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Acoustic Impedance Application of Petrophysical Assessment of Facha Reservoir (Lower Eocene), western Sirte Basin-Libya (Case Study)

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Abstract

Integration between acoustic impedance (AI), and petrophysical and mechanical properties of reservoir rocks provides a significant and substantial interpretation of lithology and fluid type discrimination in oil fields. An application of AI to define lithology, fluid type, and diagenetic history processes of Facha reservoir (Gir Formation, Lower Eocene) quality Dahab Oil Field in Western Sirte Basin, Libya. Thus, analyzing the data from three oil wells to calculate the reservoir properties: porosity (ø), water saturation (Sw), velocity ratio (Vp/Vs), Poisson's ratio (PR), and AI. Cross-plots of Vp/Vs – AI, Bulk density (ρb) – AI and PR – AI with the ø and Sw influence illustrate four rock compounds of the Facha reservoir. Meanwhile, high AI values correspond to high Sw, which is restricted to the anhydrite and low porosity limestone lithology intervals. Also, increasing the porosity is followed by decreasing the AI with less than 50% of the Sw (hydrocarbon saturation). Although dolomitization, fracturing and blocky cementation are part of the geological history of the reservoir, they have not been discovered by the acoustic impedance.

Keywords: Acoustic Impedance, Carbonate Rocks, Rock physics, Sirte Basin, Petrophysics.

تطبيق الممانعة الصوتية لتقييم الخصائص البتروفيزيائية لخزان الفاشا (الايوسين السفلي)، غرب حوض سرت – ليبيا (دراسة حالة)

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الخلاصة

دمج الممانعة الصوتية (AI) و الخواص البتروفيزيائية و الميكانيكية لصخور المكمن توفر تفسير جوهري و ذو اهمية لتمييز نوع المادة الصخرية و نوع المائع في حقول النفط. تطبيقات الممانعة الصوتية لتحديد المادة الصخرية و نوع المائع و عمليات النشأة المتأخرة لجودة خزان الفاشا (الايوسين السفلي) لحقل الذهب في الجزء الغربي من حوض سرت الرسوبي، ليبيا. عليه، بيانات المسجلة من ثلاث ابار نفطية تم تحليلها لتقييم خصائص

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خزان الفاشا النفطي: المسامية (Ø)، التشبع المائي (Sw)، نسبة السرعات (Vp/Vs)، معامل بوسون (PR) و الممانعة الصوتية (AI). اظهرت مخططات AI – VpVs، AI – ρb و AI – PR بتأثير المسامية و التشبع المائي اربعة مكونات صخرية لخزان الفاشا المكمني. في حين كانت قيم للممانعة الصوتية العالية تعكس تشبع مائي عالي بشكل ملحوظ لكل من التتابعات الصخرية الانهدريت و الحجر الجيري الصخري منخفض المسامية. ايضا تناقص المسامية المتبوع بنقص الممانعة الصوتية لتشبع مائي لا يزيد عن 50% (تشبع هيدروكربون). بالرغم ان الدلمته و التكسر والمادة اللاحمة الكتلية اثار جيولوجية للنشأة المتأخرة و مسيطرة على صخر المكمن فلم تبينها الممانعة الصوتية.

1. Introduction

Lithology discrimination, porosity, fluid type, saturation and diagenesis history are the static basic petrophysical evaluation of any reservoir rock units. Also, these properties cause low productivity in oil fields. In addition, oil fields consider this early petrophysical evaluation of exploration wells by the reservoir. In addition, integration between the available data of any reservoir rock gives fewer uncertainty results for the oil field strategic development plans [1]. Further, the changing of reservoir rocks properties commonly occurs, especially in carbonate reservoirs due to the diagenesis history [2]. The carbonate rocks have a complex pore framework, which is sensitive to diagenesis processes such as dissolution, dolomitization, cementation and compaction. Moreover, the pore complexity of the carbonate rocks causes a high scattered velocity and porosity relationship [3], then some cross plots give an idea about the general geological processes of these rocks. According to that, Voigt–Reuss–Hill average [4] A 2D model utilized to calculate the elastic properties of carbonate rocks. In addition, Makarian et al. (2023) apply the Rock Physics Templates (RPT) to discriminate lithology and fluid type of carbonate reservoir based on the well logging data that accurately defined the fluid type saturation, as well as demonstrated explanation of seismic velocity decreasing due to high oil saturation. Therefore, wire line measurements are an essential information of the petroleum industry as well as the seismic survey of reservoir evaluation that allows understanding of the lithology influences on the petrophysical and mechanical properties, which are significant issues of the carbonate reservoir studies [5][6]. Hence, velocity ratio (Vp/Vs) versus acoustic impedance (AI) cross plots are applied to define the lithology of Yamama Formation [7].

The carbonate rocks are giant hydrocarbon reservoir rocks of the Sirte Basin, and the Eocene reservoir rocks provide about 15 % of the total reserve of the basin [8]. Then, many studies related to the assistance of petrophysical, petrographic, structure and seismic attributes evaluation of the carbonate reservoirs (Facha Member) of the Sirte Basin [9][10]. That are based on the wire lines and core data. Therefore, studying the impact of the rock physical and fluid type on the acoustic impedance by the petrophysical and elastic properties of the Facha reservoir (Gir Formation), which is the utility of wire line analysis results, is essential as a quick and simple technique. According to that, integration between the petrophysical, mechanical properties and the acoustic impedance to find out lithology discrimination, fluid type, and the geological history process of the Facha reservoir is utilized by three oil wells (1, 2, and 3).

2. Geological background of Facha reservoir

The general setting of the Sirte Basin has been studied and reviewed by many authors, which is summarized by [11]. Thus, tectonic phases can be recognized during the structural and stratigraphic evolution of the basin. Structurally, the basin is formed as a series of platforms and troughs that are an oriented mainly in north-northwest direction (Fig. 1). Thus, the stratigraphy of the Sirte basin can be divided into three megasequences: pre-rift (Precambrian–Ordovician?), syn-rift (L. Jurassic–Eocene), and post-rift (Oligocene–Recent) [12]. However, Zallah Trough is considered a further asymmetrically western trough of northwest – southeast arm of the Sirte Basin as Harding documented (1984). In addition, [13] documented the Lower Eocene paleogeographic map and facies cross section of the Sirt basin (Fig. 2). Furthermore, [14] reviewed the petroleum geology of western Sirte Basin and emphasised that the Facha member is an excellent quality dolomitized reservoir rock.

As previously mentioned, the Facha Member of the Gir Formation is productive in the most western Sirte Basin (Zallah Trough). However, dolomite, dolomitic limestone, limestone and anhydrite are primarily rock types of the member [15][16][17][18]. Then, the presence of planktonic and nannofossil assemblages is demonstrated, the Gir Formation is deposited at mid-Ypresian (Eocene) age [8]. Also, during the Eocene age of the Sirte Basin tectonic movements influenced the sequence stratigraphy thickness, especially within the Zallah and Maradah Trough. Hence, three members are composed of the Gir Formation in ascending order: Mesdar Member, Facha Member, and Hon Evaporate Member [19]. Then, a typical section of the Facha member presented on Al Bayda Platform at well Y1-59 presents an open marine carbonate with planktonic foraminifera through bioclastic limestones with benthonic foraminifera to argillaceous dolomite and finally to porous microcrystalline dolomite [11].

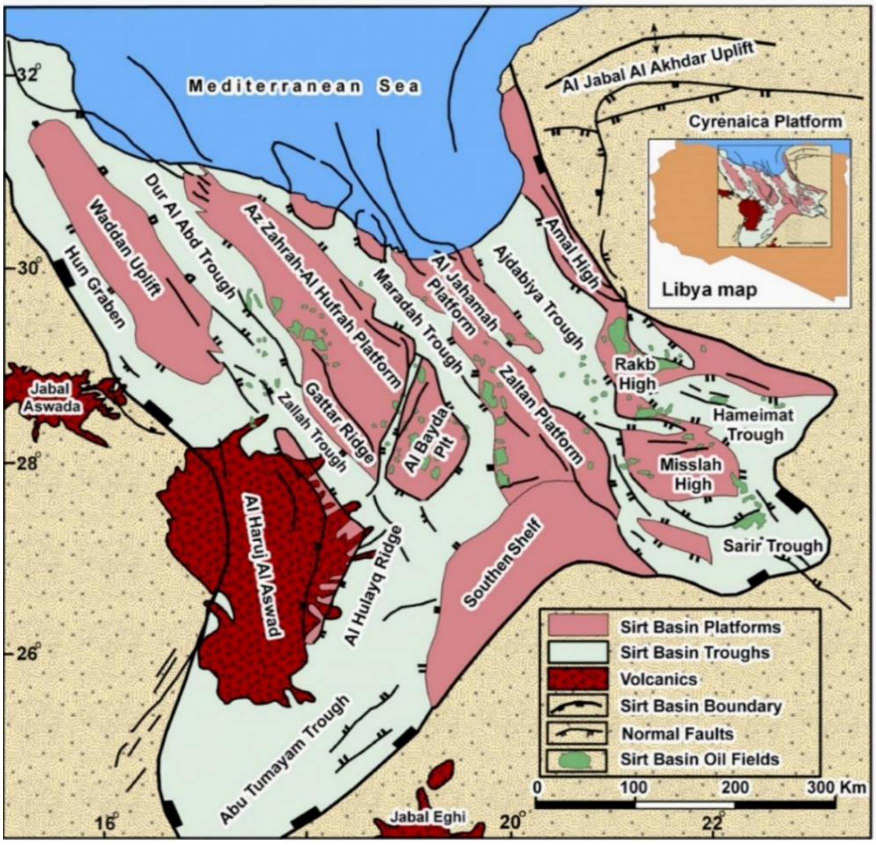


Figure 1: Structure features map of the Sirte basin, after [20]

3. Data Collection and Methodology

Many petrophysical studies of reservoir rock units concern the lithology, pore geometry and types, fluid type and saturation, which have a role in reservoir characteristics. These studies are based on well logging, core samples and well testing analysis data for reservoir rocks. The well logging measurements provide interesting and continuously valuable data as core samples [21]. Also, the core analysis data from a limited number of wells for interesting intervals is necessary. Thus, basic petrophysical evaluation includes: total porosity (Øt), secondary porosity (Øsec), water saturation (Sw) and shale content (Vsh), while Poisson's ratio (PR) is a mechanical property. Therefore, the well logging data recorded within Facha member from three wells (1, 2 and 3) of the Dahab oil field (Sirte Basin, Libya) are including: Gamma-ray (GR), Spontaneous Potential (SP), Acoustic (ΔT), Litho-Density

(RHOB and PEF), Neutron (NPHI), deep and shallow resistivity (RD and RS), Calliper (CAL), Photoelectrical factor (PEF). Special and routine core sample analysis results of both wells 2 and 3 are used to define Arcie's parameters: Tortuosity (a), Cementation exponent (m) and saturation exponent (n), as well as, core permeability (K core) and core porosity (ø core). Thus, these recorded logs are analysed for each half foot using Excel, Microsoft. However, delineating formation or member top depth based on the lithology logs is helpful and a quick and simple correlation process. Then, the interval travel time (ΔT) and gamma ray (GR) are commonly used. The ΔT logs are applied to delineate the Facha member tops depths through three wells. The PEF (Litho-density tool) is also a good lithology indicator log and has standard values of each rock type (Table 1). In this study, two main techniques were used to define the lithology discrimination of the Facha member, which depend on the overlay of the Neutron porosity and bulk density logs, the bulk density - Neutron porosity cross plot, and the Photoelectrical factor (PEF) log. It is worth mentioning that the PEF log is not recorded within the well 1, so the PEF log is only available for the two wells 2 and 3.

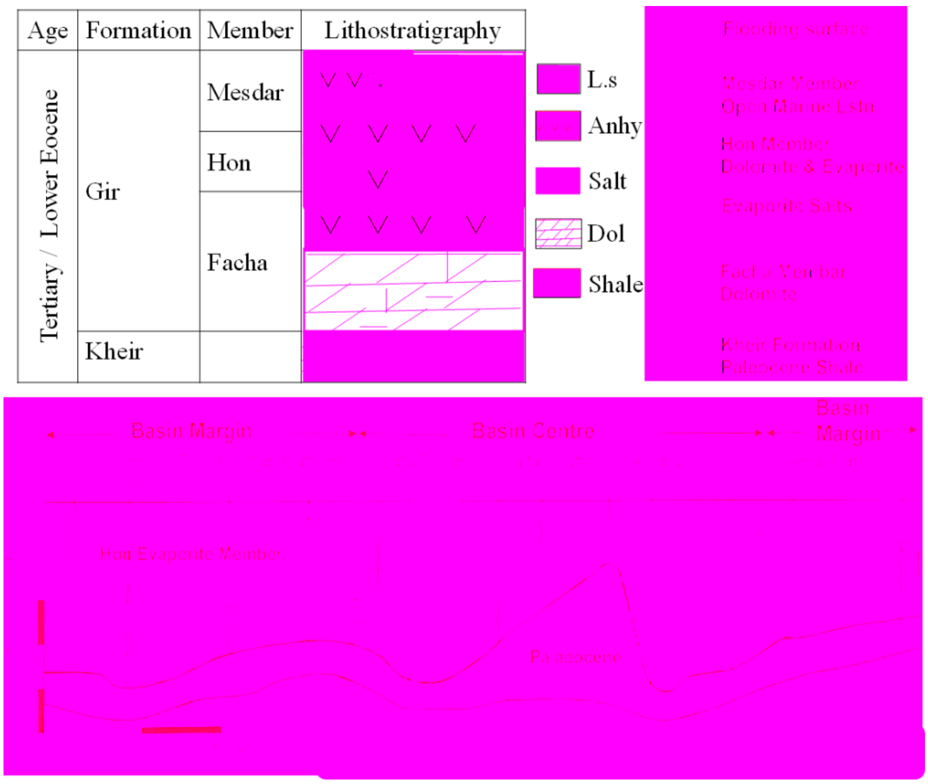


Figure 2: Tertiary column sequence and cross section lower Eocene of Sirte basin, modified after [13] [18]

Table 1: Photoelectrical factor (PEF) log standard values of rock rocks [22]

Rock type	L.S	Dol	Anhy	S. s	Salt
PEF (b/e)	5.08	3.14	5.05	1.81	4.65

The lithology discrimination of the Facha member is important to define apparent matrix parameters (ρma and ΔTma) used to compute density and sonic porosity. Then, total (Øt) and secondary (Øsec) porosity could be calculated, which helps in fluid saturation estimation of hydrocarbon detection depths. Thus, Neutron porosity (Øn) is direct porosity log and influenced by the borehole environments and any argillaceous materials associated with the reservoir rock. Whereas, the bulk density (ρb) and interval travel time (ΔT) are to be solved by equations 1 and 2 to calculate density and sonic porosity. Also, Eq. 3 and 4 [23] were used to calculate the Øt and Øsec.

$$\emptyset_d = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad (1)$$

$$\emptyset_{snc} = \frac{\Delta T_{log} - \Delta T_{ma}}{\Delta T_f - \Delta T_{ma}} \quad (2)$$

$$\emptyset_t = \frac{\emptyset_n - \emptyset_d}{2} \quad (3)$$

$$\emptyset_{sec} = \emptyset_t - \emptyset_{snc} \quad (4)$$

Where: Ød = density porosity, fraction; ρma = matrix density, g/cc; ρb = log reading of the bulk density, g/cc; ρfl= Fluid density, (equal 1 gm/cc); Øt = total porosity, fraction; Øn = neutron porosity, fraction; Øsec = secondary porosity, fraction; Øsnc = sonic porosity, fraction; Δt log = interval travel time, usec/ft. (log reading); Δtma = matrix travel time, usec/ft; Δtf = fluid travel time, (equals to 189 µsec/ft).

The Archie's parameters results of wells (2 and 3) are given by the Zueitina Oil Company, which required the water saturation assessment of the Facha member. There are many Equations or models to calculate the water saturation (Sw), and a suitable model is Archie Eq. (5). Whereas, the Shale volume is another petrophysical issue, mainly concerned within shaly reservoirs. As mentioned above, the GR logs are shale indicators and the Facha member is carbonate rocks, it also has lower GR log reading values, which makes the shale content insignificant. However, evaluation of the velocity ratio (Vp/Vs) and Possin's ratio (PR) is needed for the shear velocity (Vs = 1/ ΔTs), where the ΔTs is not measured within the three wells and to compute a synthetic shear travel time, could be calculated by empirical relations such as [24] and [25]. In the studied wells of Dahab oil field (Sirte Basin, Libya), the ΔTs is estimated by the [24] Eq. (6). On the other hand, the ability of rocks to pass seismic waves through them is the acoustic impedance (AI). Mathematically, the AI is a product of the compression velocity (Vp) with the bulk density (ρb) in rayl unit (Eq. 7).

$$S_w = \left[\frac{a \times Rw}{\emptyset^m \, Rt}\right]^{1/n} \quad (5)$$

$$V_s = 0.7858 - 1.2344V_p + 0.7949V_p^2 - 0.1238\,V_p^3 + 0.006V_p^4 \quad (6)$$

AI=ρb x Vp (7)

4. Results and discussion

Generally, the GR logs were used to identify clastic rock sequences. At the same time, the interval travel time (ΔT) is applied for carbonate rocks, because the GR logs have a low response to carbonate rocks, except salt rocks, which have high potassium elements concentration [26]. In this study, the lithology of the Facha member (Gir Formation) is primarily defined by the bulk density (ρb) – neutron porosity (Øn) cross plot (Fig. 3). The Figure is simulated with the Schlumberger lithology chart that includes the main lithology apparent matrix lithology lines. The limestone line is 2.71 g/cc, dolomite is 2.83 g/cc, sandstone is 2.65 g/cc, and anhydrite is close to 2.93 g/cc. Then, it could easily delineate the lithology of the Facha member as limestone, dolomitic limestone, dolomite and anhydrite. Also, there are recognized plotting points of well 2 that have points located on the northeast trend. This exception of well 2 may be attributed to the occurrence of the secondary porosity. In addition, the Facha member lithology is emphasized by the PEF logs of wells 2 and 3 as illustrated on Figure 4.

The special core analysis results provide the Archie's parameters; the cementation exponent is equal to 1.963, the tortuosity factor (a) is 0.997, and the saturation exponent (n) is equal to

2.075 of the Facha Member. These parameters serve to compute the water saturation (Sw), which is considered one of the petrophysical properties that contribute to the acoustic impedance (AI).

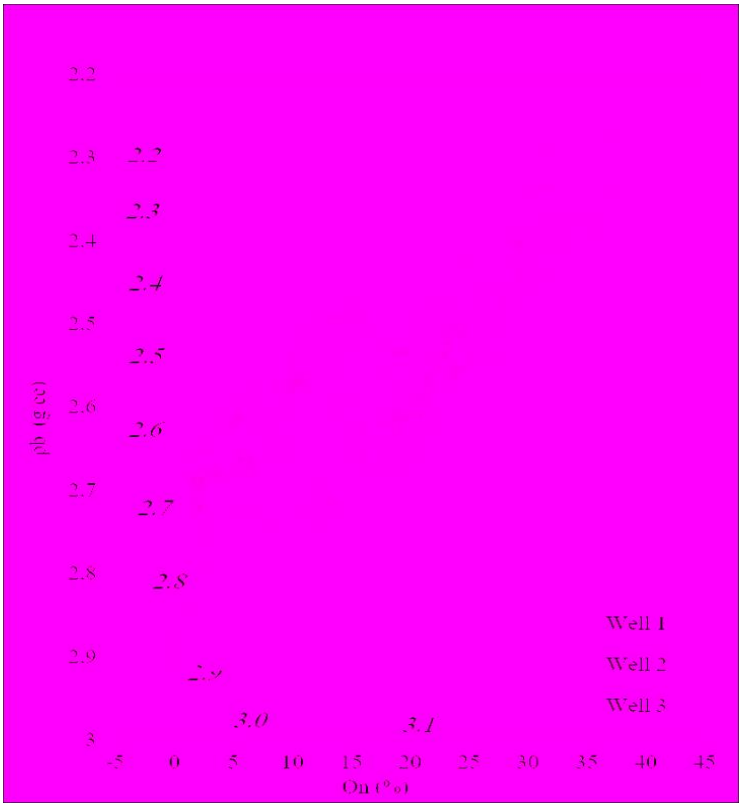


Figure 3: Bulk density (ρb) – Neutron porosity (Øn) cross plot of the Facha member (Gir Formation)

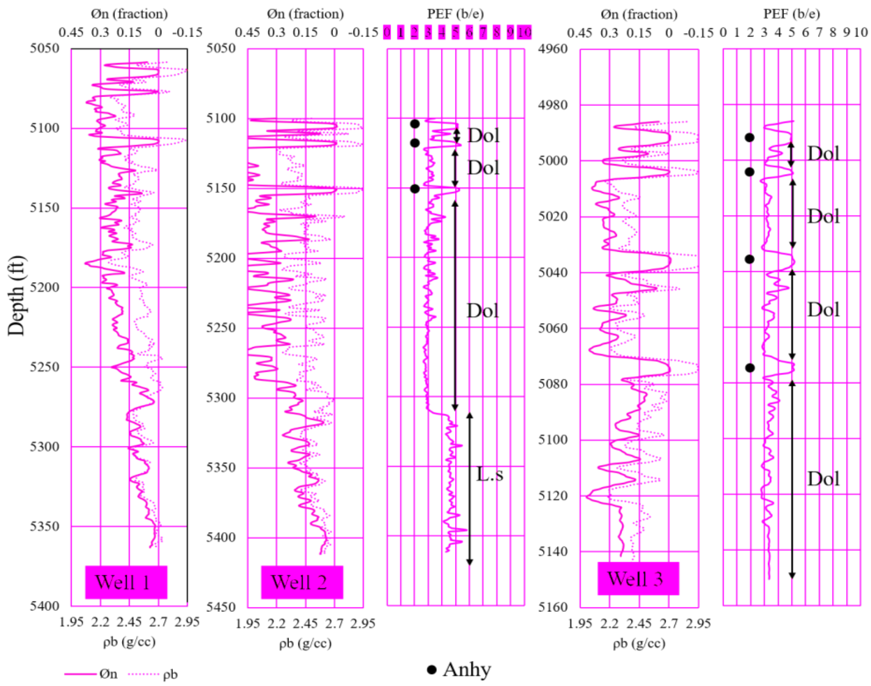
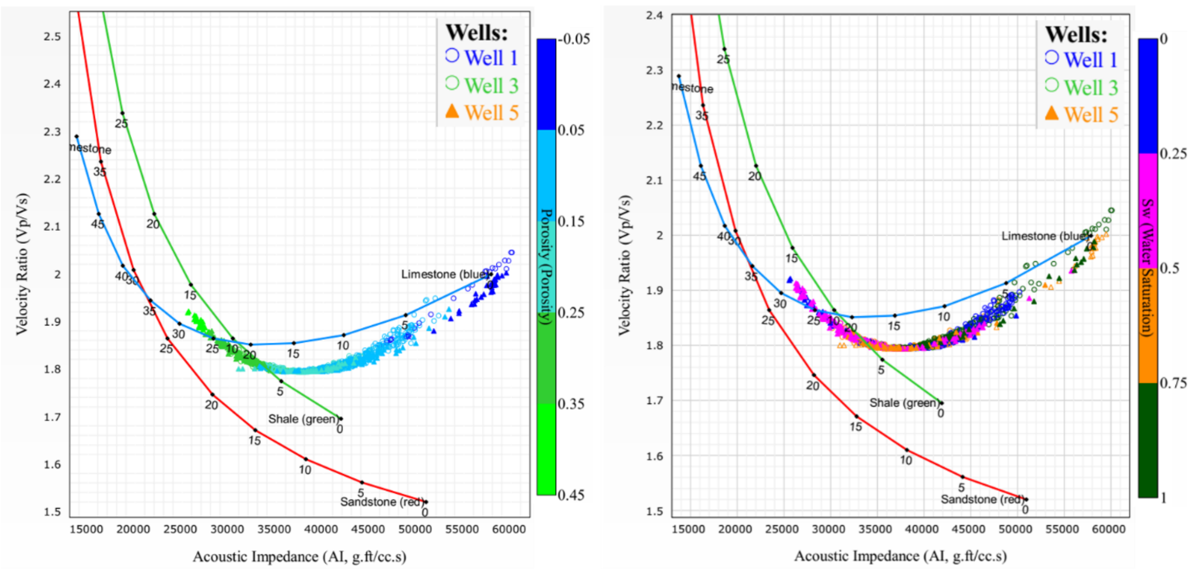


Figure 4: Bulk density (ρb), Neutron porosity (Øn) overlay and Photoelectrical factor (PEF) correlation of the Facha member (Gir Formation) of studied wells (1, 2 and 3)

The velocity ratio (Vp/Vs), bulk density (ρb) and Poisson's ratio (PR) are main properties related to the acoustic impedance (AI). Therefore, the figures (5, 6 and 7) display the cross plots between Vp/Vs – AI, ρb– AI and PR – AI of the Facha member with the porosity and water saturation as the third physical properties. Through these cross plots, it could be noted that there is an incremental relation between the Vp/Vs – AI cross plots when the porosity is decreasing. In contrast, this relation is reversed when the porosity is restricted between 30% and 40%. Meanwhile, the Vp/Vs – AI relation is stable when the porosity from 20 % to 30% along the AI increased. Also, the same pattern of the Vp/Vs – AI relation with the water saturation affect. Thus, increasing the porosity and decreasing the AI with less than 50% of the water saturation (hydrocarbon saturation). The same result of Vp/Vs – AI cross plots is documented of the upper part of the Nahr Umr Formation (Amara Oil Field, Southern Iraq) [27]. Moreover, the ρb– AI relations give a good lithology recognized more than the Vp/Vs – AI and PR – AI cross plots, which clearly present gradual form of limestone, dolomite and anhydrite as principal rock components. It is worth mentioning that the plotting points on the PR – AI cross plots are moved slightly toward the dolomite line with high porosity values and close to the limestone line with low porosity values, this agrees with [28] conclusion that the PR and porosity have a negative relationship. Further, available measured core permeability (K core) and porosity (Ø core) of wells 2 and well 3 are used to expose a brief diagenetic history, affecting the Facha reservoir quality. Dolomitization and dissolution controls the pore structure and rock homogeneity of carbonate reservoir [29], which in turn controls the permeability. Then, a cross plot (K core - Ø core) demonstrates dolomitization and fracturing are the domain diagenetic processes of the Facha member (Fig. 8). While, compressional velocity and porosity cross plot [30] discloses the dolomitization, Fracturing, and Blocky cementation are geological history of the all studied wells (Fig. 9). In addition, presence of the Vuggy and Moldic (Stiff pores), which emphasizes the presence of the secondary porosity of the well 3.



(a) (b)

Figure 5: Velocity ratio and Acoustic impedance of wells (a) Porosity influence of Facha member (b) water saturation influence of Facha member

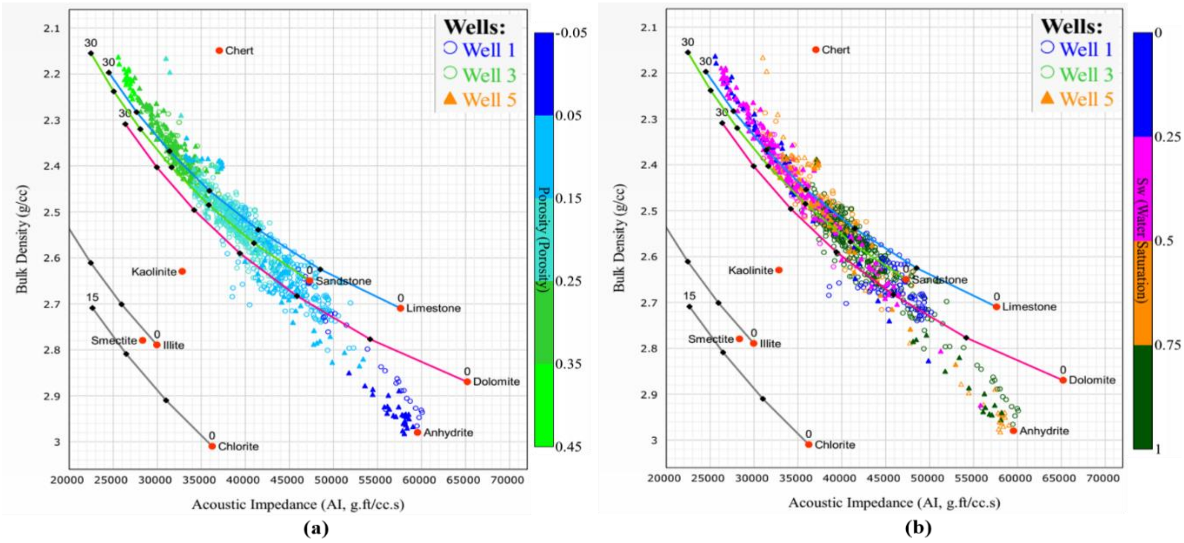


Figure 6: Velocity ratio and Acoustic impedance cross plots of wells (a) Porosity influence of Facha member (b) water saturation influence of Facha member

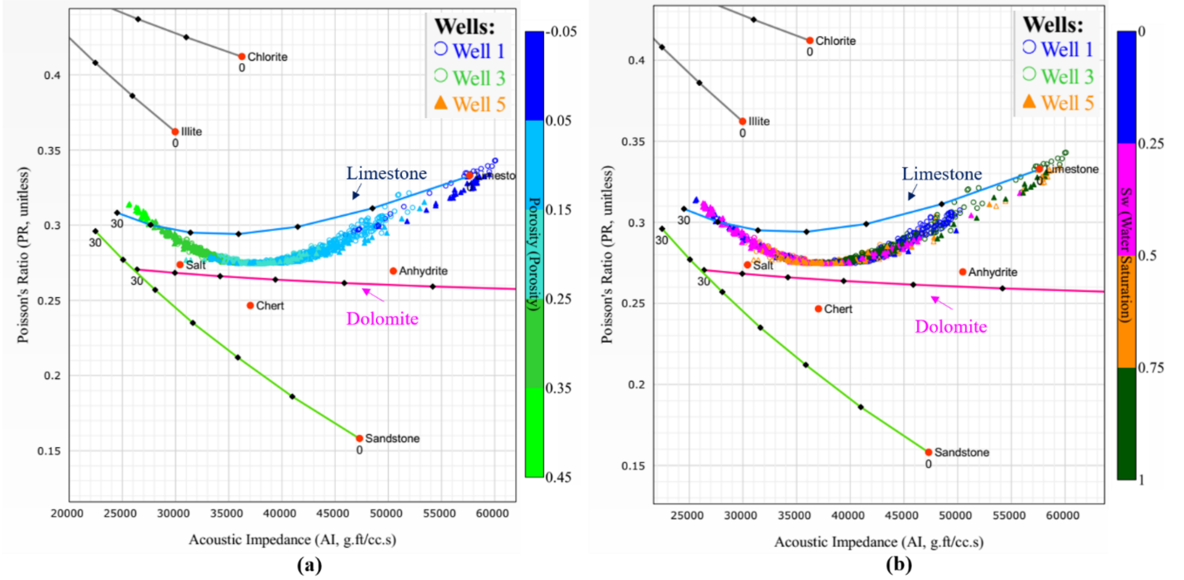


Figure 7: Poisson's ratio and Acoustic impedance cross plots of wells (a) Porosity influence of Facha member (b) water saturation influence of Facha member

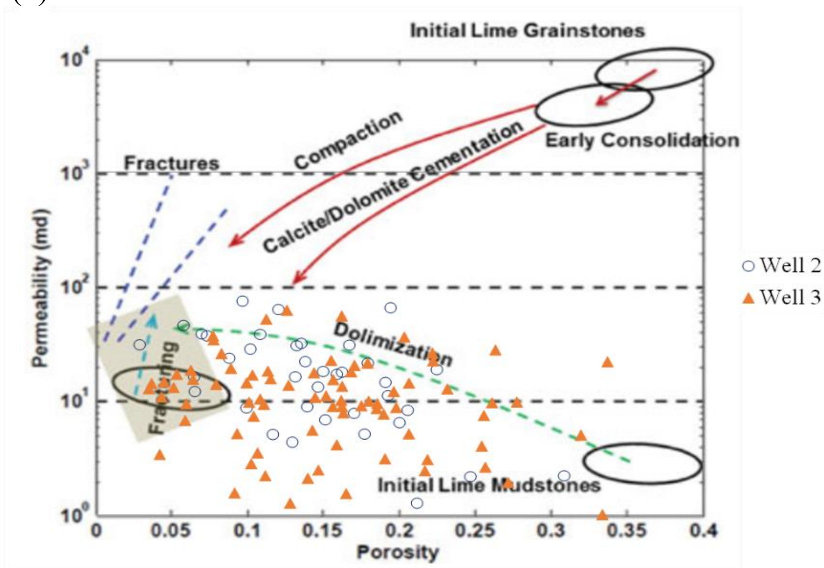


Figure 8: Core permeability and porosity cross plot of well 2 and 3, after [30]

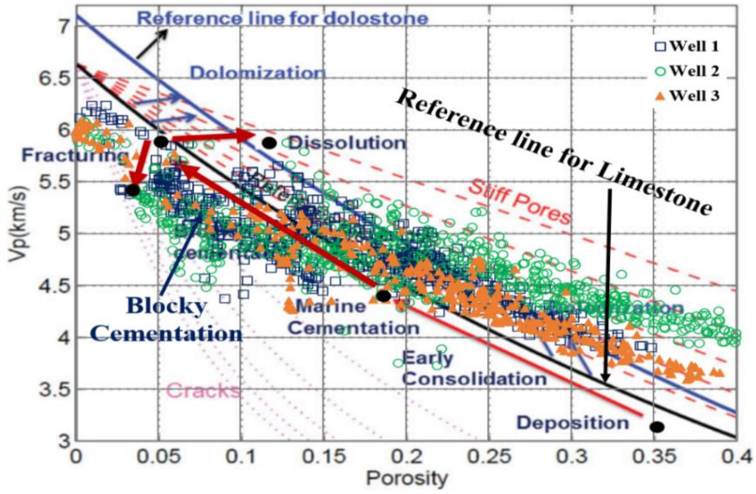


Figure 9: Compressional velocity (Vp) and porosity (Øt) cross plot of wells 1, 2 and 3, modified after [30]

5. Conclusion

Integration between rock physics and petrophysical properties gives good indications on lithology and fluid type as fundamental petrophysical reservoir information results. Dolomite, dolomitic limestone, limestone, and anhydrite are rock types of the Facha member (Gir Formation) that are discriminated by the bulk density-neutron porosity cross plot of the Dahab Oil Field (Zallah Trough, Sirte Basin). Whereas, the bulk density (ρb)– acoustic impedance (AI) cross plots also give a better lithology definition than the velocity ratio (Vp/Vs)– acoustic impedance (AI) and Poisson's ratio (PR)– acoustic impedance (AI) cross plots. Also, recognizing fluid type on the cross plots reveals a decreasing AI responding to an increasing porosity with less than 50% of the water saturation (hydrocarbon saturation). On the other hand, dolomitization, fracturing, and blocky cementation are geological history (diagenetic processes) exposed only by the core permeability – porosity, and velocity – porosity cross plots. In addition, the secondary porosity (øsec) is a result of the diagenetic process of Facha reservoir (Figures 3 and 9) that does not illustrate on the AI cross plots.

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