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ESTIMATION OF WATER AND HYDROCARBON SATURATION BASED ON WIRELINE LOGS IN CARBONATE ROCKS OF THE SARGELU FORMATION (MIDDLE JURASSIC) FROM THE KURDISTAN REGION, IRAQ

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ABSTRACT

The Zagros Fold and Thrust Belt in Iraq contain host prolific hydrocarbons and recently, significant oil reservoirs have been discovered in the Jurassic carbonate rocks. The current work focuses on Water and Hydrocarbon Saturation in the carbonate rocks of the Sargelu Formation (Middle Jurassic) based on a set of conventional Wireline logs which are: Gamma-ray, Neutron porosity, Bulk Density, three sonic types, all Resistivity, photoelectric, uranium, thorium, and potassium. The Wireline log shows that the Sargelu Formation can be divided into five units based on lithology. These units were derived from different cross plots. The computation of petrophysical properties of this carbonate reservoir is complex due to several washouts and heterogeneities, caused by the exposure of shale which is strongly influencing the reservoir saturation. The Wireline log shows that the average Water saturation in the carbonates of the Sargelu Formation is 20%, with an irreducible Water saturation of 0.2% and an average Hydrocarbon saturation of 30%. Whereas, the water resistivity is 0.03 ohm.m and the Mud filtration resistivity is 0.17 ohm.m.

تقدير مستوى الاشباع بالمياه والمواد الهيدروكربونية بواسطة الجس البئري للصخور الكربونيتية لتكوين ساركلو (الجوراسي الاوسط) في إقليم كردستان، العراق

مهدي خيري أسود

المستخلص

يحتوي نطاق طيات زاكروس والحزام الزاحف فى العراق على مواد هايدروكربونية وتم مؤخرا اكتشاف خزانات هايدروكربونية مهمة فى الصخور الكاربونيتية للعصر الجوراسى. ركزت الدراسة الحالية على التشبع المائي والهايدروكاربوني فى الصخور الكاربونيتية لتكوين ساركلو (الجوراسي الاوسط) اعتمادا على المجسات السلكية التقليدية التى تتضمن أشعة كاما والمسامية النيوترونية والكثافة الإجمالية والأنواع الصوتية الثلاثة والمقاومة الكلية والكهربائية الضوئية واليورانيوم والثوريوم والبوتاسيوم. أظهرت المجسات السلكية بأن تكوين ساركلو ينقسم الى خمس وحدات اعتمادا على الصخارية. اشتقت هذه الوحدات المختلفة من علاقات التغاير المختلفة. إن حساب الصفات البتروفيزيائية لهذا الخزان الكاربوناتي عملية معقدة بسبب بعض الإخفاقات والتغايرات فى الصخارية ويعود سبب هذه التغايرات الى وجود الصخر الطينى الذي يأثر بشدة على تشبع الخزان. أظهرت المجسات السلكية أيضا أن معدل التشبع المائي لتكوين ساركلو هو 20% ومعدل التشبع غير القابل للاختزال 0.2%، ومعدل التشبع الهايدروكربوني 30% والمقاومة المائية 0.03 أوم بينما كانت مقاومة الترشح للطين 0.17 أوم.

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INTRODUCTION

Fluid saturation is one of the most common problems in the oil reservoirs of Northern Iraq. Evaluation and identification of saturation requires interpretation of the Wireline log. Saturation is defined by the ratio of a volume of fluid to the total volume of pore space. Pores form hydrocarbon reservoirs in subsurface rocks that are usually saturated with fluid. During deposition, pores are usually saturated due to the aqueous environment. After diagenesis processes, such as compaction and cementation, the Water saturation (Sw) maintains its level at 100%, but after hydrocarbons enter the pores, saturation is changed. Many researchers discussed this parameter (e.g., Archie, 1942; Simandoux, 1963; Waxman and Smith, 1968; Zeng, 1991; Ali *et al*., 2001; Kamel and Mabarouk, 2002; Bruce *et al*., 2003; Mahmood *et al*., 2008; Budebes *et al*., 2011). Archie's equation is the most useful for the calculation of Sw in clean formations, but it needs to determine two unknown parameters, which are the formation water resistivity (Rw) and the formation porosity (Hamada *et al*., 2012). The Pickett plot (1963) is used to determine the Sw of the reservoir, whereas, the Hingle plot (1959) is used for determining Rw. In Petrophysical analysis, the main uncertainty appears in the permeability and Water saturation which influence the reservoir characteristics and hydrocarbon content. The estimation of the Sw ratio is the main problem in this field. The hydrocarbon saturation is divided into two types; residual and movable hydrocarbon (Rider, 1996). The residual hydrocarbon might be low or high quality oil or gas in the reservoir (Sullivan *et al*., 2010). Well log interpretation is a significant tool to find out reservoir parameters (Schlumberger, 1974).

Petrophysical properties of the Sargelu Formation have been studied by many researchers in Iraq due to the potentiality of this remarkable source rocks for both generation and reserving oils. Most of these studies focused only on the outcrop rocks, therefor, the main target of this study is to estimate water and hydrocarbon saturation in the multi-layer carbonate field of Harir Block-Mirawa Well in the Northern part of Iraq based on a Wireline log data.

GEOLOGICAL SETTING

The studied Harir Block-Mirawa well (HBMW) is located in the Northern part of Iraq, about 45 Km to northeast of Erbil City (Fig.1). This field was discovered in 2010 and drilled in 201l by Marathon Oil Company. The coordinates of the HBMW is (44º 17' 38.82" E) and (36º 29' 05.75" N). The area is flat on the surface due to the erosion of soft sediments, though it is lies on the Khatibian-Shakrok anticline which hasan axis direction trending NW – SE and belongs to the Zagros Fold-Thrust Belt of Iraq (Omer, 2011). The Kurdistan Region of Iraq is located in the NE part of the Arabian Peninsula. The Hercynian orogeny is the main tectonic event that affected the Arabian Plate (Haq and Al-Qahtani, 2005). The tectonic movements due to plates collision is expressed in the NE parts of Iraq by the Zagros Fold-Thrust Belt, which maintains two main trends of NW – SE in the Arabian part and E – W in the Turkish part (Csontos *et al*., 2012; and Al-Ameri *et al*., 2013).

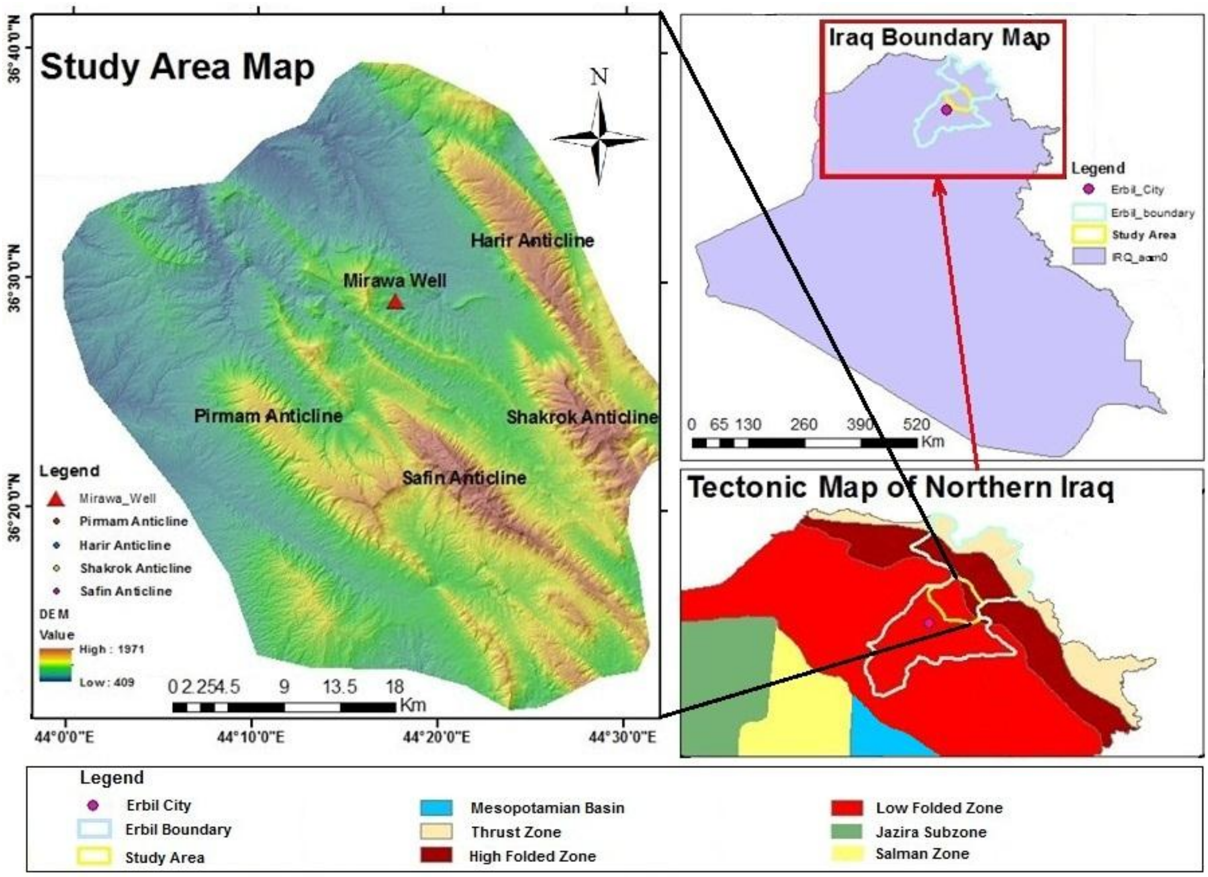

Fig.1: Location map of the studied well (modified after Al-Ameri *et al*., 2013) and study area map created by GIS from satellite image of Google Earth

The Sargelu Formation (Middle Jurassic) was first recognized by Wetzel (1948). Its thickness varies in the range 25 – 500 m, with 115 m in the type locality section (Wetzel, 1948 and Balaky, 2014). In the studied well, the thickness is 124 m based on the Wireline measurement.The upper contact of the Sargelu Formation with the Naokelekan Formation is conformableand the lower contact with the Alan Formation is also conformable (Buday and Jassim, 1987 and Abdula *et al*., 2015).The lithology of the Sargelu Formation consists of dolomitic bituminous and argillaceous limestone, laminated shale and chert, with some fossils as described in the outcrops (Figure 2) (Wetzel, 1948 and Al-Ameri *et al*., 2013).

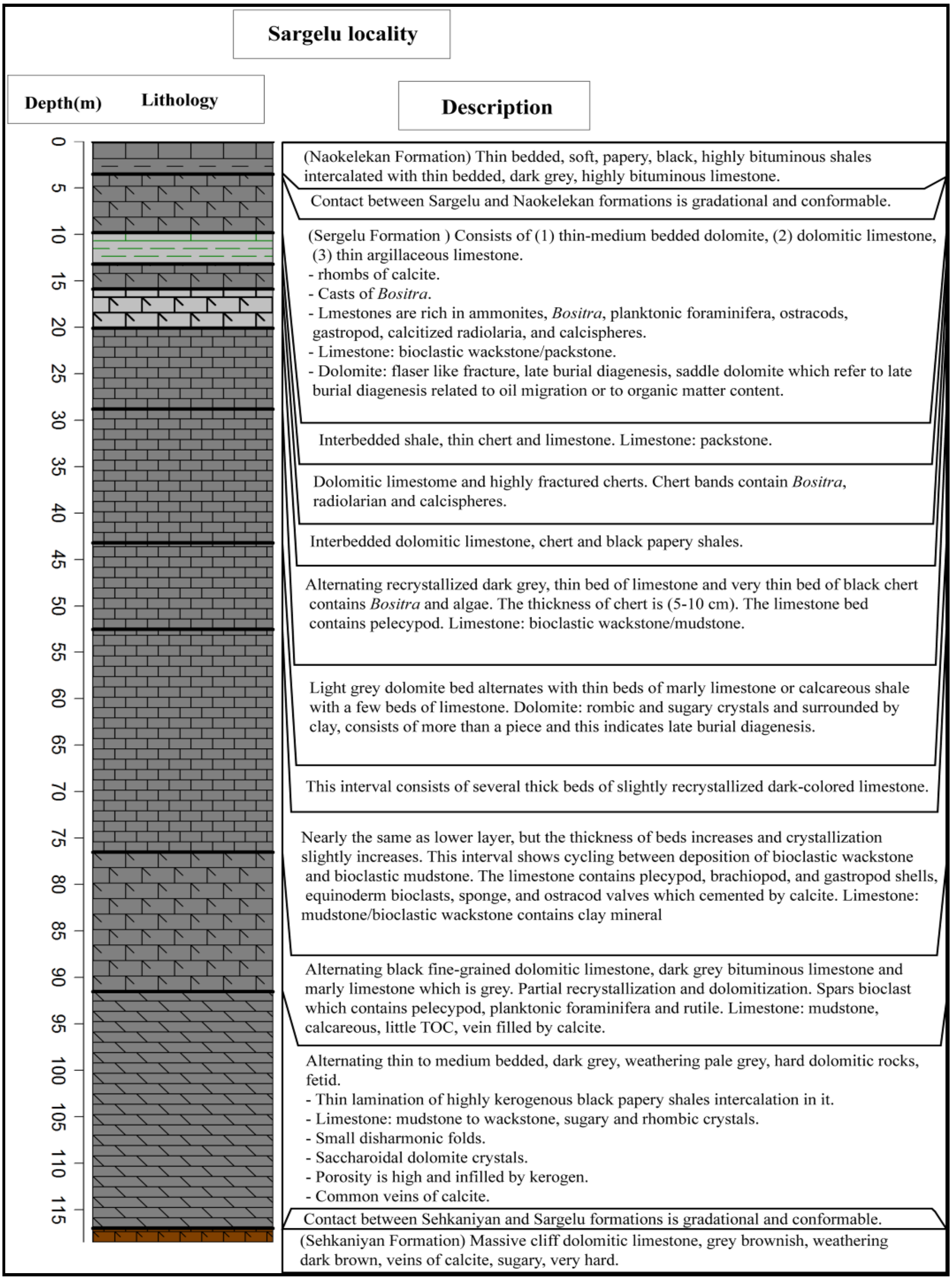

Fig.2: Lithology of the Sargelu Formation at the type locality (Abdula *et al*., 2015)

METHODOLOGY AND MATERIALS

The collected data consists of a complete set of the conventional Wireline log of the Sargelu Formation from the HBMW. The complete conventional open hole Wireline log includes Gamma-ray, Neutron porosity, Bulk Density, Sonic log types, all type of Resistivity, Photoelectric, uranium, potassium, and thorium. The data from the LAS file are loaded to Schlumberger software Tech-log 2014 from Heriot-Watt University/ United Kingdom and GIS software is used for creating a map of the area.Several equations are used in the determination of Sw in this study as summarized below:

- **Water Saturation (Sw)**

Based on the shale content, several methods are used to determine Sw, such as Archie (1942); Simandoux (1963); Waxman and smith (1968); Zeng (1991); Kamel and Mabrouk (2002); Bruce *et al*. (2003); Mahmood *et al*. (2008); Ali *et al*. (2001) and Budebes *et al*., (2011). In the current study, the Sargelu formation is divided into five zones based on its lithologic criteria. Four methods are applied in the present work and compared with each other as follows:

– ***Archie method (1942)*****:** It is used when the shale content is less than 15% and for clean formations. It is used for Sw estimation in carbonate and clastic reservoirs and to separate shale and non-shale zones in the sequence.

$$Sw = \{(F*Rw) / Rt\}^{-n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Sw = water saturation; F = formation factor; Rw = formation water resistivity; Rt = true formation resistivity; and n = cementation factor for carbonate (2)

Formation factor is obtained using Formula (2), (Archie, 1942).

$$F = a/\phi^{m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

F = formation factor; a = is a constant = 1; ϕ = formation porosity; and m = cementation factor for carbonate (2)

The m, n, a, are obtained using the pickett plot (Asquith and Krygowski, 2004)

– ***Waxman Smith equation (1968)*****:** It is used to accurately determine Sw in the Shale-bearing formations.

$$Swn* = Rw/ [(\phi m*. Rt) (1 + Rw.B (Qv/Sw))] \ldots\ldots\ldots\ldots\ldots 3$$

Sw = water saturation; n = water saturation exponent; Rw = formation water resistivity; m = cementation factor for carbonate (2) ; ϕ = formation porosity; Rt = true formation resistivity; B = from chart based on Rw and T; and Qv = can be taken from core, well log by tech-log and shale zone.

– ***Simandoux equation (1963)*****:** It is used where the shale content is more than 10% (Asquith and Krygowski, 2004).

$$Sw = \{(-Vsh/Rsh) +/- \surd (Vsh/Rsh)^{2} + (4\phi m/wart)\}/ (2\phi^{2}/aRw) \ldots\ldots\ldots\ldots\ldots 4$$

Sw = water saturation; Rw = formation water resistivity; m = cementation factor for carbonate (2); ϕ = formation porosity; Rt = true formation resistivity; Vsh = Shale volume; Rsh = Resistivity of shale; and a = is constant = 1

– ***Indonesian equation*:** This method is modified from Simandoux method and is useful for determining Sw in the shale-bearing zones and as a complementary tool for the other methods.

$$Sw= \{(1/Rt^{0.5}/ (Vsh^{1-Vsh/2}/Rsh^{0.5}) + (\phi^{m/2}/ (a*Rw)^{0.5}\}^{2} \quad \ldots\ldots 5$$

Sw = water saturation; Rw = formation water resistivity; m = cementation factor for carbonate (2); ϕ = formation porosity; Rt = true formation resistivity; Vsh = Shale volume; Rsh = Resistivity of shale; and a = is constant = 1

- **Hydrocarbon Saturation**

Hydrocarbon saturation is one of the major targets in the reservoir characterization (Al-Areeq and Alaug, 2013). It can be determined by equations 6 and 7.

$$Sh= 1-Sw \quad \ldots\ldots 6$$

Sh = total hydrocarbon saturation; and Sw is obtained from the Archie's equation)

– ***Movable Hydrocarbon Saturation (MHS)*:** Movable oil can be defined as the amount of oil that can be estimated from the reservoir rocks (Al-Areeq and Alaug, 2013).

$$MHS= (Sxo-Sw)* \phi_E \quad \ldots\ldots 7$$

MHS = Hydrocarbon Movable Saturation; Sxo = water saturation in the flushed zone; ϕ_E = Effective porosity; and Sw = Water saturation (obtained from Archie's equation)

– ***Residual Hydrocarbon Saturation (RHS)*:** Its defined as the difference between Sw from the flushed zone and unity (Al-Areeq and Alaug, 2013).

$$RHS= (1-Sxo) \quad \ldots\ldots 8$$

Sxo = Sw in the flushed zone

Movable Hydrocarbon Index (MHI): It can be defined as the ratio between water saturation and flushed zone water saturation (Al-Areeq and Alaug, 2013)

$$MHI= Sw/ Sxo \quad \ldots\ldots 9$$

Sw = Water saturation (obtained from Archie's equation); and Sxo = water saturation in the flushed zone

RESULTS AND DISCUSSION

Based on the lithological variation, identified from the wireline log, the Sargelu Formation is divided into 5 zones as shown in Fig. (3).

- **Water Saturation**

Petrophysical applications for carbonates are more difficult compared to sandstones due to changes in the grain size distribution and heterogeneities. The results of each of the four methods applied in the present study to determine Sw of the Sargelu Formation in the studied well are presented below:

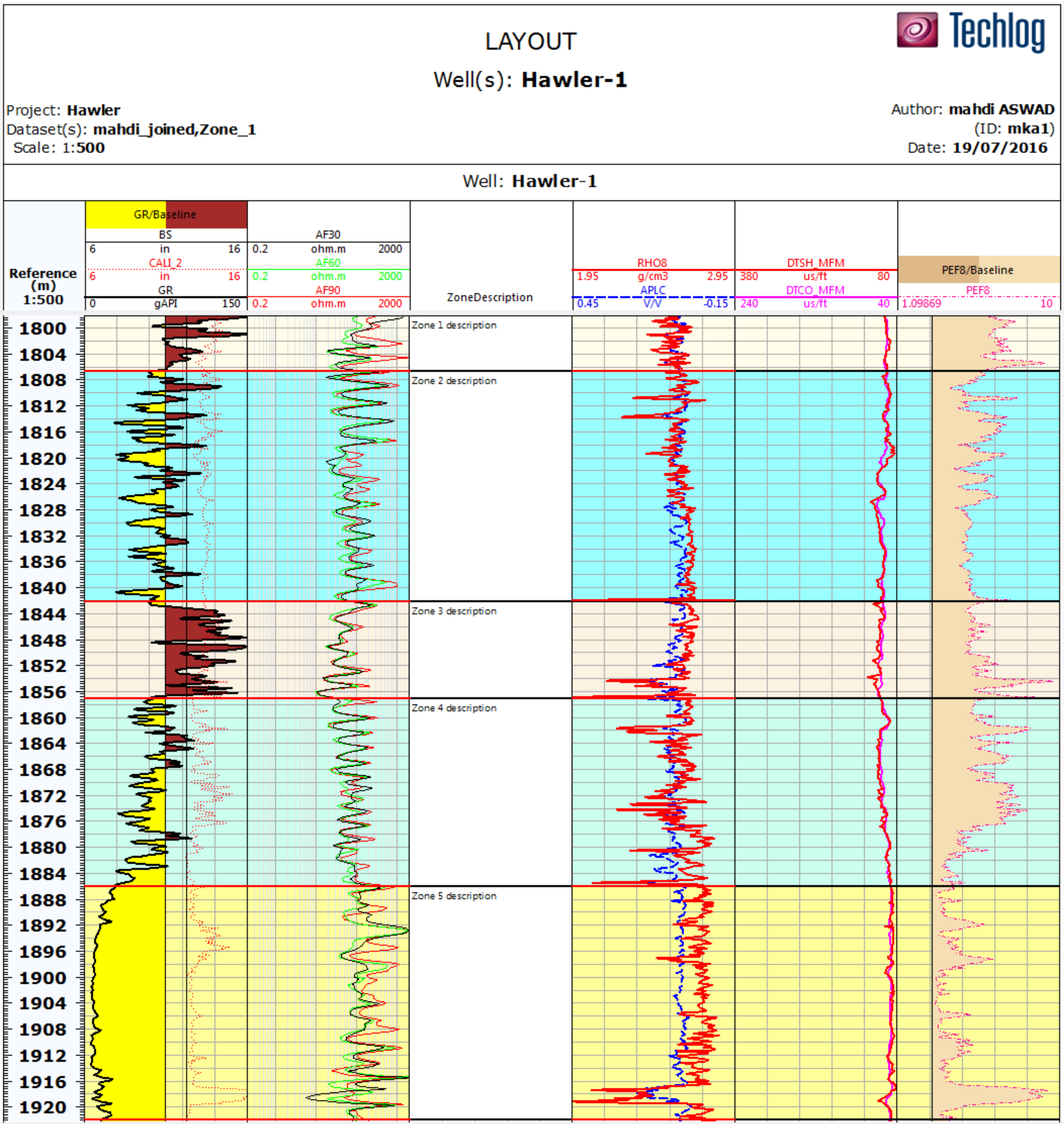

Fig.3: Composite logs and zonation of the Sargelu Formation based on lithology

– ***Saturation based on Archie's equation*:** The Pickett Plot shows variable Water Saturation values and Formation water resistivity is 0.03 ohm.m (Figure 4). This method is usually applied for carbonate and clastic rocks, when their shale and clay content is low. In most zones, shale is present as a heterogeneous component within the carbonate rocks. It shows high saturation content in zones 2 and 4 of the limestone part. In contrast, the Sw is low in the dolomite part (Zone 5) which is due to the lower heterogeneity of the shale in this zone. The relationship of saturation is directly proportional to the hydrocarbon content and opposite with the porosity. The average Sw in the limestone part of zones 2 and 4 is 30%, and 15% in the dolomite part of Zone 5 (Figure 5).

– ***Saturation from Waxman Smith method*:** This equation is used when (n and a) are known parameters Table (1). The Sw calculated using this method is different from that obtained from Archie's method at some points. The results obtained by this method point to the presence of shale within the limestone part in zones 2 and 4, whereas it shows very low content of shale in Zone 5 of the dolomite part. The differences in the Sw values appear in zones 2 and 4 of the limestone part and are attributed to the shale content. In contrast, there is no difference in the Sw values of the dolomite part in Zone 5 due to the lack of shale in this part (Figure 5).

Table 1: showing the parameters used for all methods in Tech-Log software

Parameter	**A**	**M**	**n**	**Rw (Ωm)**	**Res Shale**
Value	1	2	2	0.03	5

– ***Saturation from Simandoux method*:** The results of this equation disagree with the results of the two previous equations. It shows high ratio in Zone 5 of the dolomite part and low ratio in Zone 2 of the limestone part which is different in shale content. The average Sw in the limestone part is only 15%. In contrast, its value in the dolomite part is 26% (Figure 6). Table (1) explains the parameters used for this method.

– ***Saturation from Indonesian method*:** In this method the Sw values in some parts are slightly higher than those derived from the Simandoux method, while, in some other parts they are slightly lower. The saturation differences appear in all parts and not to a specific part. The average Sw obtained in this method is 21% in the limestone part of zones 2 and 4 and 37% in the dolomite part of Zone 5. The parameters used for this method are shown in Figure (6) and Table (1).

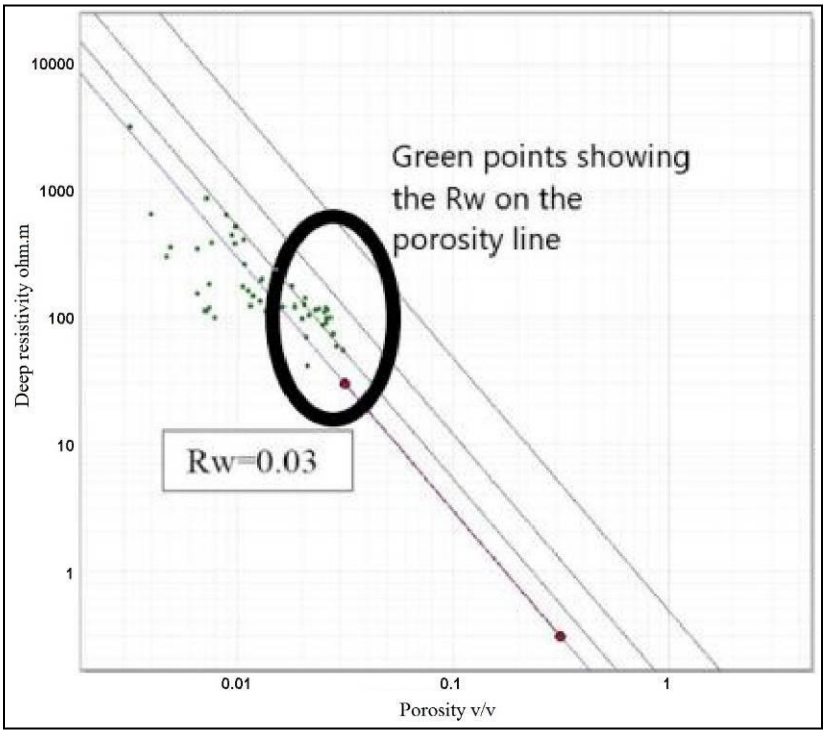

Fig.4: The Pickett Plot showing the relationship between deep resistivity and porosity. Green points show the location of the data to determine Rw on the porosity line

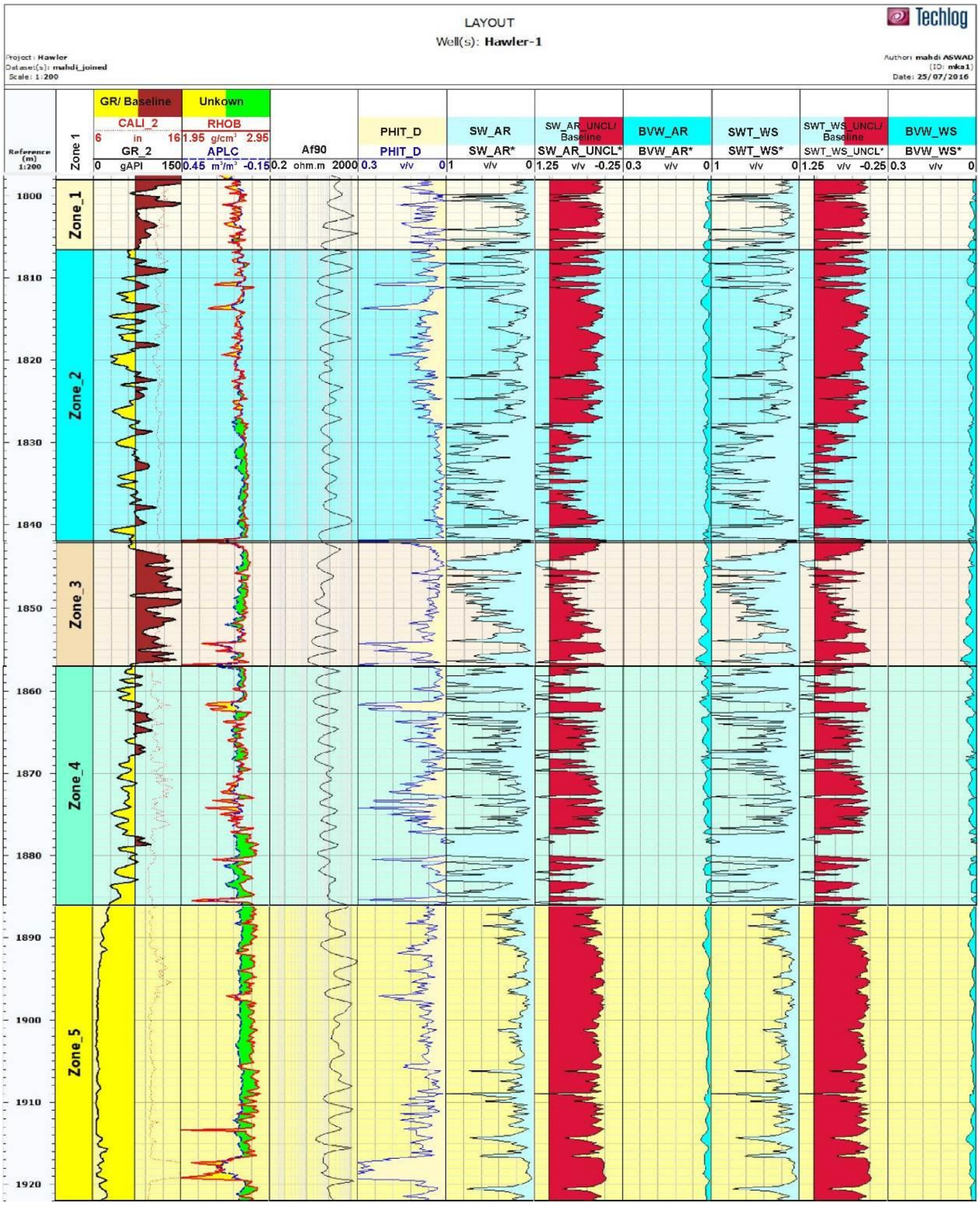

Fig.5: Water saturation values derived from Archie and Waxman Smith equations

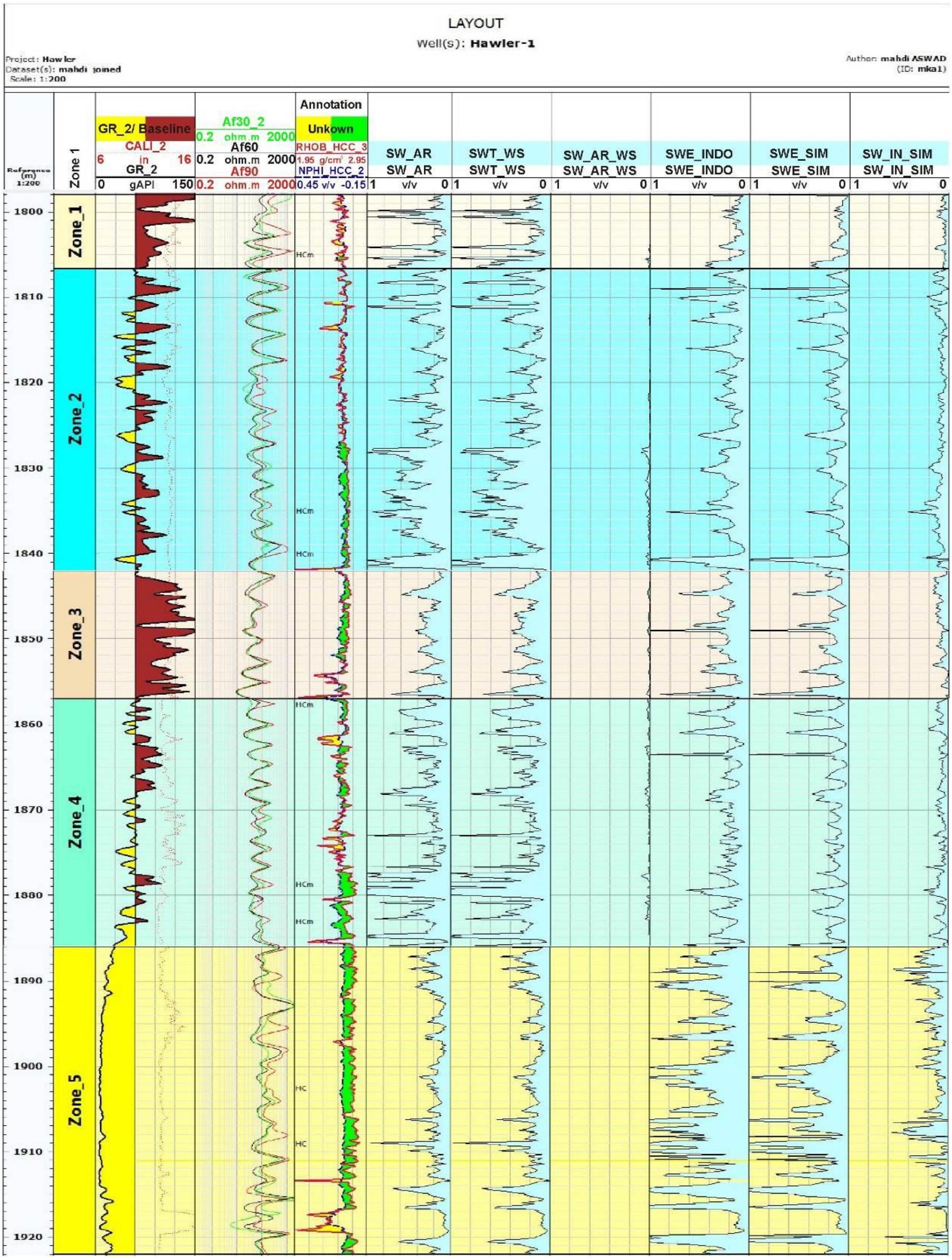

Fig.6: Comparison of the four types of Sw

- **Hydrocarbon Saturation**

There are two types of hydrocarbon saturation that may occupy the pores in the reservoirs; these are movable and residual hydrocarbon. In the Sargelu Formation both types are calculated and their ratios to the total hydrocarbon saturation is estimated. The limestone part has higher hydrocarbon saturation values than the dolomite part with increase of these values towards the reservoir units (Figure 7).

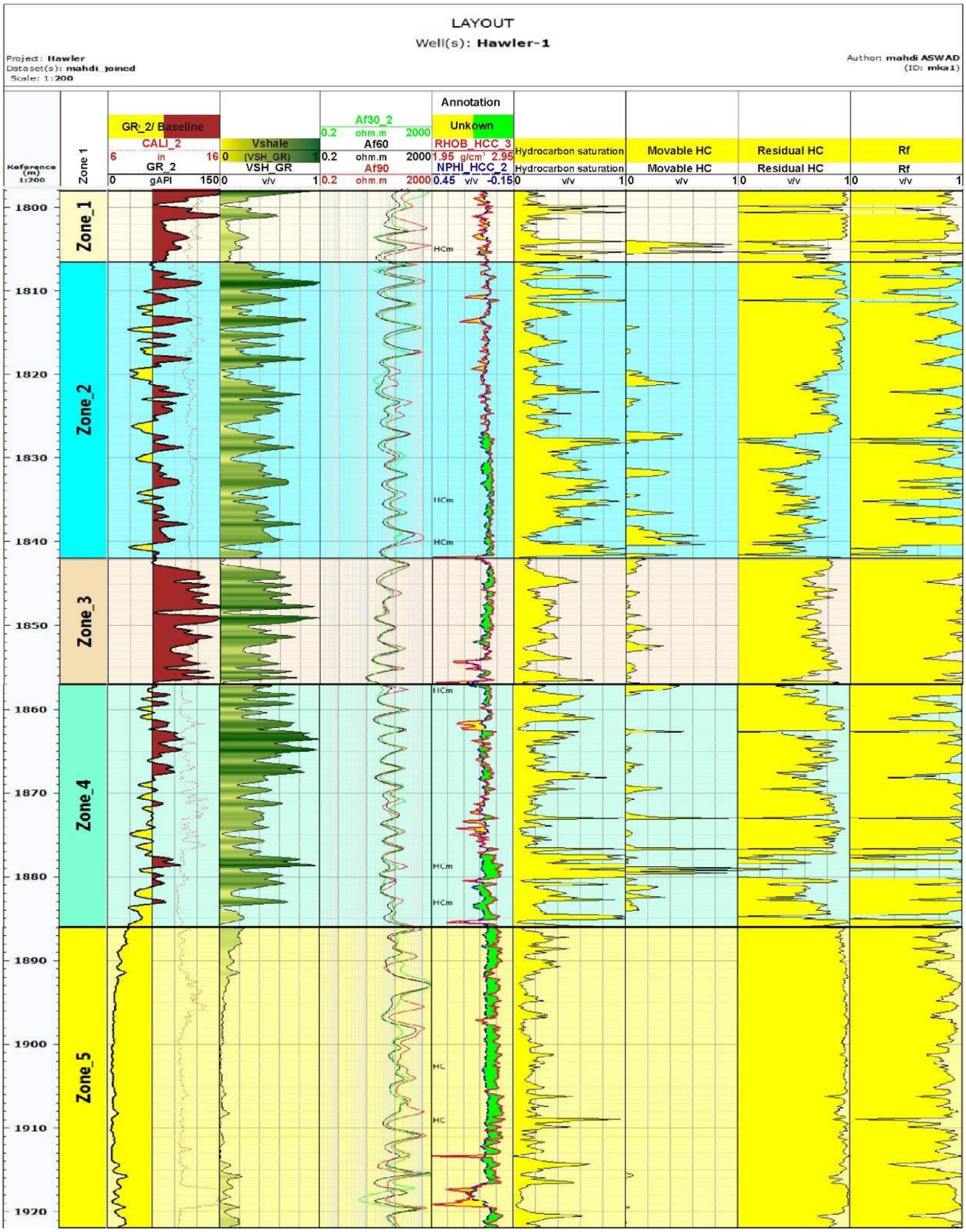

Fig.7: Hydrocarbon saturation of movable and residual hydrocarbons

– ***Movable hydrocarbon saturation (MHS)*****:** The MHS value of the Sargelu Formation varies from one part to another in the well sequence; it is very low in some parts, while in the other parts it is high. Acomparison of the MHS and RHS shows various hydrocarbon saturation values (Figure 7). In the movable area, deep resistivity is separated from the other types of resistivity.

– ***Residual hydrocarbon saturation (RHS)*****:** RHS values of the Sargelu Formation is very high especially, in the dolomite part, whereas, it is lower in the limestone part (Figure 7).

– ***Movable Hydrocarbon Index (MHI)*****:** It is widely used to indicate whether the hydrocarbon is movable or not. Hydrocarbon is not movable and produces water if the MHI is greater or equal to one. In contrast, the hydrocarbon is movable if the MHI is less than one. The hydrocarbon index is used for finding the area of perforation and separation between various types of resistivity. This index is a good parameter to determine hydrocarbon mobility from the wireline log. Based on this index, the Sargelu Formation has variable movable hydrocarbons, mostly appeared in the limestone part (Figure 7).

DISCUSSION

Understanding the Water and Hydrocarbon saturations from the Wireline log will help to minimize the uncertainty of reservoirs particularly in those areas where little work is carried out to delineate the reservoir properties. The Sargelu Formation is composed of carbonate rocks with secondary porosity, vugs, and shale volume. The interval of this reservoir is between 1798 – 1922 m. It is divided into five zones based on lithology and log response. The lithology showed shale, shale lime, and dolomitic limestone. The four methods applied to calculate Sw show different ratios of saturation (Figure 6). The major finding in the present study is the calculation of Sw for each zone. Hydrocarbon Saturation for this formation is divided into two parts; movable and residual hydrocarbon, based on the MHI for each zone. The Sargelu Formation shows different ratios of hydrocarbon saturation caused by lithology variation. The MHS is found in the zones 2 and 4 of the limestone, while in Zone 5 of the dolomite part, there is no movable hydrocarbon and, alternatively, the residual hydrocarbon is high in this zone. The average hydrocarbon saturation is (30%) except in the dolomite part of in Zone 5. The movable hydrocarbon ranges between (0 – 30%) and the residual hydrocarbon ranges between (20 – 80%).

CONCLUSIONS

- Based on the above results and discussion, the following outcomes can be highlighted which can be useful guides for future exploratory drilling in the oil field at the Harir Block:
- In the Sargelu Formation, higher values of hydrocarbon and water saturations are found in the clean zones. The major saturation appears in the limestone zones.
- Hydrocarbon saturation is different from one zone to another due to shale content.
- The Movable Hydrocarbon Saturation is mainly found in zones 2 and 4 of the limestone part, whereas, the Residual Hydrocarbon Saturation is mainly found in Zone 5 of the dolomite part.

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