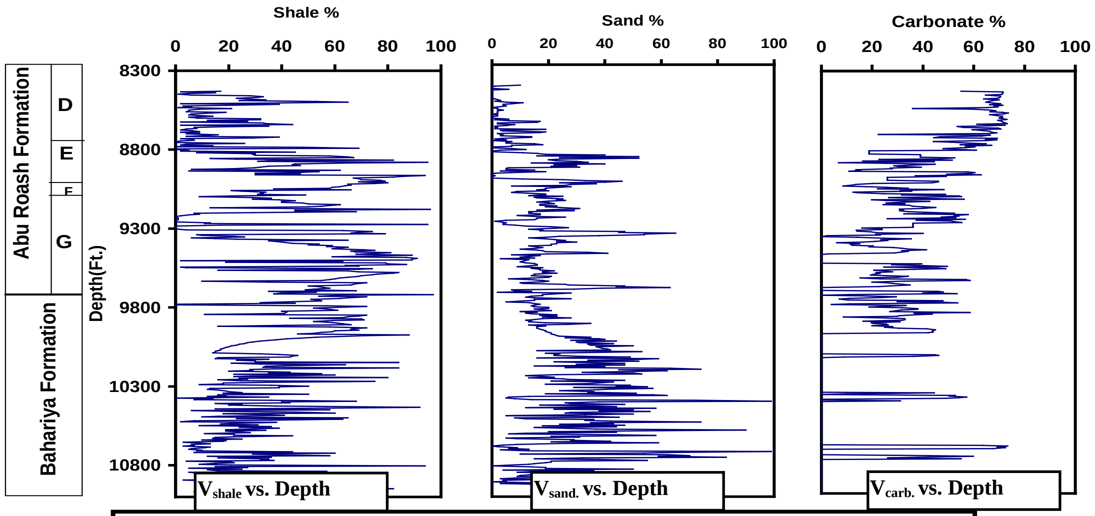

Fig.(7). Distribution of lithologies versus Depth of Upper Cretaceous Formations In N.B.Q.-2X Well

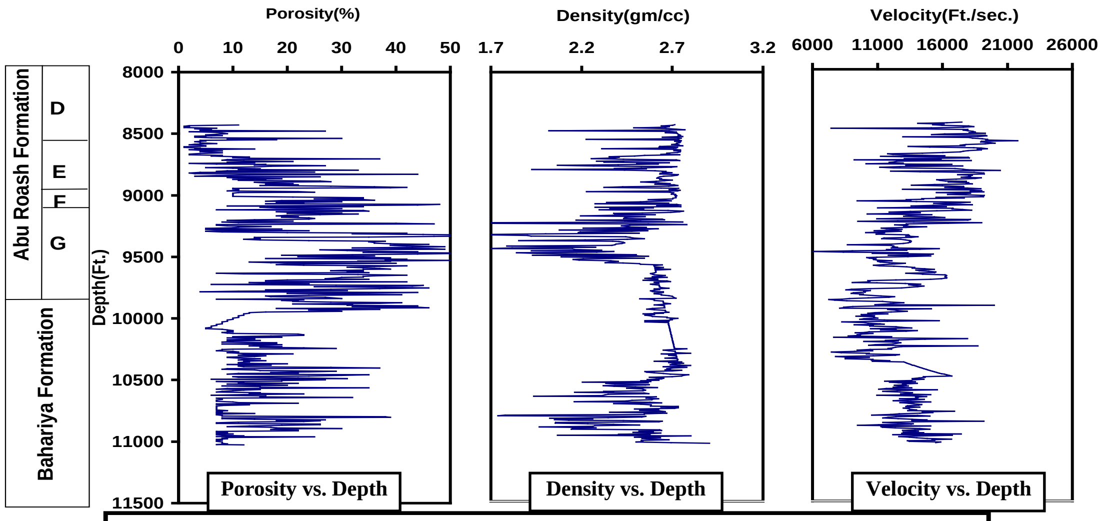

Fig.(8). Porosity, Density and Velocity versus Depth of Upper Cretaceous Formations In N.B.Q.-2X Well.

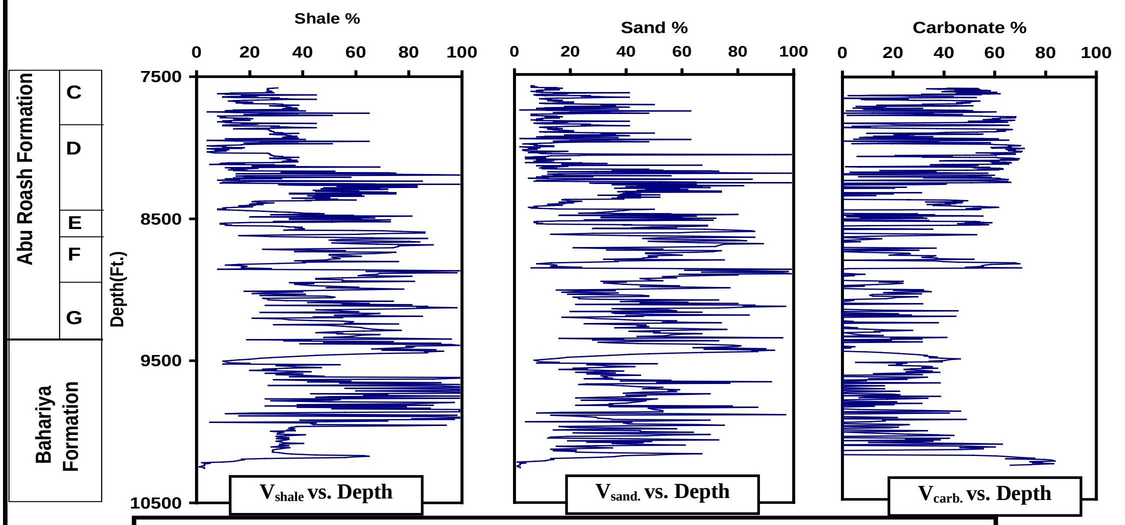

Fig.(9). Distribution of lithologies versus Depth of Upper Cretaceous Formations In Gindi Deep-1X Well

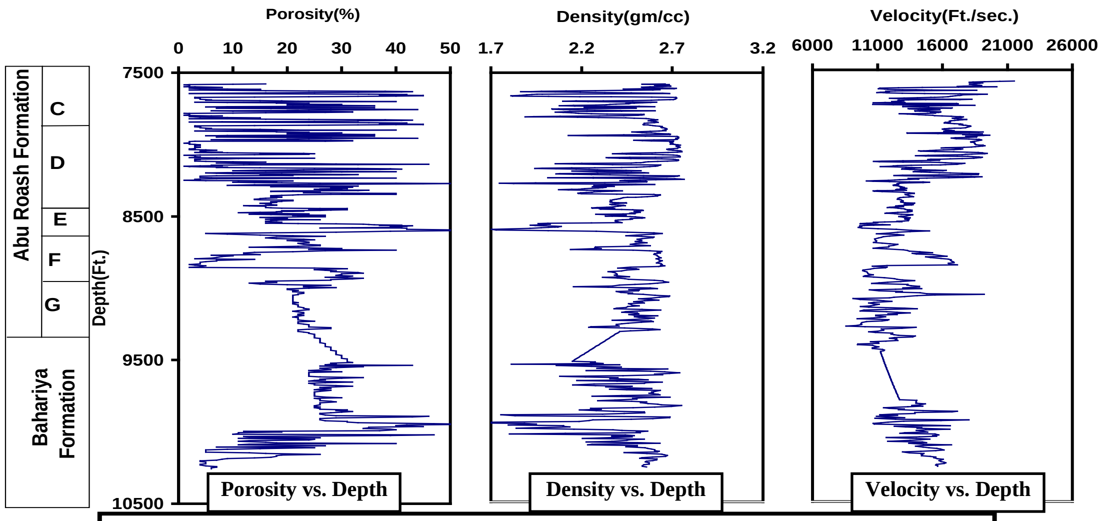

Fig.(10). Porosity, Density and Velocity versus Depth of Upper Cretaceous Formations In Gindi Deep-1X Well.

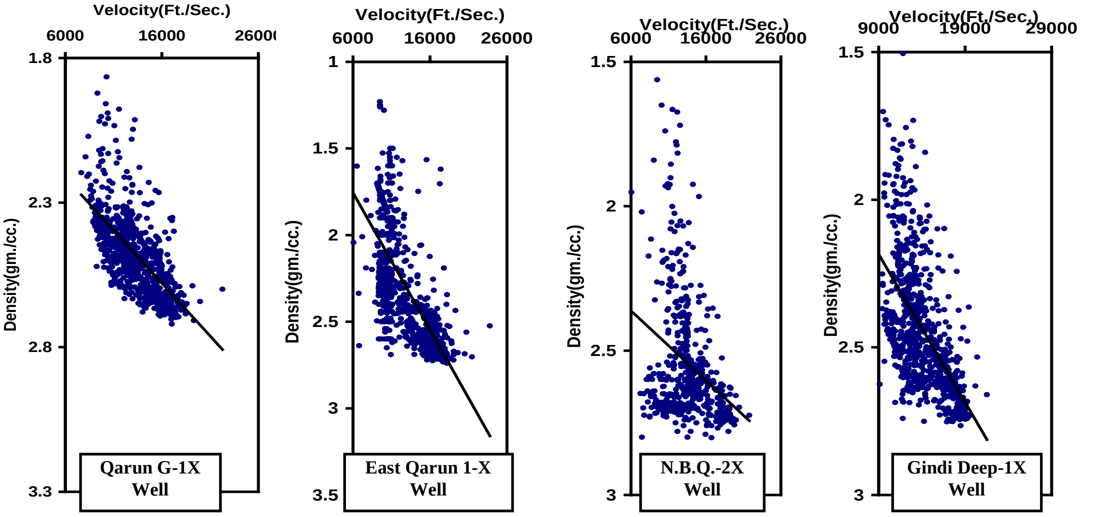

Fig.(11). Relationship between Velocity and Density in the Studied Wells.

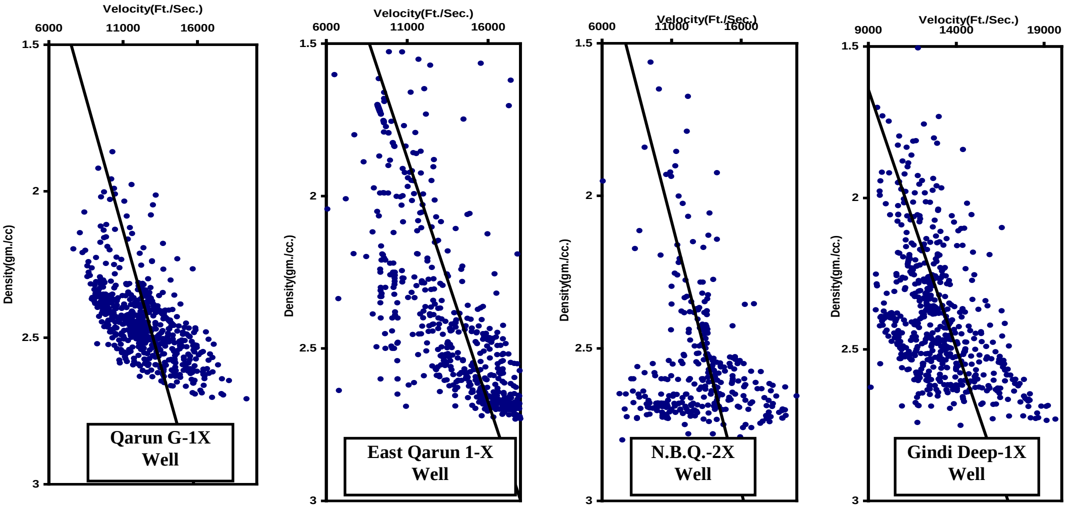

Fig.(12). Relationship between Velocity and Density for Sandstone in the Studied Wells.

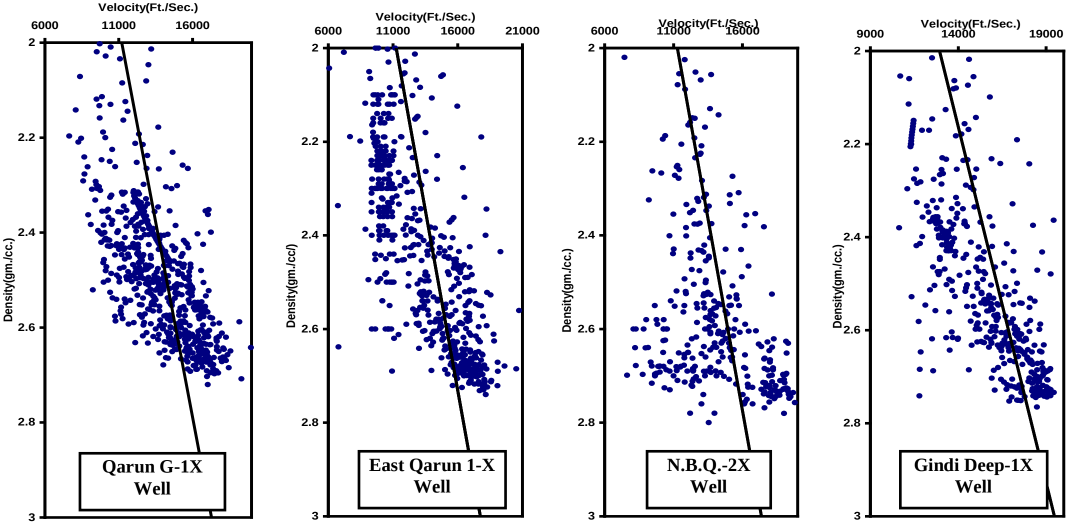

Fig.(13). Relationship between Velocity and Density for Carbonates in the Studied Wells.

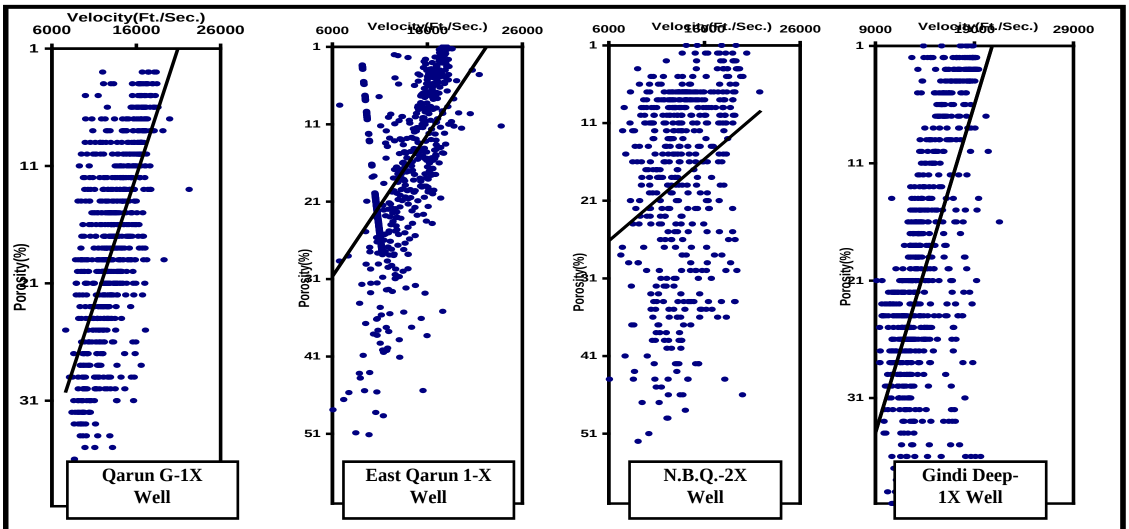

Fig.(14). Relationship between Velocity and Porosity in the Studied Wells.

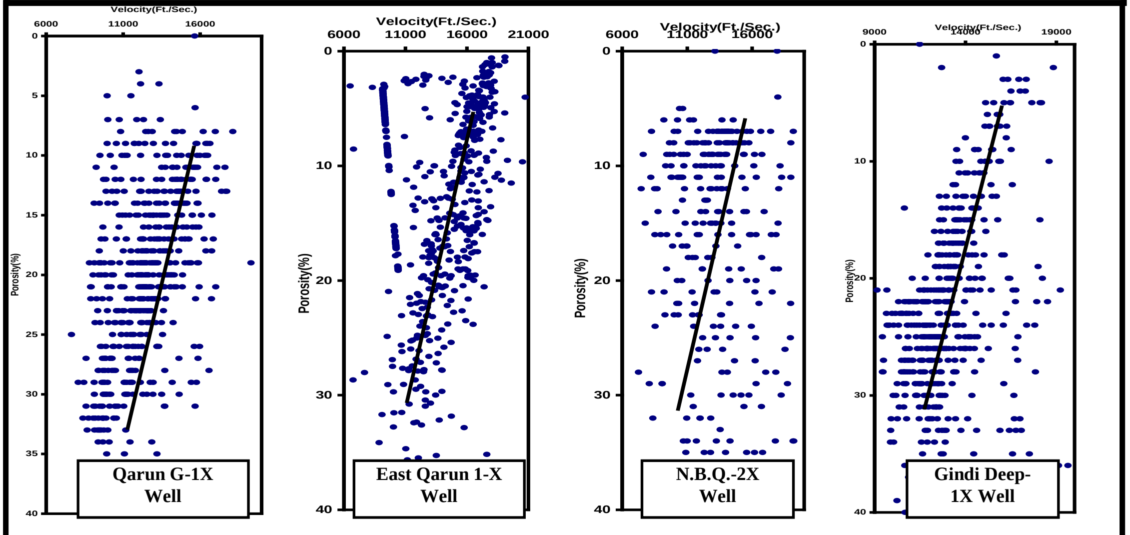

Fig.(15). Relationship between Velocity and Porosity for Sandstone in the Studied Wells.

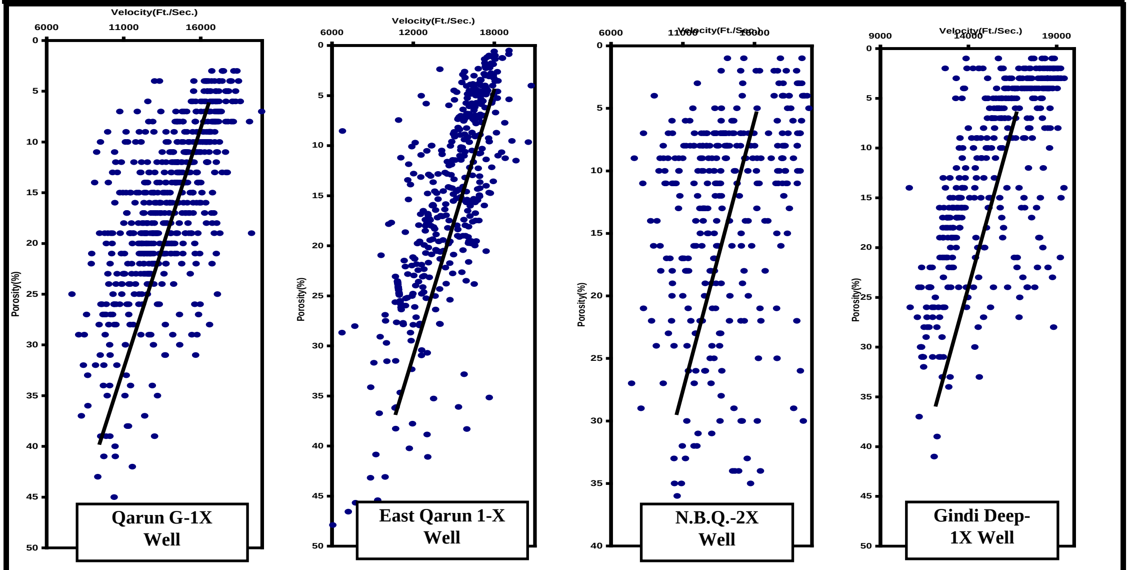

Fig.(16). Relationship between Velocity and porosity for Carbonates in the Studied Wells.

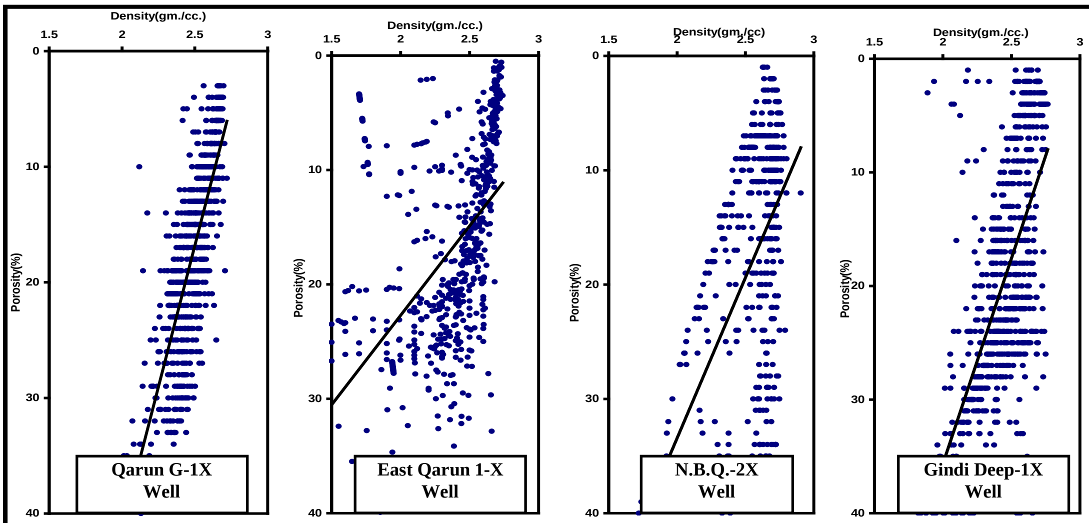

Fig.(17). Relationship between Density and Porosity in the Studied Wells.

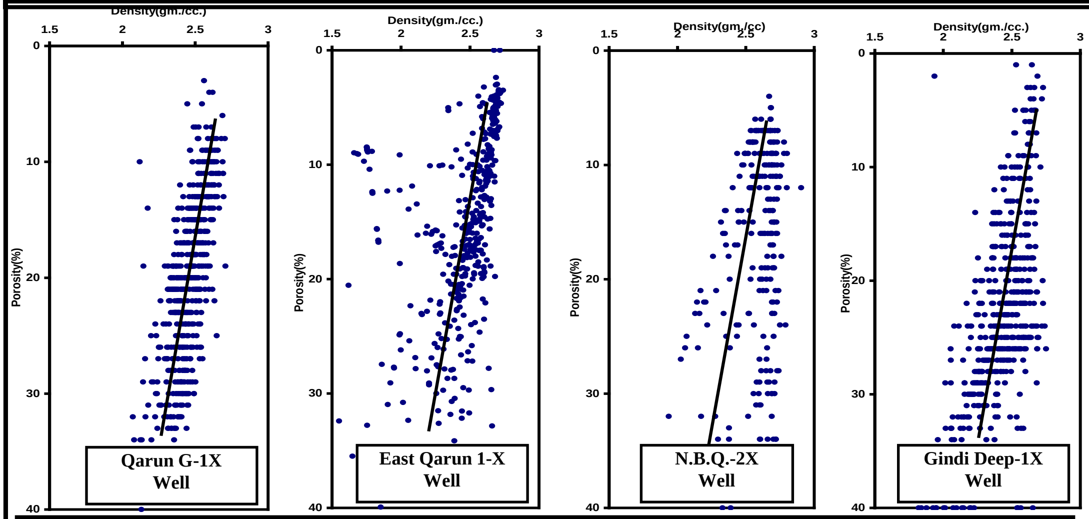

Fig.(18) Relationship between Density and Porosity for sandstone in the Studied Wells

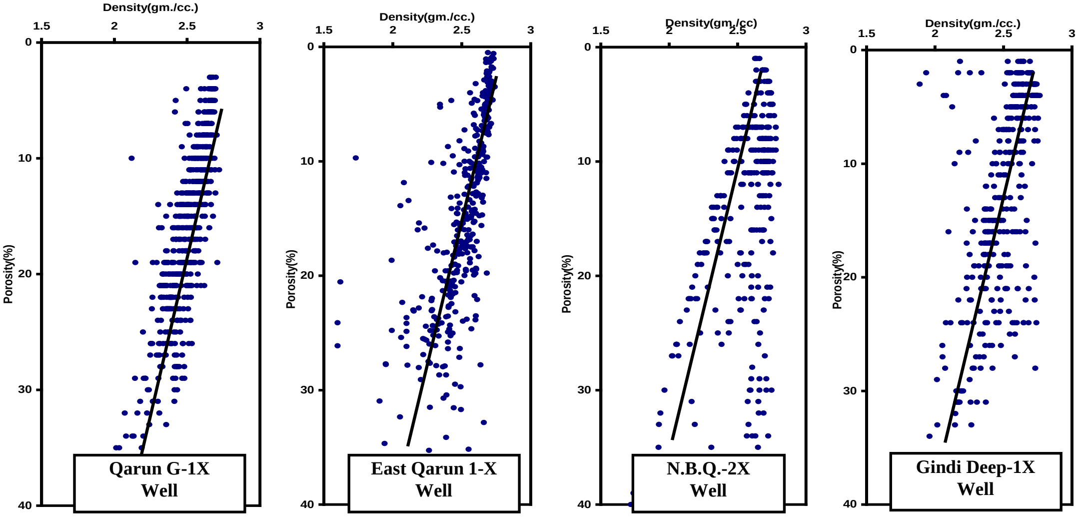

Fig.(19). Relationship between Density and Porosity for Carbonates of the Studied Wells.

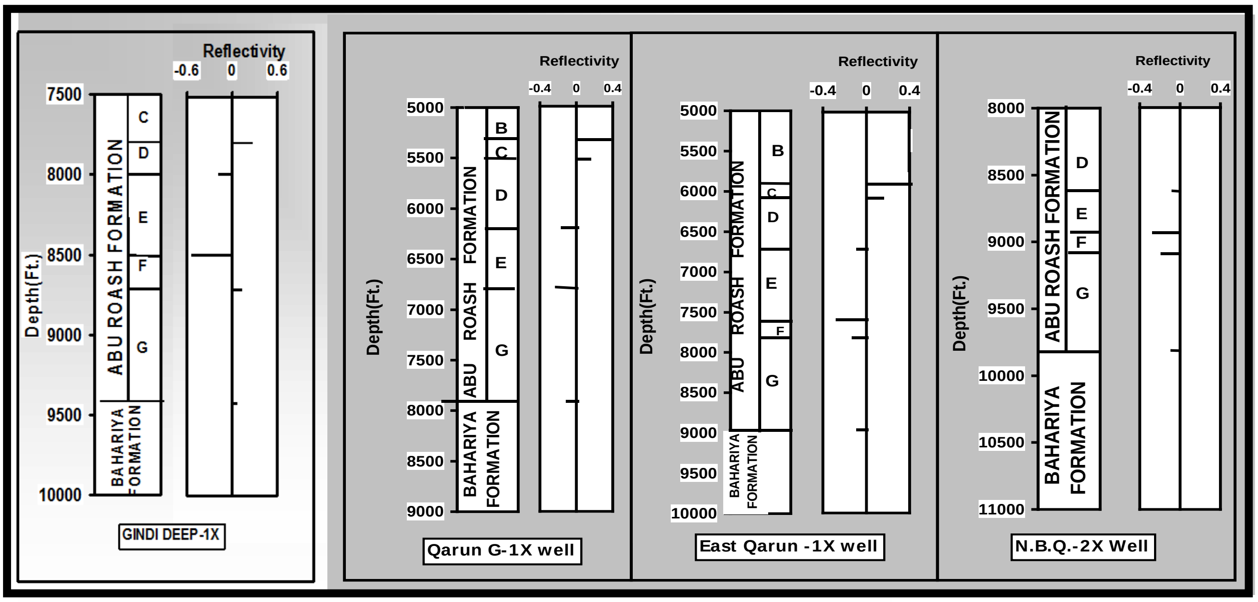

Fig. (20). Reflectivity Logs of the Studied Wells

CONCLUSIONS

The effect of rock composition, porosity and density on wave velocity is studied in the present work. It is concluded that, a decrease in the porosity of rocks due to compaction leads to an increase in the rock density and velocity, thus the wave velocity in the Bahariya Formation is lower than that in the Abu Roash "D" Member. Moreover, the velocity decreases as the porosity increases, thus the velocity of the Abu Roash clastic members is lower than that of the Abu Roash non-clastic members due to the low porosity of the latter. The bulk density is one of the most important factors that control the velocity, where the velocity increases as the density of the rock increases. This direct relation between density and velocity clarifies the high velocity of carbonates that are found at different depths. The reflectivity logs of the studied wells show that the maximum reflectivity is found at the contact between clastic and non-clastic rocks as between the Abu Roash "E" and Abu Roash "F" Members.

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