Using Ultrasonic Technique to Measure Some Petrophysical Properties of Yamama Formation at Ratawi-7 Oil Well Core Samples, Southern Iraq

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Abstract

Twenty nine core samples were taken from Ratawi 7 Oil well according to the presence of oil in formation and availability of core samples. This well is located in the province of Basra/southern Iraq. The samples were collected from Yamama Formation. The core samples are taken from the well at different depths, ranging between (3663m-3676m). The range of Vp for these core samples is (668-4017 m/sec) and its average is (1779 m/sec), While the range of Vs is (291-1854 m/sec) and its average is (796 m/sec). In the current study the ultrasonic method is conducted to measure Vp, Vs as well as some petrophysical properties for core samples and some elastic moduli such as (Young's modulus, Bulk modulus, Shear modulus, Poisson's ratio and Lame's constant) depending on the values of Vp and Vs as well as to density. The relationship between seismic wave velocities and elastic moduli and petrophysical properties are plotted. The average of densities for this well is (2661 kg/m^3). The average of porosities which calculated depending on Vs values for this well is (22.08%). Two core samples from Rt7c1 well are selected to conduct laboratory measurements for porosity and compare it with the results of porosity which calculated from Vs, the results show that the values of porosities are similar as shown in the following table:

Well No.	Sample No.	Porosities values from Vs	Porosities from laboratory
Rt-7 c1	1	30.3%	33%
Rt-7 c1	16	14.42%	14%

استخدام تقنية الموجات فوق الصوتية لحساب بعض الخواص البتروفيزياوية لنماذج اللباب لتكوين اليمامة في بئررطاوي-7 النفطي ،جنوب العراق

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الخلاصة:

في هذا البحث ، أخذ تسعة وعشرون نموذج لبابي من بئر رطاوي -7 النفطي ، حيث تم اختيارها على اساس تواجد النفط في هذا التكوين . اخذت نماذج اللباب من تكوين اليمامة ، وتقع هذه النماذج على اعماق مختلفة مابين (3663 – 3676) متر. تراوح مدى سرعة الموجة الطولية المحسوبة لهذه النماذج بين (668 – 4017) متراثا ، وبمعدل (1779) متراثا . بينما تراوح مدى سرعة الموجة القصية بين (291 – 1854) متراثا وبمعدل (796) متراثا . استخدمت طريقة الموجات فوق الصوتية لحساب سرعة الموجة الطولية

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وسرعة الموجة القصية وبعض الخواص البتروفيزياوية لنماذج اللباب وكذلك معاملات المرونة لها مثل (معامل يونغ ، معامل الحجمي ، معامل القصي ، نسبة بويزون وثابت لامي) اعتماداً على قيم سرع الموجات والكثافة . كذلك رسمت العلاقات مابين السرع ومعاملات المرونة والخواص البتروفيزياوية المحسوبة. قيم معدل الكثافة هي (2661)كغم/م3 ، ومعدل المسامية المحسوبة اعتماداً على سرعة الموجة القصية هو (22.08%). اخذ نموذجين من رطاوي-7 اللباب رقم 1 لحساب المسامية مختبرياً ومقارنة النتائج مع قيم المسامية المحسوبة بطريقة الموجة القصية ، والتي اظهرت تقارب بالقيم كما مبين بالجدول التالي:

رقم البئر	رقم النموذج	قيم المسامية المحسوبة من السرعة القصية	قيم المسامية المحسوبة مختبرياً
رطاوي-7 لباب 1	1	%30.3	%33
رطاوي-7 لباب 1	16	%14.42	%14

Introduction

Geophysical seismic surveys had been used widely for different important fields in order to identify the geology of the layers beneath the suggested sites that are considered as convenient locations for such engineering establishment, rocks nature and its bearing capacities are the main factors that must be taken into consideration during geophysical surveys [1, 2]. Ultrasonic Technique was used for this purpose. This technique was developed in subsequent years because of the need for detailed information about the quality of the rocks in evaluation of engineering processes as well as, it is necessary for the development of dynamic methods which includes a comprehensive study of the rocks [3]. The study area is shown in figure-1.

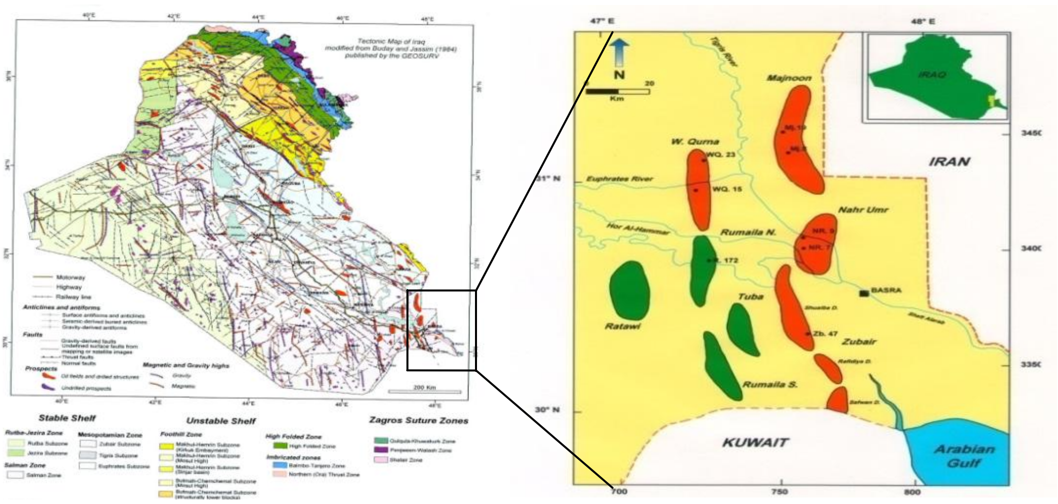

Figure 1- Location map of the study area

The Ratawi oil field

This oil feild is located at about (70km) north of Basra governorate, and (12km) west of the northern Rumaila. The first exploration well (Rt-1) were drilled in 1948 to investigate the geological Formations which obtained oil.[4] figure-2. Depending on resultant of drilling wells (Rt-3, 4, 5, 6, 7) the study of the seismic information reinterpretation on Ratawi field in 2010 that, the dimension of structure at Yamama Formation level is 29km length, and 18km width and 290m envelop [5].

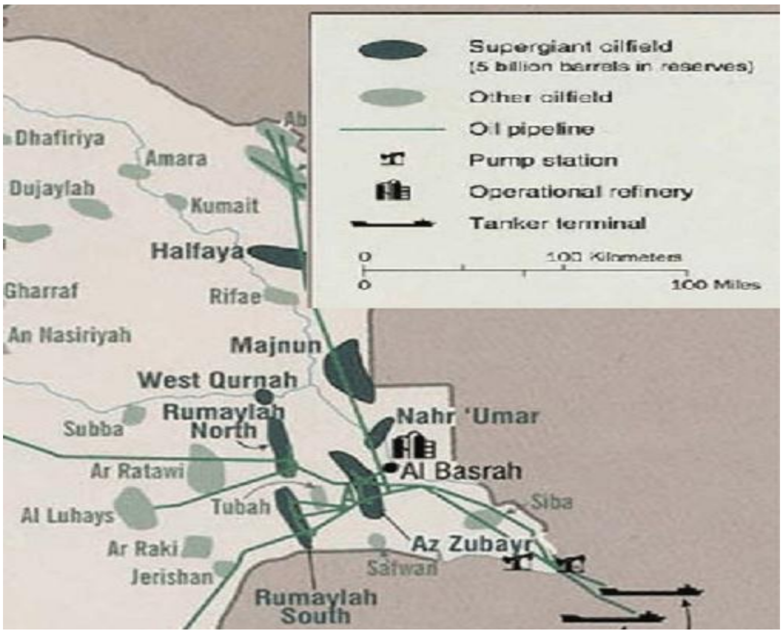

Figure 2- Oil field map [6].

Topography and geology of the study area

The topography of study area is flat and semi desert, gradually reduce in the south direction to be at sea level, and the highest level is about (120m) above the sea level [7]. So it was located in unstable zone of Mesopotamian zone under Zubair subzone.

Yamama Formation

The Yamama Formation was defined by Steinke and Bramkamp in 1952 in [8] from outcrops in Saudi Arabia [9] described a 257m interval in Ratawi 1 as the Yamama-Sulaiy Formation. The upper 203m ,now assigned to Yamama Formation [10] comprises 12m of spicular and brown detrital limestone with thin shale beds overlain by 191m of micritic limestone and Oolitic limestone, The Formation is up to 400m thick in the Euphrates area near Najaf and up to 360m thick in SE Iraq .The Yamama Formation in southern Iraq comprises outer shelf argillaceous limestone and Oolitic, Pelloidal, Pelletal and Pseudo- Oolitic shoal limestone, Oolitic reservoir units are present in several NW-SE trending depocentres [10] . The Formation is of Berriasian – Valanginian age [9]. Two variations of the Yamama Formation (originally described as separate Formation) are the Garagu and Zangura Formations.The Formation was deposited in alternating oolitic shoal and deep inner shelf environments within a carbonate ramps, probably controlled by subtle structural high within a carbonate ramp [10].

Aims of study

1. Determination of the elastic moduli and some petrophysical properties of core samples.
2. Determination of bulk porosities of core samples, using shear wave velocity.
3. Determination of the relationships between the elastic moduli and petrophysical properties.

Methodology

The core samples must not be cut with a length less than 10 cm. for measuring the velocities for both of Vp and Vs by using new sonic viewer, also measuring the densities of the above core samples to calculate the dynamic and geotechnical properties, as well as porosities of these rocks from the velocity of S-wave. The new sonic viewer send electric pulses that are transfer to mechanical waves in transmitter and received by receiver which transfer these waves to electrical pulses and showing it on CRT as sinusoidal waves [11].

Theoretical Background

The seismic wave is the basic measuring rod used in seismic prospecting. If we are to understand how it works and evaluate the information we get from it in geological terms, we must be familiar with the basic physical principles governing its propagation characteristics. These include its generation, transmission, absorption, and attenuation in earth materials and its reflection, refraction, and different characteristics at discontinuities [12]. The property of resisting changes in size or shape and returning to the undeformed condition when the external forces are removed is called elasticity [13]. Seismic waves are generally referred to as elastic waves because they cause deformation of the material in which, the propagate like that in an elastic band when it is stretched. [12]. Seismic wave is acoustic energy transmitted by vibration of rock particles [14].

Compression wave (P – wave)

These waves generally travel faster than secondary waves and can be travel through any type of material. The particle motion of P-wave is extension (dilatation) and compression along the propagation direction of wave spread [12, 15]

It expressed by these equations:

$$Vp = \sqrt{\frac{\lambda + 2\mu}{\rho}} \qquad (1)$$

$$Vp = \sqrt{\frac{k + \frac{4}{3}\mu}{\rho}} \qquad (2)$$

$$V_p = \sqrt{\frac{E(1-v)}{t\,(1+v)(1-2v)}} \qquad (3)$$

Where

λ : Lame's constant

μ : Shear modulus

ρ : Density

k : Bulk modulus

E : Young's modulus

σ : Poisson's ratio

Transverse waves (S-wave)

Transverse wave is slower than P-wave in solid. S-waves have particle motion perpendicular to the propagation direction, like the obvious movement of a rope as a displacement speeds along its length. The particles displacement in vertical plane for Sv –waves, and displacements in horizontal plane for SH –waves. SH – waves are often generated for S-wave refraction evaluations of engineering sites [16], so it is not travel through the liquid[17]. It was called shear waves [12, 18].

It expressed by :

$$Vs = \sqrt{\frac{\mu}{\rho}} \qquad (4)$$

$$Vs = \sqrt{\frac{E}{2\rho(1+\sigma)}} \qquad (5)$$

Factors affecting seismic wave

The velocities of seismic waves depend mainly on the elastic properties of the minerals making up the rock itself.[12]. There are several factors that have significant effect on the propagation of seismic waves Vp &Vs through rocks. These factors are density, lithology, depth, age, joints and fractures, texture, frequency, pressure and temperature, anisotropy and saturation.

Elastic Constants

A cording to Hook's law a strain is directly proportional to the stress producing it. The relationship between stress and strain was expressed as elastic constant, these constants explain the rock properties, and these are [19- 21].

1. **Young's modulus(E)**

The dynamic Young's modulus is given in the following eqation:

$$\mathbf{E = \frac{\rho V_p^2 (1+\sigma)(1-2\square)}{(1-\sigma)}} \qquad (6)$$

Expressed by Nt/m2=Pascal

Vp : Primary wave velocity

ρ : Density

σ : Poisson's ratio

2. **Bulk Modulus (K)**

It is deformation in body volume without changing in its shape.[12]

It expressed in this equation :

$$K = \rho\left(V_p - \frac{4}{3}V_s\right) \quad (7)$$

It expressed by Nt/m2 =Pascal

The inverse of K is called compressibility (β), it is expressed in equation:

β = 1/k (8)

3. Shear modulus or rigidity (μ)

It is deformation in body shape without changing in its volume, so present proportion between shear stress and shear strain. The value of shear modulus ranged between (10×10^3-7×10^4) Mpa in rock material. [22], shear modulus equal zero for liquid and gas. [23].

It expressed by Nt/m2 =Pascal

$$\mu = \rho V_s^2 \quad (9)$$

4. Poisson's ratio (σ)

It is representing as relation between the transverse strain and the longitudinal strain whether the stress is compressive or tensile [23-25].

It is expressed in the following equation:

$$\sigma = \frac{\left(\frac{V_p}{V_s}\right)^2 - 2}{2\left(\frac{V_p}{V_s}\right)^2 - 2} \quad (10)$$

5. Lame's constant (λ)

It is a scale of material strength, it is valid for isotropic media i.e. media in which the elastic properties are independent of direction [24]. Lame's constant (**λ**) is the same as shear modulus (**μ**) , in perfect elastic condition when Poisson's ratio is equal 0.25 , these constants (**λ**) and (**μ**) are equal .

It is expressed in the following equation:

$$\lambda = \rho\left(V_p^2 - 2V_s^2\right) \quad (11)$$

Field work and Instrumentations

The field work is made in geological workshop in the core rock packages in Iraqi southern oil company, after selecting, prepare the core, the samples were numbered and marked to their tops and bottoms, then smoothing the faces.

The arrival time of P and S wave measurement is taken by the following steps:

1. Cutting the samples by parallel faces, and their lengths were not less 10cm.
2. Smoothing the faces by grinding paper to get good coupling with receiver and transmitter of Ultrasonic instrument.
3. Measuring the transit time for both P and S waves (P- wave is taken by putting sample between receiver and transmitter after putting the vaseline on sample faces) by using their transducers after calibrating the instrument , then powered enhance adjust to recognize the first arrival point of the wave. The shift adjustment use to matching the start of arrival time of wave with vertical axis and take the reading that appear on bottom of the screen which present time of wave transmit through sample (micro sec). then calculating the velocities of longitudinal and transverse waves from these equation :

   Vp = L/Tp (12)

   Vs = L/Ts (13)

   Tp, Ts: Transmitted time (P or S waves)

   L: Length of core sample
4. Measuring the length of each core sample with their diameter to get their volumes, because all samples are geometrical in shape.
5. Weighing the samples by electronic balance with an accuracy of (1gm).

Density measurement

The density of core samples (ρ) is calculated by traditional way, by calculating samples volume and weight. The density was calculated using the following equation:

ρ = sample weight / sample volume (14)

Porosity measurement

Pickett, 1963 in Domnico, 1984 suggested equation to determine the porosity depending on seismic velocities: [26, 27]

$$\frac{1}{V} = A + B\text{ø} \tag{15}$$

V: velocity (Vp or Vs)
A,B: constants
Ø : porosity
A: (291.967) for sandstone B: (54.601983) for sandstone
A: (213.79) for limestone B: (59.62) for limestone

Instruments

Many instruments we used in this work field such as

1. OYO's NEW SONICVIEWER (model-5217A) to determine velocity measurements of rock samples.
2. Cutter for cutting the core samples with parallel faces.
3. Electronic balance for measuring the weight of samples of accuracy 1gm and maximum of 7 kg.

Laboratory measurements:

Longitudinal and transverse wave velocities

The velocity of seismic waves (Vp and Vs) determined from transmitted time of the waves by the equations (12) and (13), respectively.

Density determination:

The bulk density is the average density of the rock including its void, matrix density, and pore-fluid density. The bulk density is calculated for all core samples by using equation (14).

Porosity determination:

The equation (15) used to calculate the porosity from S-wave velocity after calculating the constants A and B (291.967, 54.601). A liquid saturation method is used to determine the porosity in laboratory for (2) samples of Rt-7c1.

1. The dry weight of sample is measured using a sensitive balance.
2. Saturate the sample in known density liquid (used water in this laboratory test) not less than (24) hours.
3. The saturated weight of each sample is measured after (24) hours.
4. The deference in weight between saturated and dry samples are calculated, and divided by the density value of water (1gm/cm3) to get the pore volume, which is given in this equation:

$$V_{po} = \frac{W_s - W_d}{water\ density} \tag{16}$$

Vpo: Pore volume
Ws: Saturated sample weight
Wd: Dry sample weight
Water density = 1gm/ cm3

5. Bulk volume is determined by calculating the difference between the volume of liquid before and after immersing sample inside the liquid.
6. The porosity is calculated using this equation:

Ø = Vpo /Vb (17)
Vb: Blk volume

Results and Discussions

Ratawi Oil well NO.7 core No.1

Twenty nine core samples were taken from this well from depth (3663-3676)m distributed with different interval because of their length which must not be less than 10cm. The core samples are sandstone and little shale and limestone which belong to theYamama Formation.

The values of P- wave velocities of core samples in this well range between (668- 4017m/sec), and its average is (1779m/sec). The values of shear waves velocities in these well core samples ranges between (291- 1854m/sec), and their average is (796m/sec). Depending on the results of P-wave and

S-wave velocities, the relationship for these core samples is shown in figure-3. The resulting relationship is given in the following equation:

Vs= 0.4426Vp + 8.8706

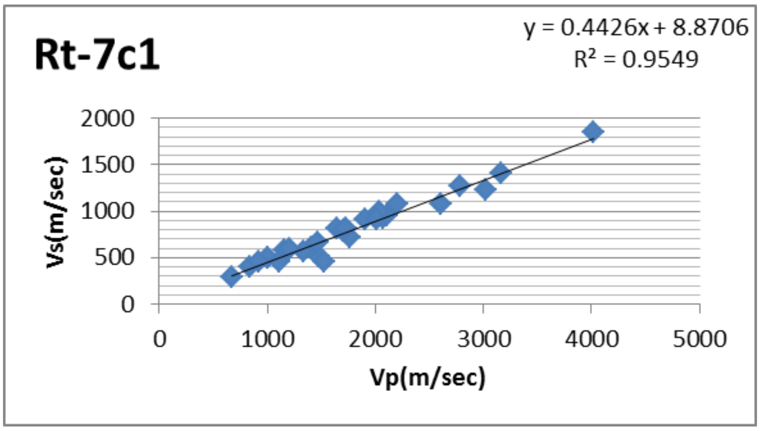

Figure 3- The relationship between Vp & Vs.

The average porosities in these well core samples is (22.08%). The relationship between S-wave velocities and porosities is shown in figure-4. The resulting relationship is given in the following equation:

Ø= 0.0031(1/Vs) - 0.9772

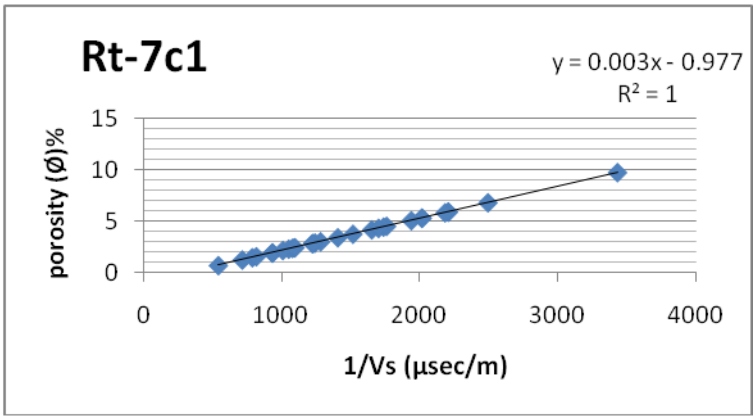

Figure 4 - The relationship between Vs & porosity.

The densities of core samples are calculated, and their values ranged between (2068- 3179) kg/m^3, and their average was (2661) kg/m^3. The relationship between P - wave velocities and density is shown in figure-5a, also the relationship between shear wave velocities and densities is shown in figure-5 b. The resulting relationships are given in the following equations:

a) Vp= 0.5763 ρ+ 246.36

b) Vs= 0.2863 ρ + 34.746

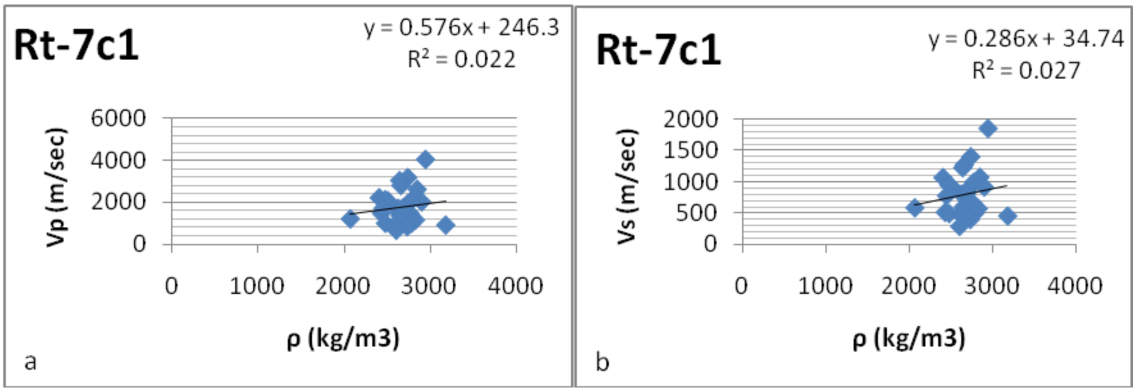

Figure 5- a- The relationship between the densities & Vp; b) The relationship between the densities & Vs.

Young's modulus values range in these well core samples between (0.61 - 27.631) GPa , and its average is (5.559) GPa, The relationship between Young's modulus and P-wave velocities of core samples is shown in figure-6a, also the relationship between Young's modulus and S-wave velocities is shown in figure-6b . The resulting relationships are given in the following equations :

a) E= 0.0067 Vp - 6.4465

b) E= 0.0151 Vs - 6.498

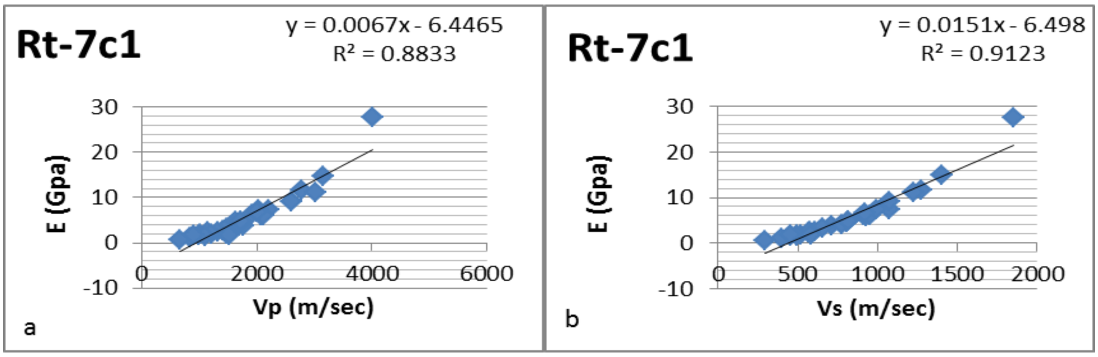

Figure 6a- The relationship between Vp & Young's modulus; b) The relationship between Vs & Young's modulus.

Shear modulus values ranges in these core samples between (0.22 - 10.124) GPa, and its average is (2.029)GPa. The relationship between the shear modulus and P-wave velocities is shown in figure -7 a, also the relationship between the shear modulus and S- wave velocities is shown in figure-7b . The resulting relationships are given in the following equations:

a) μ= 0.0025Vp - 2.3397

b) μ= 0.0061Vs-2.7594

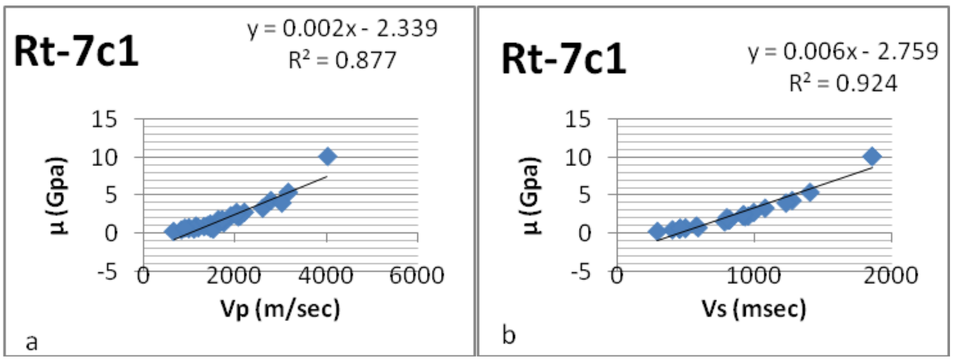

Figure 7a- The relationship between Vp & shear modulus; b) The relationship between Vs & shear modulus.

Bulk modulus values ranges in these core samples between (0.869 - 34.028) GPa, and its average is (7.382) GPa. The resulting relationship between Bulk modulus and P-wave velocities is shown in figure-8a , also the relationship between the S- wave velocities and Bulk modulus is shown in figure -8 b. The resulting relationships are given in the following equations:

a) K=0.009Vp - 8.5664

b) K=0.0193Vs-7.9562

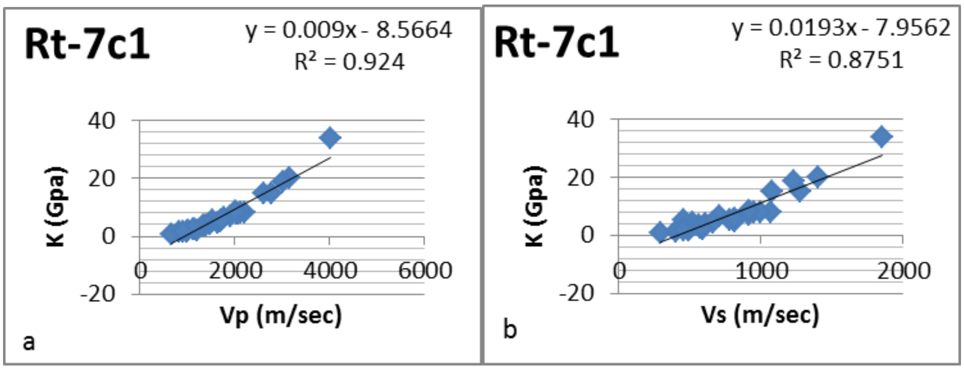

Figure 8a- The relationship between P- wave velocities & Bulk modulus; .b) The relationship between S- wave velocities & Bulk modulus.

Poisson's ratio values ranges in these core samples between (0.333 - 0.452) , and its average is (0.37) . The relationship between Poisson's ratio and Vs /Vp ratio is shown in figure-10 . The resulting relationship is given in the following equation:

Vs/Vp = -1.576 Ϭ + 1.0333

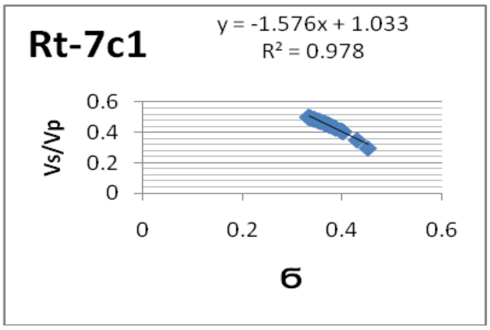

Figure 10- The relationship between Vs /Vp .ratio & Poisson's ratio.

The values of Lame's constant ranges in these core samples between (0.722 - 27.278) GPa, and its average is (6.029) GPa. The relationship between Lame's constant and P-wave velocities is shown in figure -11 a, also the relationship between S- wave velocities and Lame's constant is shown in figure-11b . The resulting relationships are given in the following equations:

a) λ= 0.0073Vp -7.0066

b) λ = 0.0156Vs - 6.3751

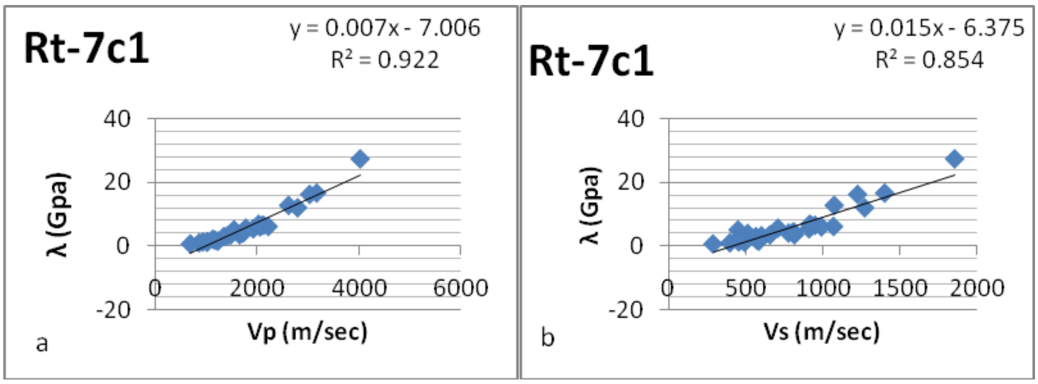

Figure 11a- The relationship between Vp & Lame's constant; b) The relationship between Vs & Lame's constant.

The values of (Vp / Vs) ratio in these core samples ranges between (2 - 3.38), and its average is (2.253). The (K / µ) ratio values ranges in these core samples between (2.666 - 10.092) , and their average is (3.824). The relationship between the two rates above is shown in figure-12, and the resulting relationship is given in the following equation :

K/µ = 5.1844(Vp/Vs) - 7.8574

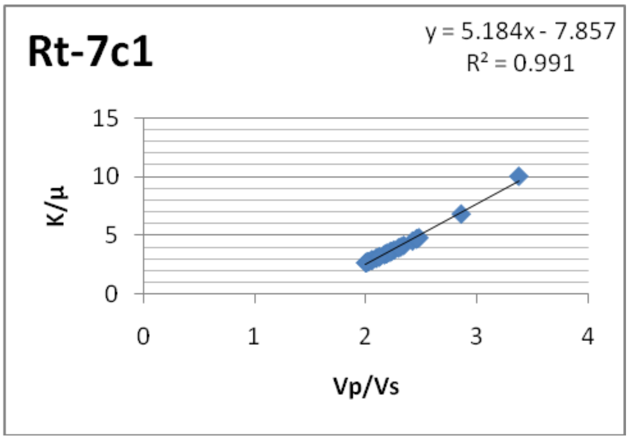

Figure 12- The relationship between (Vp / Vs) & (K / µ).

Conclusions

1. Seismic velocities of P and S waves for core samples are measured, and the range of Vp is (668-4017m/sec) , and the average is (1779m/sec). The range of Vs is (291- 1854m/sec), and the average is (796 m/sec), table-1. The relationship between Vp and Vs is linear and directly proportional in this core sample.
   The measurements of the P and S waves for some samples showed that, clear vacillation and a wide range of the seismic wave velocity values, and this is caused by the presence of fractures and cracks, as well as the pores and differences in lithology, Where the presence of the clay is an impact on velocities which leads to a decrease in velocities of seismic waves.
2. The average of densities of core samples for this well is (2661 kg. m^{-}), table-1.
3. The porosities of core samples are calculated from shear wave velocities Vs, because Vs is more sensitive to changes in porosity than Vp [27], the average of porosities for this oil well is (22.08%), table-1. The relationship between porosity with Vp and Vs is plotted and the result show that it is directly proportional to each other.

Table 1-The averages of Vp, Vs, porosity & density.

Well NO.	Range of Vp (m/sec)	Range of Vs (m/sec)	Average of ø %	Average of ρ (kg m^{3})
Rt-7 c1	668 - 4017	291 - 1854	22.08	2661

4. These results of porosities determined from Vs are compared with the laboratory determination of porosity for two samples, and the results were closer to each other, as shown in table-2.

Table 2- The porosity values.

Well No.	Sample No.	Porosity (Vs) %	Lab. Porosity %
Rt-7c1	1	30.3	33
Rt-7c1	16	13.9	14

5. Elastic moduli are calculated using the seismic wave velocities of (Vp and Vs) as well as the densities. The results of these transactions are shown in table-3.

Table 3 - The average of elastic moduli values.

Well NO.	E (Gpa)	μ (Gpa)	K (Gpa)	λ (Gpa)	б
Rt-7-c1	5.559	2.029	7.382	6.029	0.370

The relationships between Vp , Vs and these transactions were plotted for the core samples. The relationships in Ratawi - 7c1 oil well { (between Vs and Vp), (between ø and Vs), (between Vp and ρ), (between Vs and ρ), (between E,μ,K,λ and Vp) and (between E,μ,K,λ and Vs) }were directly proportional to each other, but the relationship between Poisson's ratio and Vs/Vp was inverse.

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