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RESERVOIR CHARACTERIZATION OF QAWASIM FORMATION IN BALSAM FIELD, ONSHORE EAST NILE DELTA, EGYPT

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توصيف خصائص الخزانات فى تكوين القواسم فى حقل بلسم- شرق دلتا النيل الشاطئية-مصر

الخلاصـة: حقل البلسم هو الاكتشاف الأكثر أهمية في تكوين القواسم ، وتكشف التفسيرات عن هيكل كتلة صخرية معقدة مليئة بالصدوع بشكل كبير ذات إتجاه من الشمال إلى الجنوب ، وتوضح البيانات السيزمية ذات النتائج الزاهية العلاقة بين مدى الخزان وسمكه ، ويقسم تكوين القواسم إلى وحدتين (قواسم–١ و قواسم–٢).

كانت التسجيلات الكهربية للأبار جيدة بما فيه الكفاية للتقييم الصحيح لتكوينات القواسم. يتم العمل البتروفيزيائي عن طريق حساب (Vsh) باستخدام بيانات (GR)، وقد تم تحديد نوع الصخور بإستخدام توصيف العينات الصخرية أثناء حفر الآبار وعرضها علي سجلات الطين (Mud logs) ، وعن طريق العلاقات البيانية التي تبين نوع التكوين الصخري مثل رسم علاقة بين كثافة وحجم مسامية الصخور والتي أشارت إلي زيادة نسب السمنتة الجيرية بدرجة كبيرة داخل الحجر الرملي خصوصا بالجزء العلوي من خزان تكوين قواسم –٢.

تم استخدام علاقات بيانية لبيانات سرعة إنتشار الموجات بالتكوينات الصخرية (VP / Vs Crossplot) للتمييز بين مختلف أنواع الصخور ومحتوى السوائل مثل (الحجر الرملي يحتوي علي الماء و الحجر الرملي يحتوي علي الغاز أوحجر طيني). أثبت التقييم البتروفيزيائي أن صافي سمك الخزان يصل إلى ٥٨ متراً في تكوين القواسم.

في هذه الدراسة نهج متكامل يتم تطبيق التحليل البتروفيزيائي وتحليل فيزياء الصخور لتوصيف خزانات حقل غرب المنزلة باستخدام كل بيانات لتسجيلات الآبار المتاحة. يظهر التحليل البتروفيزيائي لوحدة القواسم– ١ في بئر(بلسم–١) صافي ١١ متر من الحجر الرملي مع نسبة صافي / إجمالي ١٠٪ وصافي خزان فعال ٦ أمتار مع متوسط مسامية ٦ ٪ وتشبع الماء (Sw) ٦٠٪ و حجم الطين (Vsh) ٢٠٪.

ويبين التحليل البتروفيزيائي لوحدة القواسم –٢ في بئر بلسم –١ صافي ١١٢ متر من الحجر الرملي مع نسبة صافي / إجمالي ٨٠٪ وصافٍي خزان فعال ٥٤،٤ متر بمتوسط مسامية٢٠ ٪ وتشبع الماء (Sw) ٣٠٪ و حجم الطين (Vsh) ١٪.

عادة ما يتم إجراء تحليل الفيزياء الصخرية لاكتشاف وفهم العلاقات بين بيانات البحث السيزمي و الخزانات وهي في غاية الأهمية لفصل طبقات الخزان المختلفة (الصخر الرملي و الصخر الطيني) ومحتوى السوائل (الغاز أو المياه المالحة) ، ويمكن إستخدام الموجات الصوتية في تحديد نوع التكوينات الصخرية ونوع الموائع التي تحتويها حيث تكون الموجة الضاغطة وموجات القص عبارة عن موجات ميكانيكية تعتمد على طبيعة الصخور وخصائص الموائع بداخلها.

ABSTRACT: *Balsam Field is the most significant discovery in Qawasim Formation. The geological geophysicsal data interpretation reveals complicated horst block structure which is heavily faulted with north-south trending lineaments, the bright amplitude shows some correspondence to the reservoir extent and thickness, Qawasim Formation is divided into two units (Qawasim-I and Qawasim-II). The open-hole logs were good enough for proper formation evaluation. A Petrophysical work was done by calculating shale volume using single indicator (GR). Lithology determination was determined by using Mud-log description, cross plots for lithology indicators as density Vs porosity which indicates calcareous to highly calcareous sandstone especially on the top part of Qawasim-II pay. Vp/Vs crossplot was used to differentiate between different lithologies and fluid content (wet and gas sandstone and clay). The petrophysical evaluation proved 58 meters net pay in Qawasim Formation.*

1- INTRODUCTION

The Nile Delta plays an important and early role in the history of fluvial deposits in Egypt and is considered as one of the largest and well documented classic delta between Wadi El Natrun and Bahariya Oasis (described by Shata et al., 1970) to be developed during Oligocene time.

The Nile delta basin was affected by the complex evolution and interference of the African, Eurasian and Arabian plates. From structural point of view, the basin is bounded from the South by the hinge zone, which is composite of flexure lines. The stratigraphic framework of the Nile Delta will be discussed in relation to the different sub-domains according to the tectono-stratigraphic setting. The hinge zone separates the south Delta platform from the middle belt, which is separated from the outer mobile belt northwards by major fault zones.

Qawasim Formation is identified as of Late Miocene (Tortanian-Messinian) in age. It forms an angular unconformity over Sidi Salim Formation as shown in Fig. (1).

Qawasim Formation is encountered with a variant thickness depending on the scouring of the pre-existing formation which is Sidi Salim and also on the eroded part by the overlying Abu Madi Formation. There are several potential wells which have a good production from Balsam field.

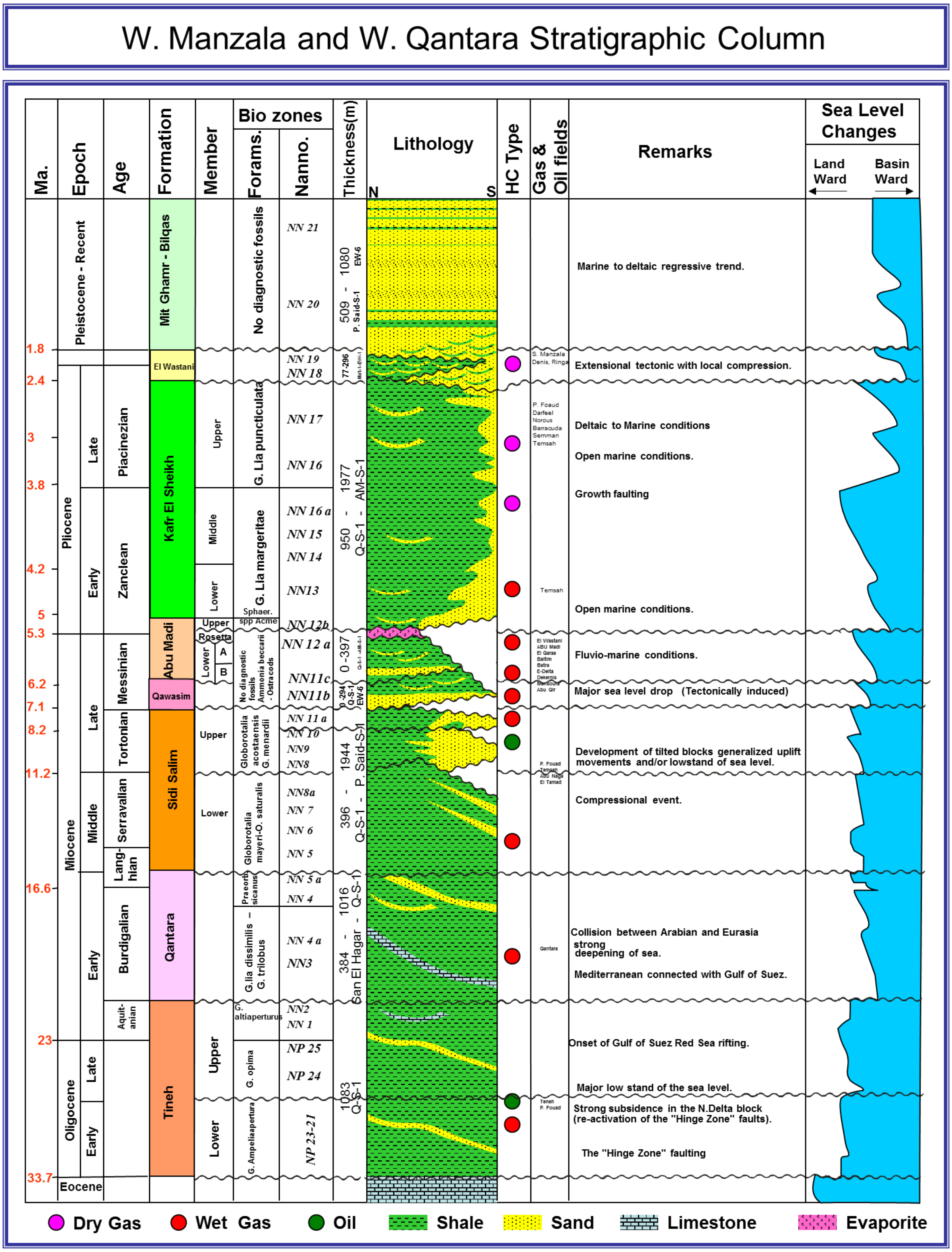

Fig. (1): Litho-Stratigraphic and Depositional Environment of Nile Delta (Dana Gas, 2009).

2- AIM OF THE STUDY

The study concerns with reservoir characterization of Qawasim Formation in Balsam field which encountered two potential reservoir units through petrophysical studies of these units such as porosity, shale, content, water and gas saturations. Also rock physics models for lithology and fluid content were discussed.

3- PETROPHYSICAL ANALYSIS

In petrophysical analysis, reservoir parameters like porosity (ø), shale volume (Vsh) and water saturation (Sw) are calculated. Petrophysical analysis also focuses on defining the net pay and reservoir intervals from the gross formation thickness. This part of the study gives the basic platform to conduct the rock physics analyses giving the idea about the sensitivity of different parameters utilized in calculations. Moreover, an effort is made to investigate and to understand the lateral variations and vertical thickness of different reservoir units.

3.1 Porosity Estimation

Porosity is the pore volume of the rock. It can be filled with hydrocarbons, moveable water, capillary water or clay bound water. Porosity of pay zones were determined using neutron and density logs.

3.1.1 Neutron Porosity

Neutron log is used to measure the porosity in the formation. In most cases like in limestone lithology, it can be read directly from the neutron log. For the other lithology, it should be used by taking the average of porosity calculated from density and neutron logs to get rid of the lithologic effects, the porosity from the neutron log overestimate the values compared to the average porosity in shales, while in sandstones, it almost gives the same values as shown in Fig. (2).

3.1.2 Density Porosity

Density log is useful to discriminate lithology as well as to calculate the porosity and hydrocarbon density

The general equation (1) is applied to measure the porosity expressed by (Schlumberger, 1972)

$$\Phi = (\rho ma - \rho b) / (\rho ma - \rho f) \quad (1)$$

ρma = Density of the matrix material

ρf = Pore fluid density

ρb = Bulk density log reading

Densities of common lithologies are shown in Table 1 (Modified from Rider and Kennedy, 2011).

Table (1): Matrix Density Parameters.

Lithology	Range (g/cm3)
Clays–Shales	1.85 – 2.75
Sandstones	1.9 – 2.65
Limestones	2.2 – 2.71
Dolomites	2.3 – 2.87

3.1.3 Average Porosity from Neutron and Density Logs

Figure 2 illustrates the density porosity underestimate the value of porosity as compared to the average porosity in shales (Eq. 2) while in sandstones it gives almost the accurate porosity values. The value of matrix density, which are used during porosity calculation varied with respect to the volumetric percentage of shales presence in the formation.

$$\emptyset_{Avg} = \sqrt{\frac{\emptyset^2_{neutron} + \emptyset^2_{Density}}{2}} \quad (2)$$

3.2 Shale Volume Calculation

The main step before calculating the shale volume is to calculate the gamma-ray index, which can be calculated by applying Equation-3, (Schlumberger, 1972).

GRI= (GRlog – GRMin) / (GRMax – GRMin) (3)

Where

GRI = Index of Gamma ray (Fraction)

GRlog = Gamma Ray Log in the zone of interest (API Unit)

GRmax = Gamma Ray Maximum (API Unit)

GRmin = Gamma Ray Minimum (API Unit)

For taking the GR max and GR min values, a histogram is run on the well data in order to mark the maximum average and minimum average values (Fig.3).

In Figure 3, the red line is for the gamma ray minimum (13 API) and the green line is for the gamma ray maximum (64 API).

After calculating Gamma ray index, volume of shale is calculated. In this study, Larionov (1969) equations are used for shale volume calculation (Rider and Kennedy, 2011).

Larionov (1969) gives following equations for different rocks on the basis of their age.

Older Rocks Vsh = 0.33 (22xIRA – 1.0) (4)

Tertiary Rocks Vsh = 0.083 (22.37x IRA -1.0) (5)

In this study the following Vsh values are used to differentiate between different lithologies as shown in Table 2.

Table (2): Vsh Ranges for Different Lithologies, used in this Study.

Lithology	Range (Frac.)
Sandstones	<0.25
ShalySandstones	>0.25and<0.5
SandyShale	>0.5and0.75
Shale	>0.75

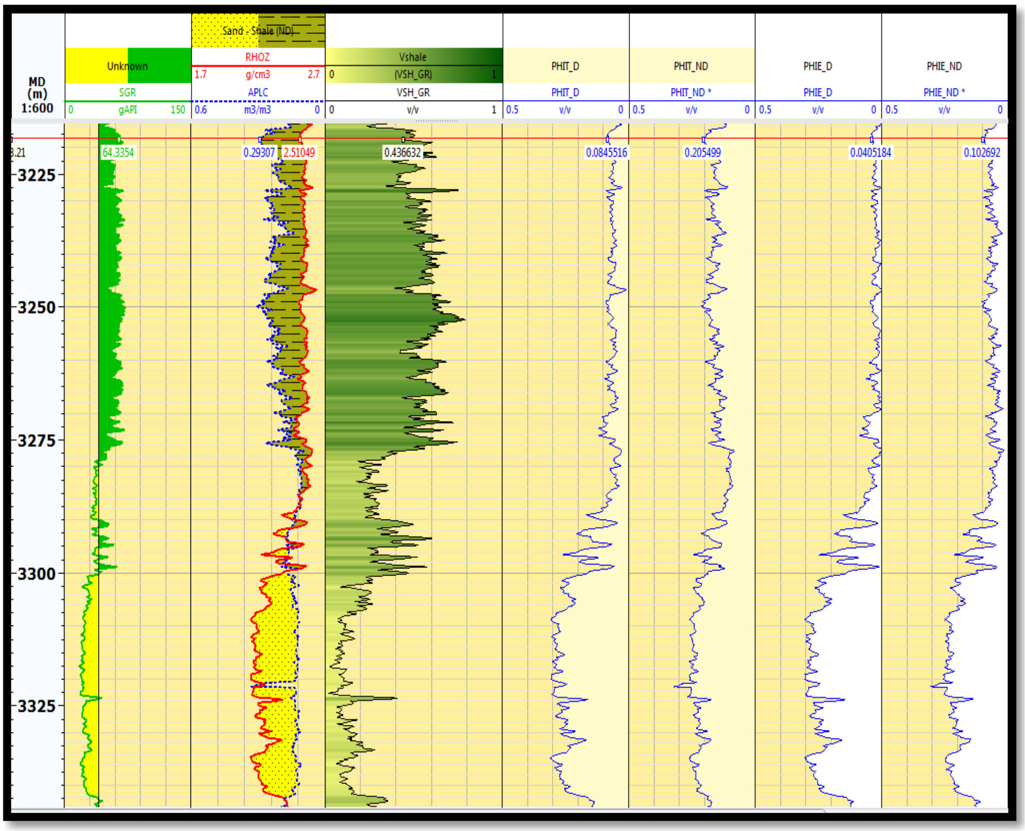

Fig. (2): Porosity from Neutron and Density Logs of Balsam-1 Well.

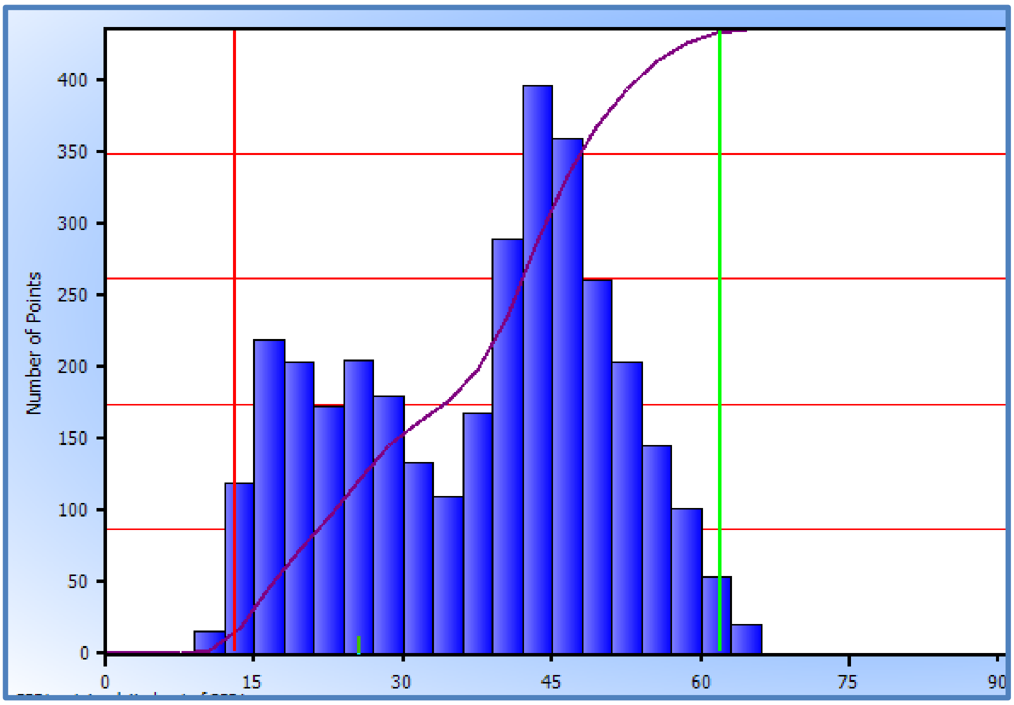

Fig. (3): Gamma Ray Histogram in Balsam -1 Well.

3.3 Water Saturation

Water saturation (Sw) is calculated by using the Archie (1942) equation (Eq. 6) in Interactive Petrophysical software. Porosity is used from Eq. (2), which calculate average porosity. Cement value (m) is taken as 2, tortuosity factor (a) is taken as 1. Deep resistivity values are used from RD. On the basis of water saturation, pay zone is separated from reservoir intervals. The Rw values are used from water sample analysis and picket plot. Rw is 0.325@ 60 Deg F equivalents to salinity 22 Kppm determined using picket plot, applied on the wet zone within Qawasim-2. Following, Archie, (1942) equation is used, as defined in Worthington et al., (2011).

$$Sw = [a/ \Phi m * Rw/Rt]^{1/n} \quad (6)$$

Where n varies are between 1.8 and 1.95

There is large uncertainty associated with water saturation calculation as no petrographic or core data analyses are available to get better more reliable values of porosity, cementation exponent or water saturation factors. But still results are good enough to do the analyses and further interpretation and discussion of outcomes. These results are quite comparable to the data published like Bergslien, 2002; Briedis et al., 2007; Jenssen et al, 2001.

3.4 Hydrocarbon Saturation

For hydrocarbon saturation (Sh) calculation, the following equation (Eq. 7) is used as defined by (Schlumberger, 1972).

$$Sh = (1- Sw) \quad (7)$$

*Sw in fraction.

The formation tops in Balsam-1 well is shown in Table 3.

Table (3): Formation Tops in Balsam-1 Well.

Formation	Depth TVDSS (m)
El Wastani Fm.	838.5
Kafr El Sheikh	1090.5
Abu Madi	2852.5
Qawasim Shale	2973
Qawasim pay -I	3083.3
Qawasim-pay-II	3265
T.D	3504.2

The estimated petrophysical parameters for Qawasim-I pay in Balsam-1 well is shown in Fig. (4); the net pay in Qawasim-I is 6 meters with 20% average porosity and 60% water saturation.

The estimated petrophysical parameters for Qawasim-II pay in Balsam-1 well is shown in Fig. (5).

The net pay in Qawasim-II is 48.5 meters with 20% porosity and water saturation of 30%

The total net pay of Qawasim-I and Qawasim-II are 54.4 meters pay as shown in Table-4.

Table 4: Reservoir Properties Summery of Qawasim Pay Zones in Balsam-1 Well.

		Reservoir SUMMARY						
Zone Name	Top	Bottom	Gross	Net	N/G	Av Phi	Av Sw	Av Vcl
Qwassim (I)	3084.5	3261.5	176.9	11.1	0.1	0.2	0.7	0.2
Qwassim (II)	3261.5	3409.1	147.7	112.2	0.8	0.2	0.7	0.1
All Zones	3084.5	3409.1	324.6	123.4	0.4	0.2	0.7	0.1

		Pay SUMMARY						
Zone Name	Top	Bottom	Gross	Net	N/G	Av Phi	Av Sw	Av Vcl
Qwassim (I)	3084.5	3261.5	176.9	6.0	0.0	0.2	0.6	0.2
Qwassim (II)	3261.5	3409.1	147.7	48.5	0.3	0.2	0.3	0.1
All Zones	3084.5	3409.1	324.6	54.4	0.2	0.2	0.3	0.1

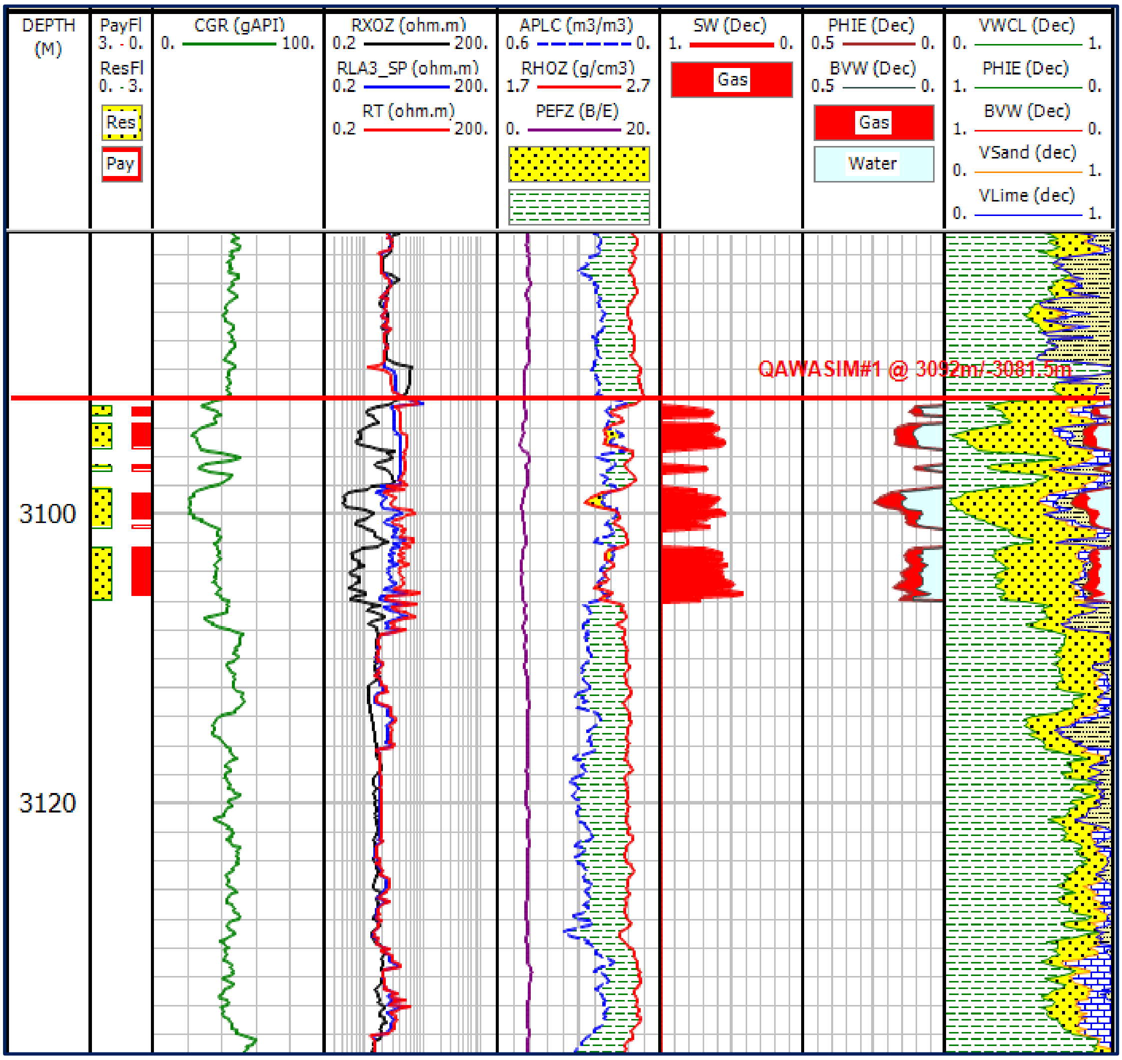

Fig. (4): Petrophysical Analysis of Qawasim-I Pay in Balsam-1 Well.

3.5 Gas Water Contact

A pressure survey is conducted in the interval 3302.5 to 3365m MD revealed the presence of hydrocarbon and water bearing zones; a pressure gradient calculated across the hydrocarbon zone indicated a value of 0.14 psi/ft matching a gas density of 0.26 g/cc, the pressure points in the lower part were sitting a gradient 0.44 matching water density 1.03 g/cm3 Fig. (6).

Assuming that these zones are in direct contact and in equilibrium with both gradients were extrapolated and a fluid contact was identified at the intersection of the gradients at MD 3341.8 m (TVDSS -3331.31m). This contact was supported also by open-hole log.

Rock Physics Models for Lithology and Fluid Content:

The Neutron/Density crossplot for tight sand interval with clay content (V_{clay}) in the Z-axis in Qawasim Formation pay zone shows that the reservoir is of calcareous and argillaceous sandstone with thickness 23 m, the reservoir is affected by gas as shown in Fig. (7).

The Neutron/Density crossplot for excellent clean sand reservoir interval (3300-3342 m) of about 42 m in Qawasim Formation with excellent gas effect is shown in Fig. (8).

One of the most important and useful crossplots for lithological identification and fluid content discrimination is the Vp-Vs crossplot. Fig. (9) Balsam-1 in Qawasim Formation is showing this discrimination, where sandstone is well separated from clay and gas sandstones are readily separated from other clusters of wet sandstones and shales, Dashed blue lines represent lines of constant Vp/Vs ratio.

Another useful crossplot is the Poisson's ratio (PR) versus depth shown in Fig. (10) In Balsam-1 in Qawasim Formation. Gas sandstone, wet sandstone and shale are also well separated from other clusters, the lower values of Poisson's ratio in gas sand and its separation from wet sand and clay. Where gas sand has PR ratio less than 0.24, wet sand ranges between 0.24 and 0.3, while the shale interval is ranged from 0.3 to 0.4.

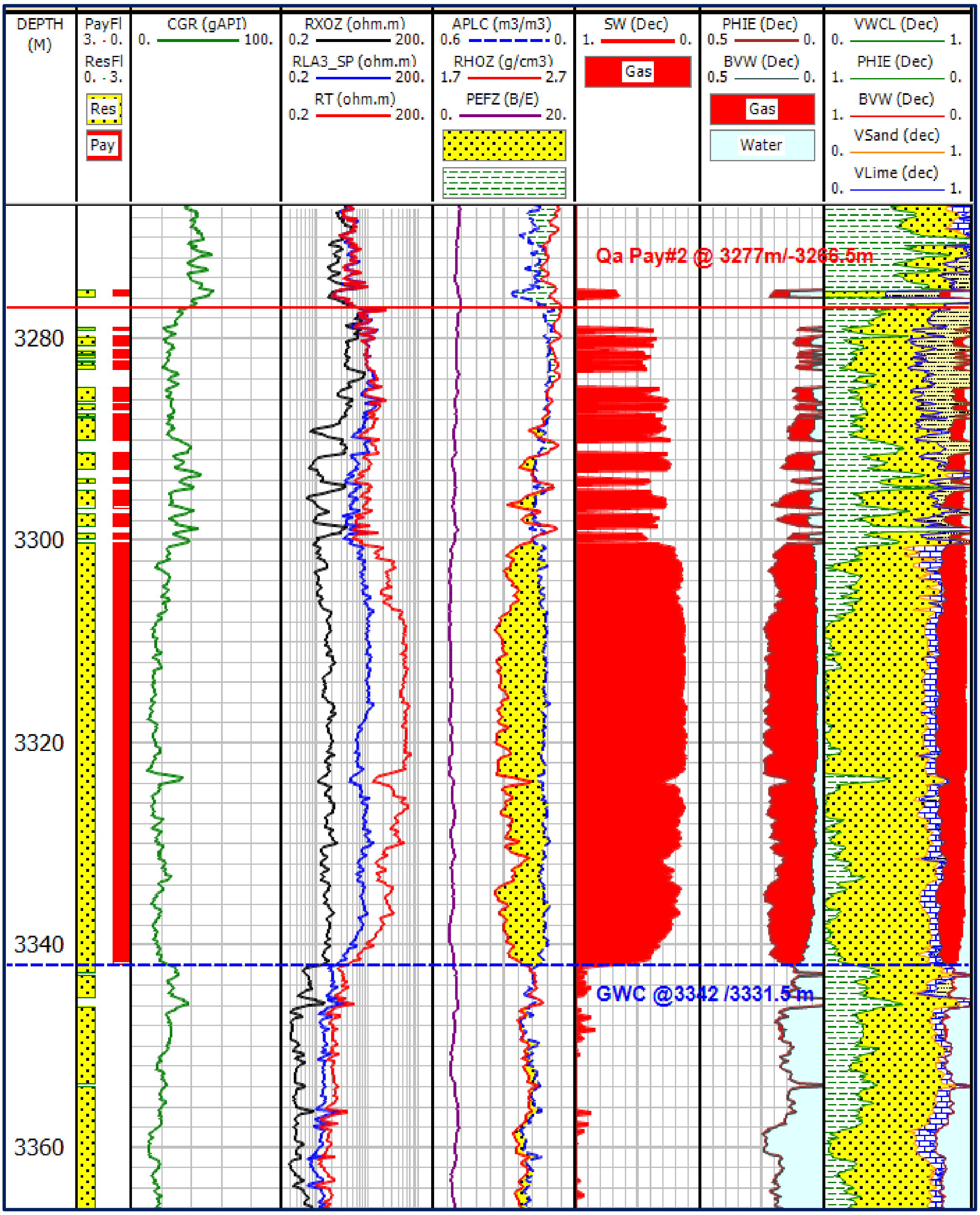

Fig. (5): Petrophysical Analysis for Qawasim-II Pay in Balsam-1 Well

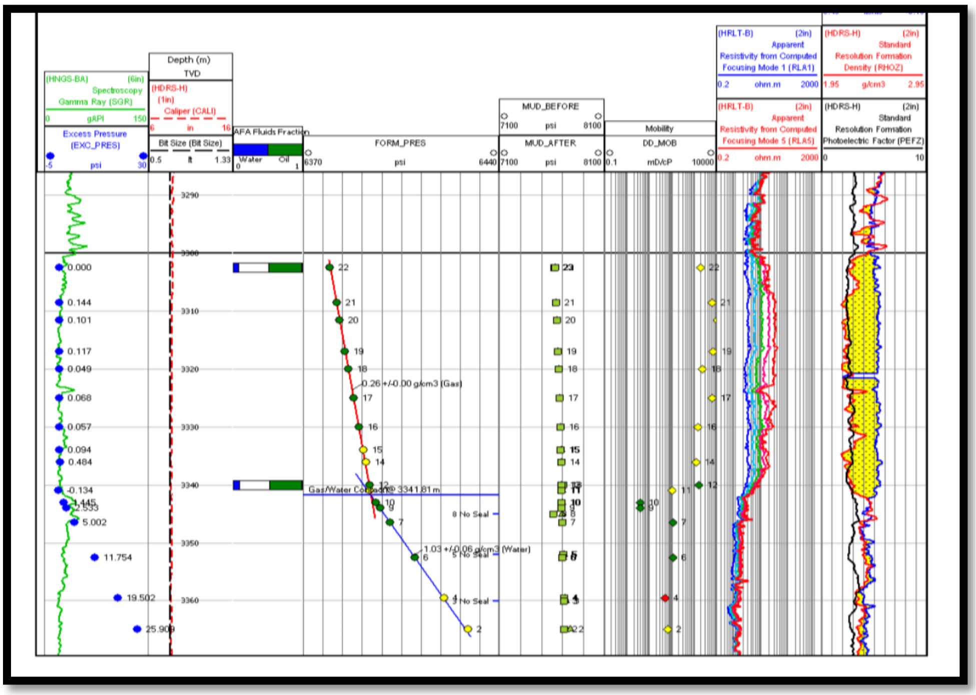

Fig. (6): MDT Pressure Points of Balsam-1 Well.

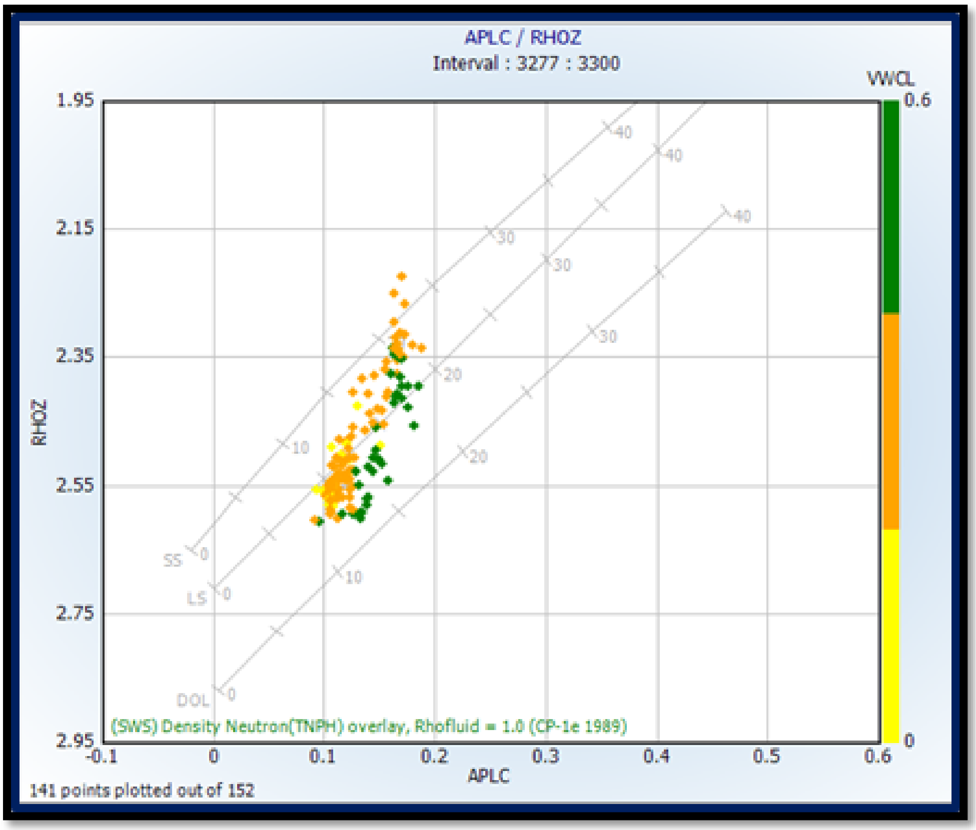

Fig. (7): Neutron-Density Crossplot in Balsam-1 Well for the Top Tight Sand Reservoir.

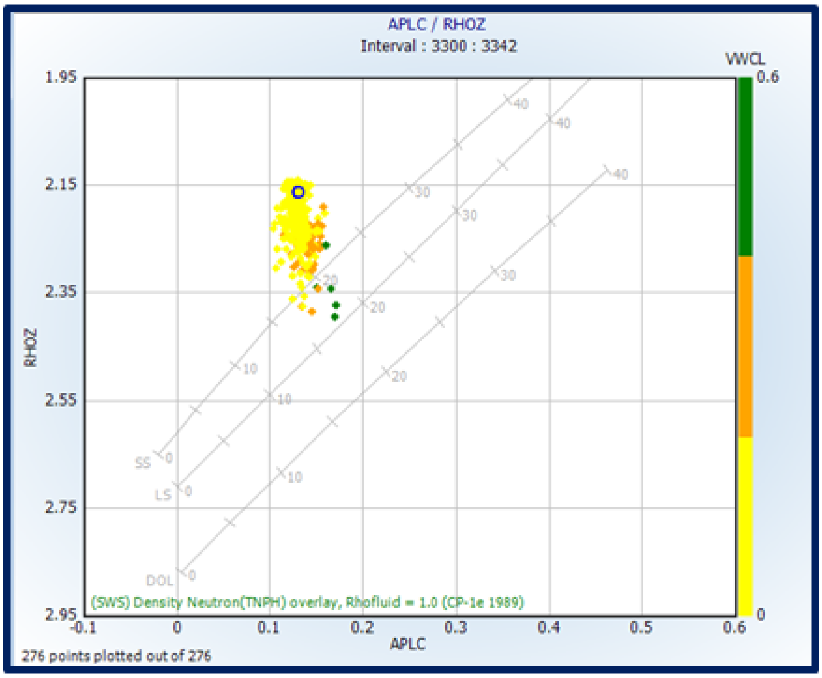

Fig. (8): Neutron-Density Crossplot for Balsam-1 Well in Qawasim Formation with Excellent Gas Effect in Clean Gas Sand Reservoir.

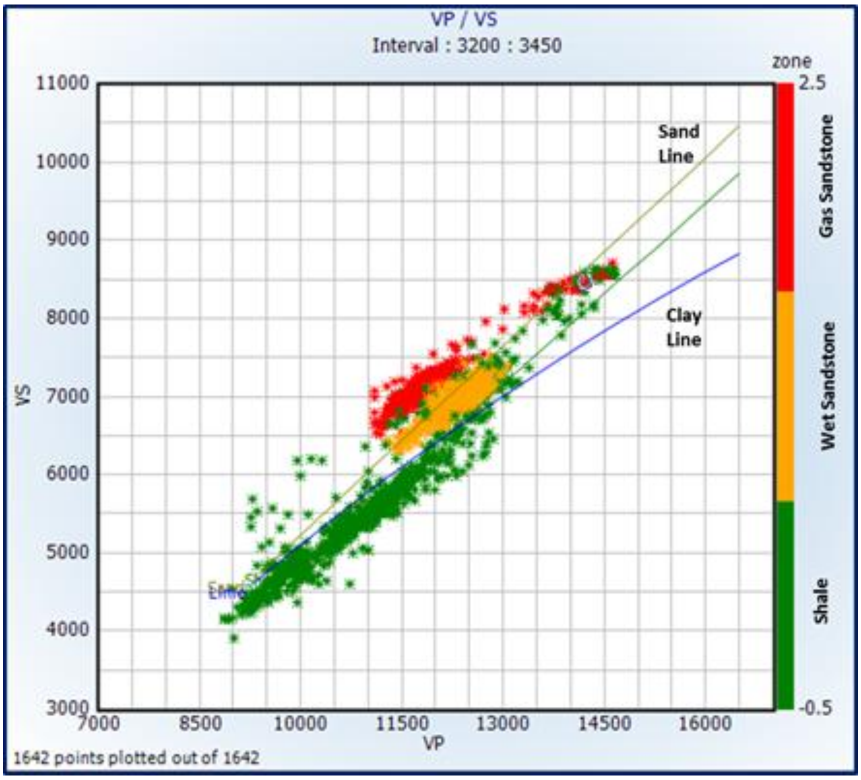

Fig. (9): Vp-Vs Crossplot for Balsam-1 Well in Qawasim Formation, with Gas Sand, Wet Sand and Clay Separation.

A crossplot between Vp/Vs ratio and Vp with V_{clay} in Z-axis for the top tight sand of Qawasim pay in Balsam-1 that is also used to differentiate between the gas sand, wet sand and shale as shown in Fig. (11).

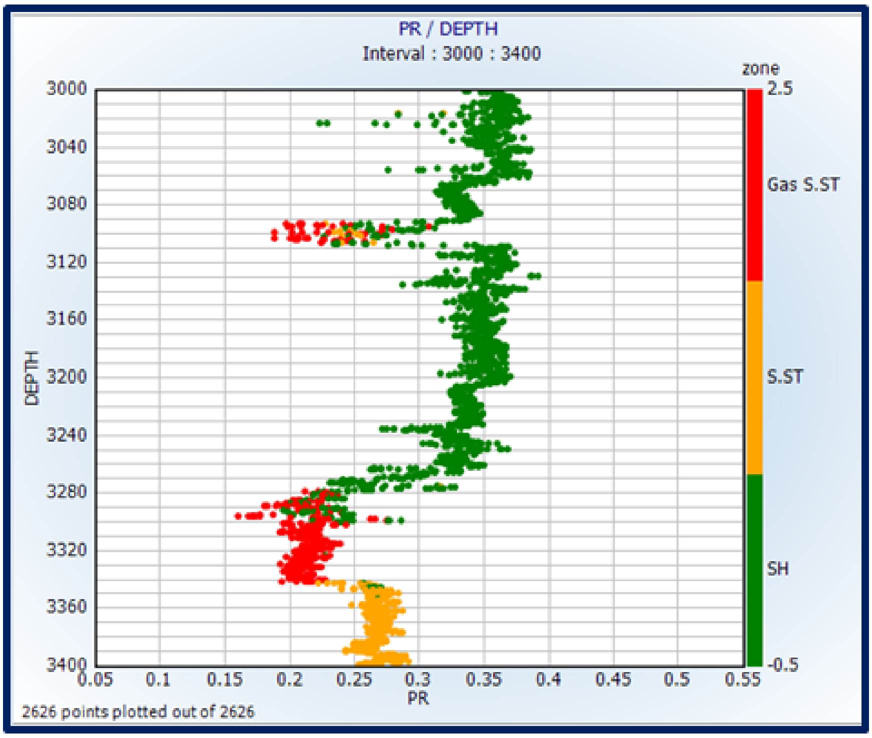

Fig. (10): Poisson's Ratio-Depth Crossplot for Balsam-1 Well in Qawasim Formation

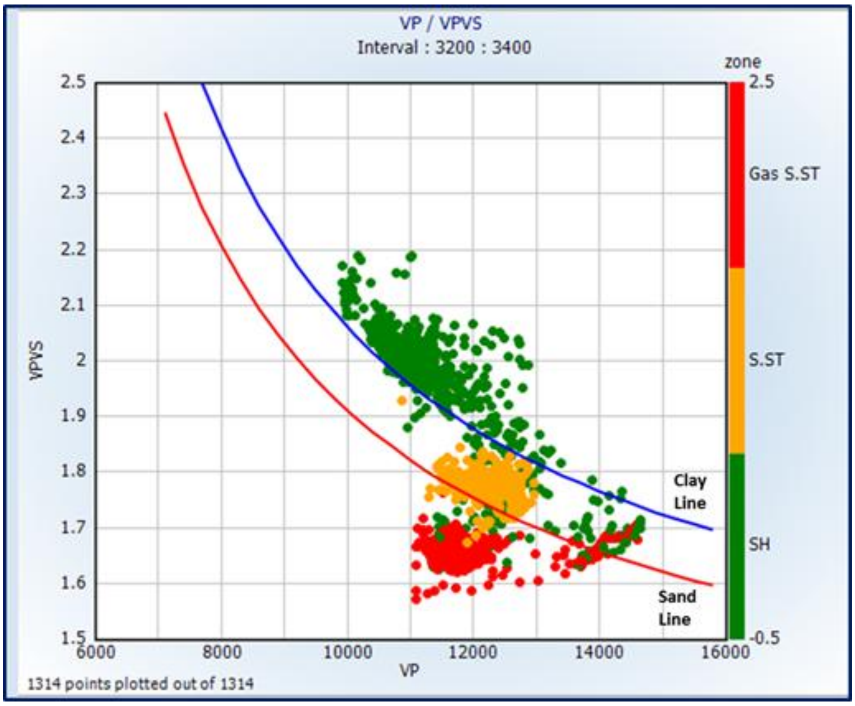

Fig. (11): Vp/Vs Ratio-Vp Crossplot for Balsam-1 Well in Top Tight Sand of Qawasim Pay-II

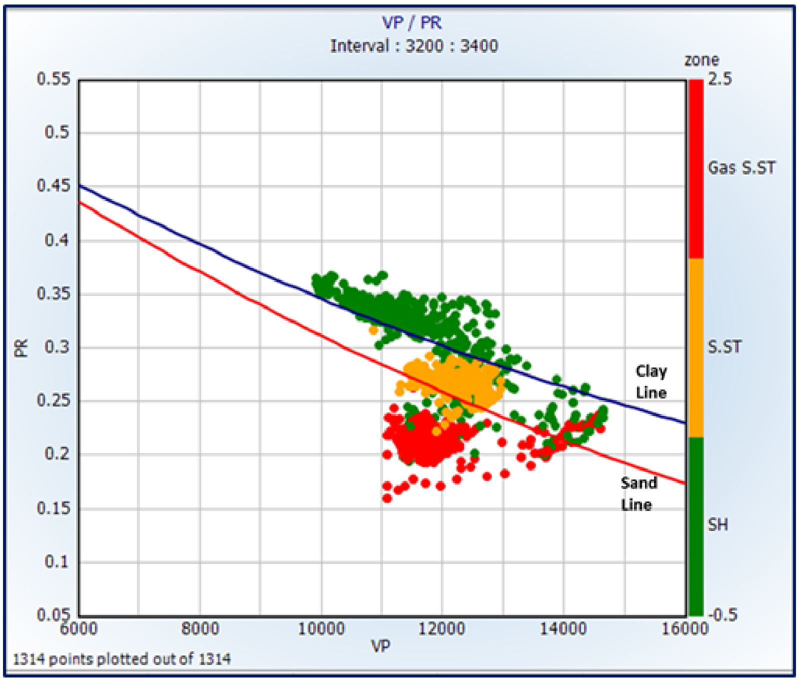

Fig. (12): Poisson's Ratio-Vp Crossplot for Balsam-1 Well in Excellent Qawasim Sand Pay-II.

A crossplot between Poisson's ratio and Vp with V_{clay} in Z-axis for the excellent sand of Qawasim pay is shown in Fig. (12) to differentiate between the gas-sand, wet sand and shale brine-saturated rock. Shale brine-saturated rocks have higher PR values than that of gas-saturated rocks because brine is stiffer than gas. Consequently, the effect is that PR ratio of gas-saturated rock will be lower than that of shale brine-saturated rock.

4- CONCLUSIONS

In this study, an integrated approach; petrophysical analysis and rock physics analysis are applied to characterize the reservoirs of the West Manzala field using all available log data.

The petrophysical analysis of Qawasim-I unit in Balsam-1 well shows net sand of 11 meters with net/gross thickness 10% and net effective pay (6 meters) with average porosity of 20% and water saturation 60% with V clay 20%.

The petrophysical analysis of Qawasim-II unit in Balsam-1 well shows net sand of 112 meters with net/gross thickness 80% and net effective pay (54.4 meters) with average porosity 20%, water saturation 30% and V clay 10%.

Rock physics analysis is usually carried out to discover and understand the seismic-to-reservoir relations and crossplots that is very important task to separate between the different reservoirs facies (sand or shale) and their fluid content (gas or brine), sonic waves can be used in lithology and fluid determinations.

The compressional and shear waves are of mechanical types and depend on the nature of rocks and their fluid content properties.

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