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3D Geological Modeling for Yamama Reservoir in Subba, Luhias and Ratawi Oil Fields, South of Iraq

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Abstract

3D geological model for each reservoir unit comprising the Yamama Formation revealed to that the formation is composed of alternating reservoirs and barriers. In Subba and Luhais fields the formation began with barrier YB-1 and four more barriers (YB-2, YB-3, YB-4, YB-5), separated five reservoirs (YR-A, YR-B, YR-C, YR-D, YR-E) ranging in thickness from 70 to 80 m for each of them deposited by five sedimentary cycles. In the Ratawi field the formation was divided into three reservoir units (YR-A, YR-B, and YR-C) separated by two barrier units (YB-2 and YB-3), the first cycle is missing in Ratawi field.

The study involves 1 well in Luhais field (Lu-12), 3 wells in Subba field (Su-7, Su-8, and Su-9), and 5 wells in Ratawi field (Rt-3, Rt-4, Rt-5, Rt-6 and Rt-7), the Luhais, Subba, and Ratawi fields located in the Mesopotamia zone (Zubair subzone).

The reservoir units (YR-C and YR-D) in Subba oil field, and YR-B in Ratawi oil field represent the major reservoir units that characterized by the best Petrophysical properties (the highest porosity, the lowest water saturation, and the best Net Pay Thickness), Luhais oil field has poor to moderate Petrophysical properties and low oil bearing in YR-A, YR-B and YR-C units, and produce heavy oil and salt water from YR-D and YR-E as indicated by low resistivity log reading, and according to the Drill Steam Test (DST) with the description of cutting in final geological reports.

Keywords: Yamama Formation, 3D-Geological Model, Petrophysical properties

الموديل الجيولوجي الثلاثي الابعاد لمكمن اليمامة في الحقول النفطية صبة واللحيس ورطاوي جنوب العراق

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الخلاصة

عمل موديل جيولوجي ثلاثي الابعاد لكل وحدة مكمنية لتكوين اليمامة واستنتج منها ان التكوين يتالف من تعاقب لوحدات مكمنية وعازلة. في حقلي صبة واللحيس يبدأ التكوين بالوحدة العازلة YB-1 مع اربع وحدات عازلة أخرى هي (YB-2, YB-3, YB-4, YB-5) تفصل بين خمسة وحدات مكمنية هي (YR-A, YR-B, YR-C, YR-D, YR-E) وبسمك يتراوح بين 70 الى 80 متر لكل وحدة, ترسبت خلال خمسة

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دورات رسوبية. اما في حقل رطاوي يقسم التكوين الى ثلاث وحدات مكمنية هي (YR–A, YR–B, YR–C) تفصل بينهم وحدتين عازلتين هي (YB–2, YB–3), الدورة الترسبية الأولى مفقودة في حقل رطاوي.
تمثل الوحدات المكمنية (YR–B, YR–C) في حقل صبه النفطي, و YR–B في حقل الرطاوي النفطي الوحدات المكمنية الرئيسية والمتميزة الحاوية على أفضل الصفات البتروفيزيائية (الأعلى مسامية, وأقل نسبة تشبع مائي) واقضل سمك للعطاء الصافي. اما حقل اللحيس فهو ذو محتوى نفطي قليل في كل من الوحدات YR–A, YR–B, YR–C , وهو منتج للنفط الثقيل والماء المالح من الوحدات YR–E و YR–D وكما مبين في القراءة الواطئة لمجس المقاومية, وحسب فحوص الـ DST وأيضا وصف الفتات الصخري في التقارير الجيولوجية النهائية.

Introduction

The Yamama formation represents one of the most promising carbonate reservoir, because of its wide geographic distribution over most parts of southern Iraq and the neighboring area, and carries a special economic importance, since it's consider one of the well-known oil traps in southern Iraq.

The formation's name was taken from the town of Al-Yamama at outcrops in Saudi Arabia. As defined by Steineke and Bramkamp in 1952 [1].

The formation extends from Valanginian – Early Hauterivian within the main deposition cycle (Berriasian – Aptian) south of Iraq, this cycle is represented from shore to the deep basin by the (Zubair, Ratawi, Garagu, Yamama, shuiaba, Sarmord, and Lower Balambo) Formations [1].

The Reservoir is consists mainly of limestone and was deposited in distinctive oolitic shoals as low energy, shallow restricted marine carbonates and ramp/slope to open marine facies in south and central Iraq [2].

The Yamama Formation comprises three deposition sequences as a third order sequence, each duration sequence from 2 to 3 Million years, these sequences consist of para–sequences which exhibit very well developed cyclicity on a scale few to ten meters [2].

The Formation grades upward into the Ratawi Formation which considered as the cap rock of the Yamama reservoir, and underlain conformably by the Sulaiy Formation [3].

The Lower Cretaceous Yamama formation reported containing hydrocarbons at more than 26 structures in southern Iraq including West Qurna, North Rumaila, Majnoon [3], in addition to Siba, Sindibad, Nasirya and the three studied fields (Luhais, Subba, and Ratawi).

The Yamama Formation is one of the main reservoirs in the south of Iraq area due to its high reserves of oil as well as its high quality which ranges between 37 to 40 (API). This study aims to evaluate the formation in the southwest area of Basrah government, comparisons of the petrophysical properties of the three studied fields to estimate the amount of hydrocarbon and the differences in productivity between them.

The Study Area

The study area accrued within the Zubair Sub-zone, that forms the southernmost unit in the Mesopotamian zone, and has a uniform structural style controlled by the underlying basement because of the faulting and uplifting [4], Figure-1.

Luhais oil field located within the Mesopotamian basin at the stable shelf, within the southern desert, about 90 km south-west of the city of Basra, which lies about of 50 km southwest of the Northern Rumaila oil field. The Luhais oil field has been discovered in 1961 and began the first production in 1970 [5].

Subba field located in Thi Qar governorate, about 110 Km northwest of the Basrah city, 30 Km north of Luhais field, 70 km south-east of Nasiriyah city, as well as 40 km north-west of Ratawi field.

Ratawi oil field is about 70 km to the west of Basrah city, and 12 km to the west of North Rumela field and south of Hor Al-Hamar along the Euphrates River, the field was discovered by Basrah Petroleum Company in 1947 by a prominent closed seismic anomaly, this discovery became one of the under-developed oil fields of South Iraq [5].

The axis of Subba, Ratawi and Luhais oil fields takes the trend North-South same as the giant oil structures in the neighboring area (Rumaila and Zubair) by the effect of the mountain building force of the Zagros series that has the same axis.

The study involves 1 borehole in the Luhais field, Lu-12 (due to that Lu-12 is the only well which penetrate the Yamama formation in the field), 3 boreholes in the Subba field (Su-7, Su-8, and Su-9), and 5 boreholes in the Ratawi field (Rt-3, Rt-4, Rt-5, Rt-6 and Rt-7), (Figure-2).

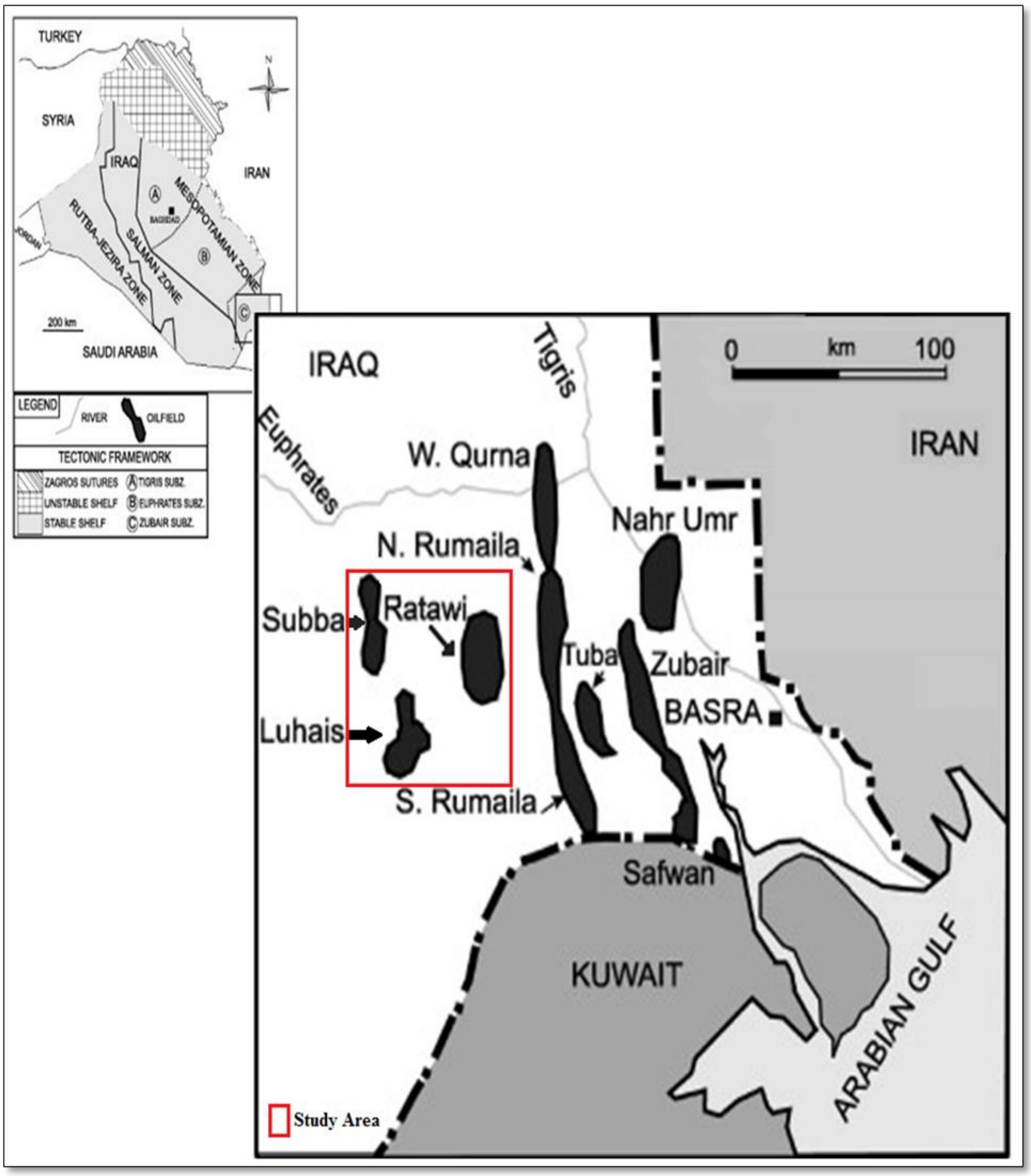

Figure 1- Map of the study area with a larger site in southern Iraq showing the locations of the study Area included the three studied oil fields, modified from the map of Iraq [5]

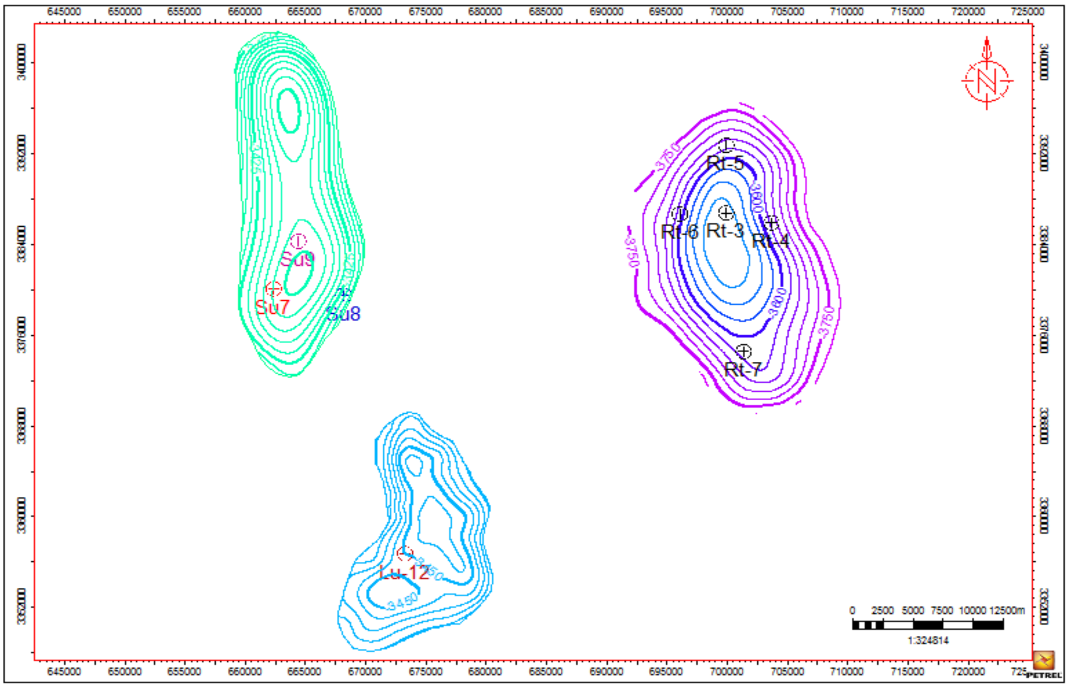

Figure 2- Location of the studied wells within structure contour map of Luhais, Subba, and Ratawi oil fields

Tectonic and Structural Setting

The area is located over the Jurassic Salt Basin (Gotnia–Jurassic basin) in the Interior Stable Arabian Shelf tectonic regime. The N-S trend of the most fields in this area is probably because of the interplay of Pre-Cambrian N-S basement faults and Infra-Cambrian salt tectonics. The gentle dip may be hiding a steeper dip of the structural flanks of the deformable Gotnia salt [5].

The Early Cretaceous rifting was also formed by the extensional forces between Bitlis/Sirjan and the north of the Arabian plate, the tectonic movements formed in the beginning or Early Cretaceous, and the Valanginian age basin is inherited from the Jurassic–Gotnia basin (Toarcian rifting during late Jurassic), which has taken place in the Berriasiain time, confirmed that the tectonic history of the Arabian plate was influenced by the events that occurred around its margins related to the rifting of Gondwanaland and the later collision with Asia [2].

The top of the Formation has been delineated on the first downward appearance of a relatively pure carbonate below the argillaceous limestone and shale of the Ratawi Formation, (the contact was then traced in all the studied wells).

The lower contact was placed at the first appearance downward of mud-supported argillaceous limestone characteristic of the Sulaiy Formation, (Figure-3), [6].

Aims of Study

The essential goal was building an accurate 3D geological static model for Yamama formation in the three studied fields (Subba, Luhais, and Ratawi) fields. The Yamama Geo-model includes (Structural), and the distribution of the Petrophysical properties (Porosity, Water Saturation). The software to be used is Petrel software (version 2015), which is a product of Schlumberger; the steps will be shown with screen shots of the necessary figures.

Methodology

1- Digitized the structural contour maps for top of the Yamama formation at (Subba and Ratawi oil fields) by (Didger) program and loaded into petrel software**.**

2- Finding the petrophysical properties of the Yamama reservoir units in the study area using the Equations below:

The secondary porosity index (SPI) may be computed as the difference between total porosity as determined from Neutron and/or Density logs, and primary porosity obtained from sonic log.

SPI = Ø total - Ø primary

SPI = (Ø *N.D* - Ø *S*)

Where:
SPI = Secondary porosity index.
$\emptyset\ N.D$ = neutron - density properties combination.
$\emptyset\ S$ = sonic derived porosity, [7].
The shale volume (V_{sh}) for Yamama Formation in the study area actually is very small value ranges between 7 to 14%, So the effect of shale on S_W calculation was not taken into account and the next Archie's Equation was applied for S_W calculation:
$S_W = (F * R_W / R_t)^{1/n}$
$Sxo = (F * Rmf / Rxo)^{1/n}$
$F = a / \Phi^m$
Where:
S_W = Water saturation
Sxo = Water saturation of the invaded zone
F = Formation Resistivity Factor
a = tortuosity factor (a = 1)
m: cementation factor
n: saturation exponent
R_W: Formation water resistivity (ohm-m)
$\emptyset$: Porosity
Rmf = Resistivity of mud filtrate at formation temperature
R_t : True formation resistivity (ohm–m)
"a", "m" and "n" values were decided as follows according to its lithology, those are same or close to empirically standard values:
a = 1.00, m = 2.00, n = 2.00, [7].
3- Building a 3D geological modeling includes (structural, and petrophysical model) which were built Using Petrel software (version 2015).

3D Geological Model

The 3D geological model represents the physical space of the reservoir by an array of discrete cells, these array cells delineated in a three-dimensional grid which may be regular or irregular, the value for each cell attributes such as porosity and water saturation [8].

The determination of hydrocarbon accumulation in the reservoir is the main goal of studying the petroleum exploration. Building high-precision 3D static geological model can offer a basic information platform for oil & gas exploration and give the base for dynamic model which is essential to sustain the high production and development for any oil field [9].

It became clear that the fundamental for the correct static characterization of the reservoir is the integration of different disciplines, static and dynamic model. 3D visualization of geological body can give the information platform that allow to the gradual construction of a model (structural, petrophysical), all of that were carried out by the results of the log interpretations into Petrel software [8].

Modeling Workflow

In this study the essential workflow to build 3D geological model. Figure-4 shows the Basic workflow of 3D geological modeling, On the one hand, modeling method can reflect on the impact of structural factors on geological body, On the other hand, the petrophysical model can reflect anisotropy of geological body [8].

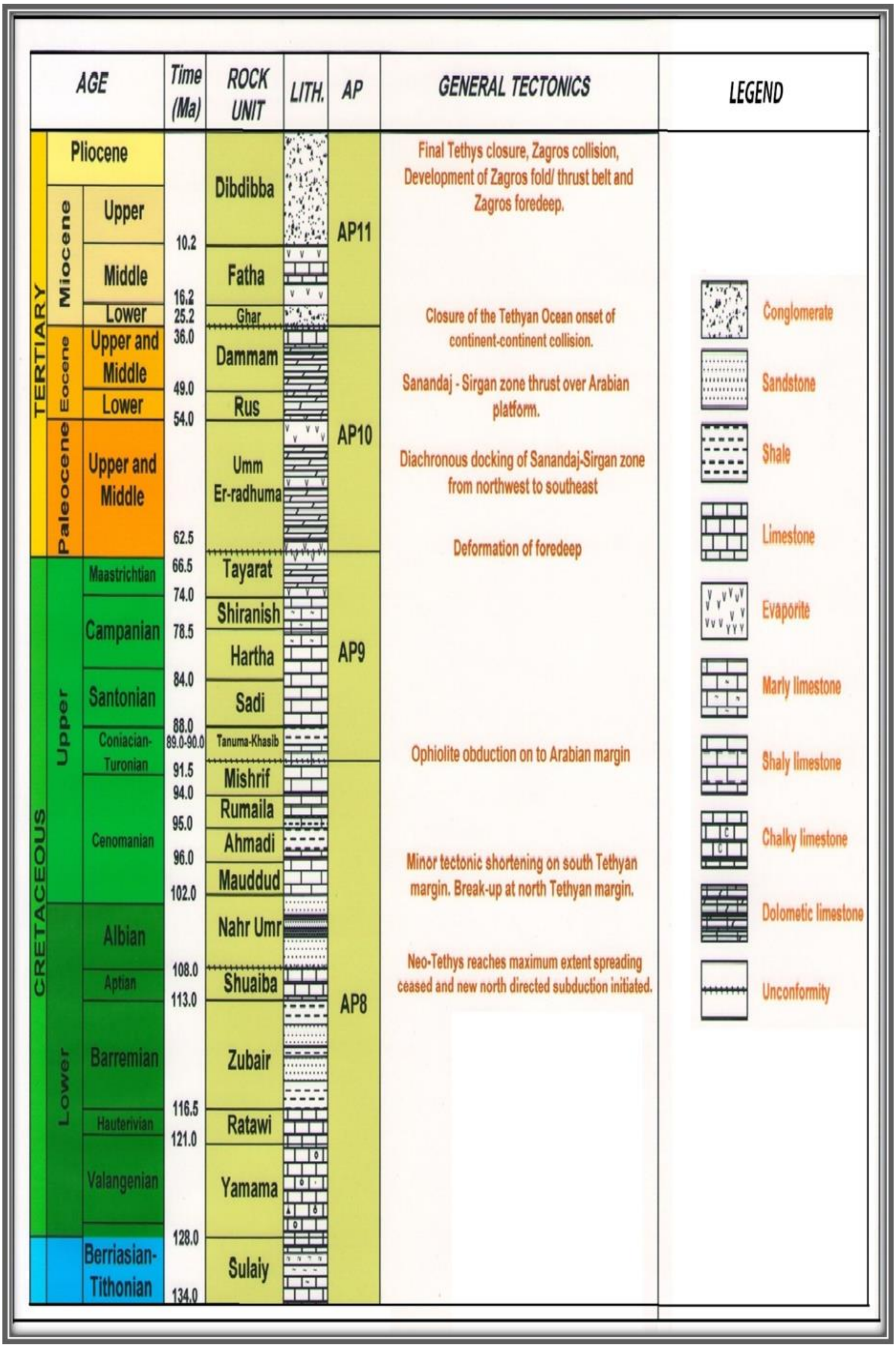

Figure 3- A Stratigraphic column of Mesopotamian Zone (Zubair Subzone), [5].

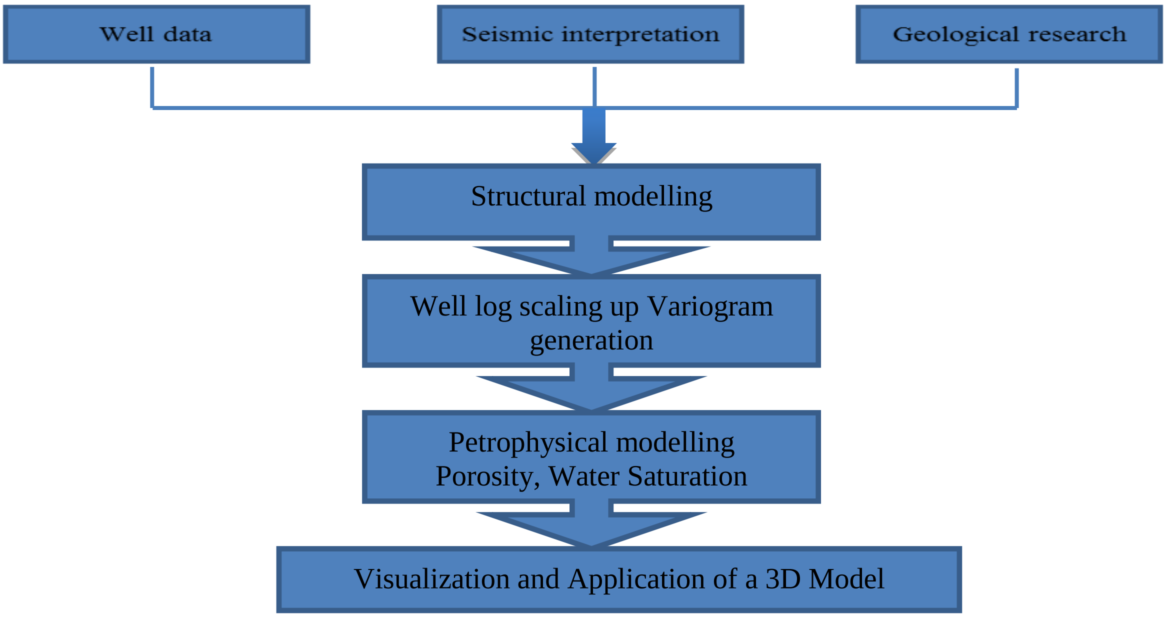

Figure 4- General Workflow of 3D geological modeling [7].

The Formation Units

The Yamama formation was divided into several zones and units which delimit the stratigraphic interval and the series of petrophysical property based on the response of the log data.

In the Ratawi field the formation compresses of three reservoir units (YR-A, YR-B, and YR-C) separated by two barrier units (YB-2 and YB-3), but in Subba and Luhais fields the formation began with barrier YB-1 and represent a third order cycle consist of five barriers and five reservoirs, so the first cycle was missing in Ratawi field.

The formation thickness in Ratawi field is about 270 m, 310 m in Subba field, and 262.8 in Luhais field.

The Structural Contour Map

The structural contour maps for top of the Yamama formation at (Subba and Ratawi oil fields) have been provided by (Oil Exploration Company). In the Luhais oil field, there was no available structure contour map for the top of the formation and no previews study for the formation in the field were found, so the author depends on the seismic section for the top Yamama at the study area including the three studied fields, (Figure-4).

The Yamama structural contour map in Subba Field shows that it has a long structural nose composed of two main asymmetrical anticlinal domes (northern and southern), with closure of North-South axis, the three studied wells that penetrated the Yamama are located on the southern one.

The structural contour map of Yamama formation in the Lahais Field shows an irregular shape with asymmetrical anticline of elliptical shape, having a folding axis oriented in the N-S direction because of variation of the seismic velocity information. In addition to the structure crest zone, the South-West part of the field is structurally higher than the North-East part, with a dip of less than one degree on the flank. The irregular shape of the Luhais structure as compared to the adjacent structures, including the other two studied fields (Subba and Ratawi) leads to belief that there was a compound of geological forces that revealed to form this irregular shape, which means that there is a more than simply horizontal force in addition to the vertical force leads to produce the complexity of the Luhais structural subsurface image.

In the Ratawi field the Yamama structure is composed of elongated semi-symmetrical anticline, (with Rt-3 is located on the crest), the dome closure of North-South trend axis. The dimensions of the field are about 29.5 km long and 15 km wide. A structural contour map for the top of Yamama has been introduced in Figure-5.

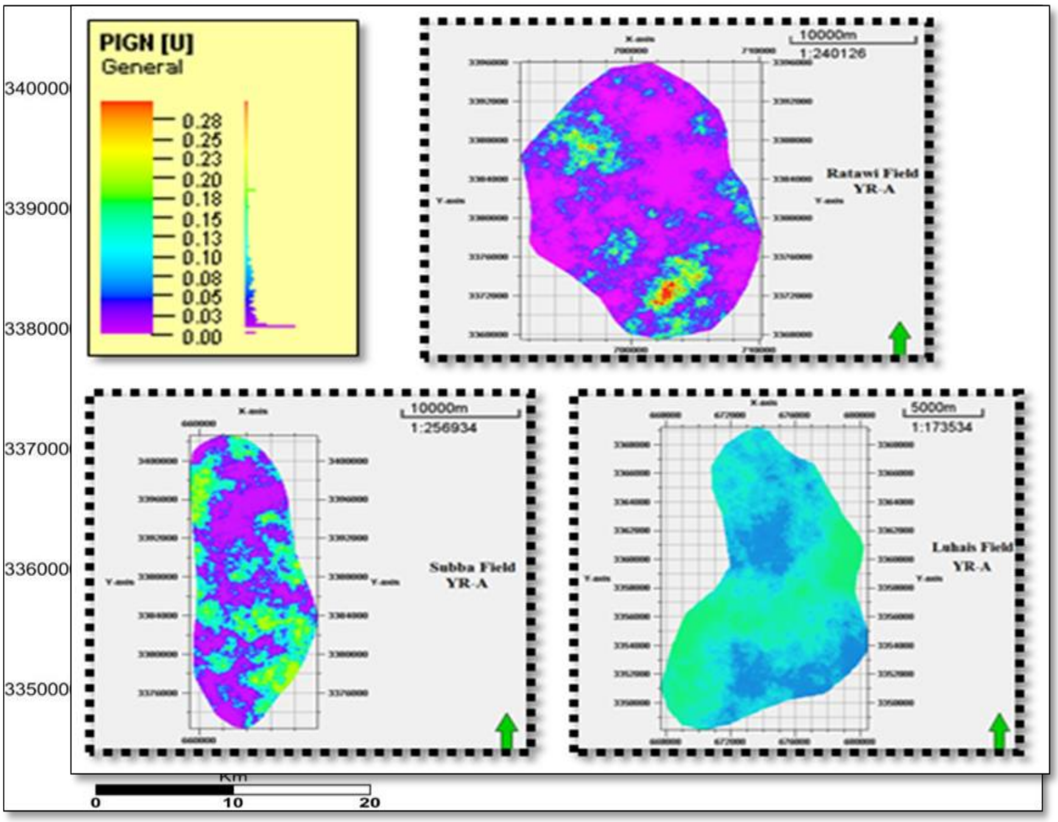

Figure 5- Structural map of the top Yamama Formation for the study area including the three studied fields (Luhais, Subba, and Ratawi).

Property Modeling

The formation modelling is depending on the petrophysical properties and their distribution within the formation, which has been computed from the conventional log interpretation to determine the reservoir interval pay zone.

Property modeling is the process of distributing a number of different properties (mainly) within the 'net reservoir' in order to assess the lateral heterogeneity and resulting hydrocarbon distribution [9].

To obtain the property modelling, the geo-statistical method was used to determine the distribution of the intentional properties for un-drilled reservoir cells, reliance on the data obtained from the drilled areas. The geo-statistic algorithm is the essential and modern method to calculate these properties overall the reservoir area [10].

Porosity (Ø)

Porosity is the primary parameter that's used to evaluate the hydrocarbon accumulation in the reservoir [11]. To estimate the average porosity, it was computed for the studied wells in the three studied fields, and the results were distributed into the 3D porosity model, mapping as shown in Figure-6 for unit YR-A, Figure-7 for unit YR-B, Figure-8 for unit YR-C, and Figure-9 for unit D and E.

Generally, the dominant effective porosity values range from 0.2-0.3 (violet to yellow colors). The light yellow and red colors are the zone of interest. Porosity model was built depending on the results of porosity logs (density, neutron, and sonic logs) which have been interpreted from GeoFrame software.

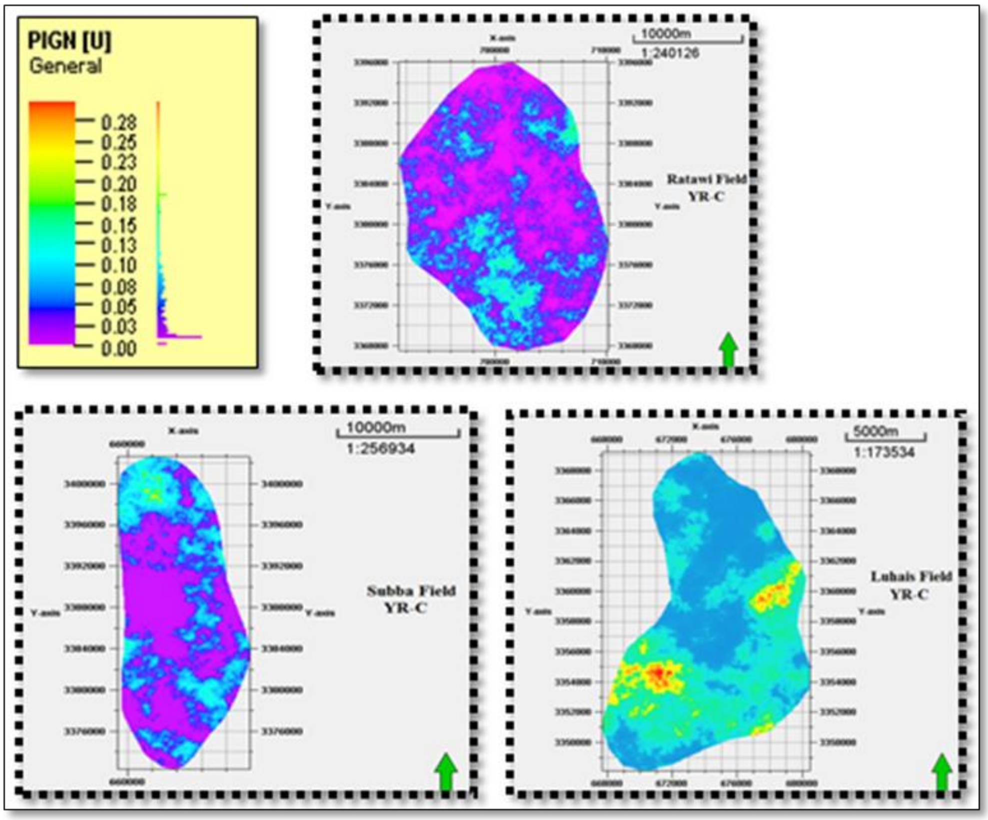

Figure 6- Map distribution of Effective Porosity of (YR-A) in Subba, Luhais and Ratawi

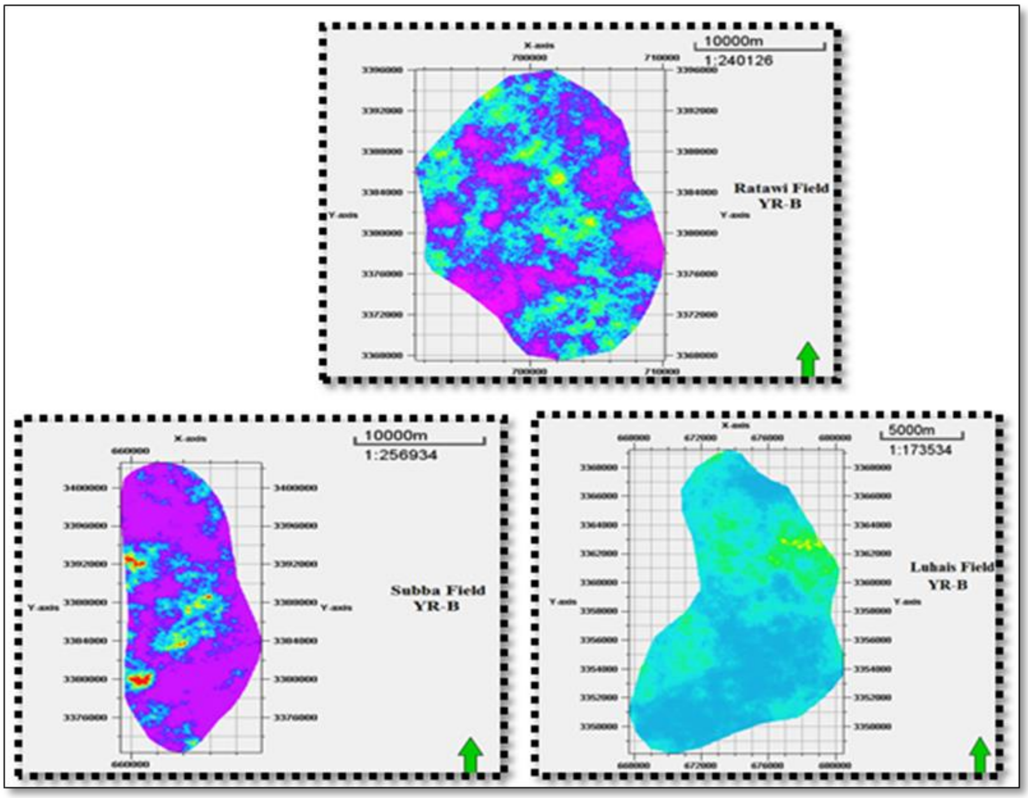

Figure 7- Map distribution of Effective Porosity of (YR-B) in in Subba, Luhais and Ratawi

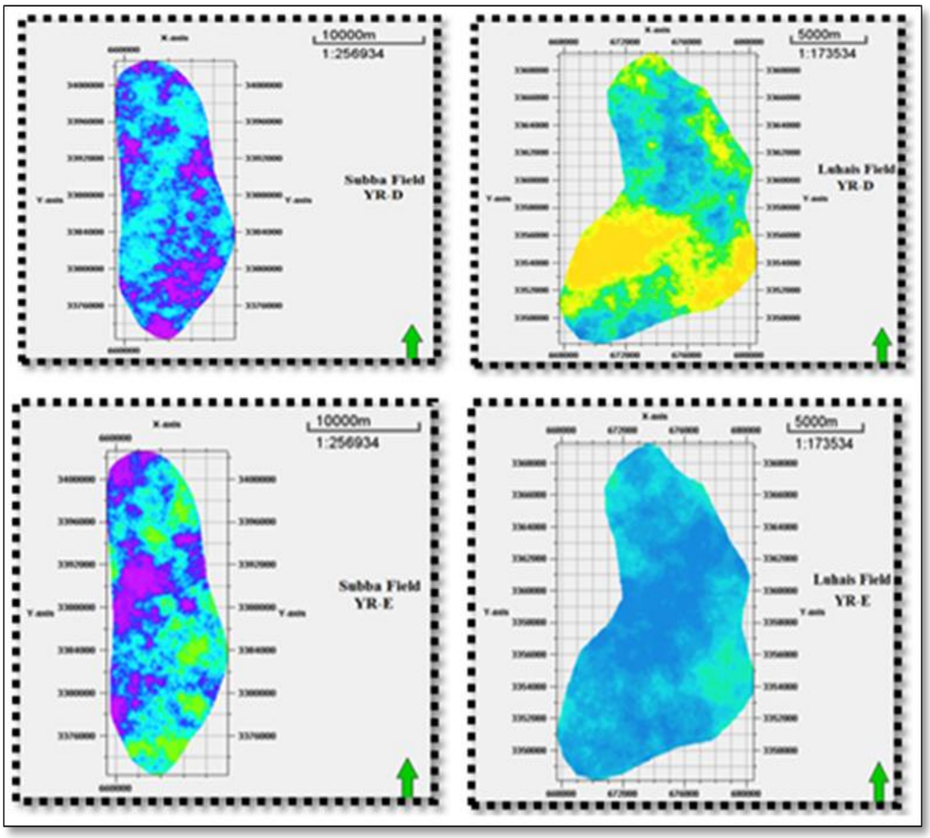

Figure 8- Map distribution of Effective Porosity of (YR-C) in Subba, Luhais and Ratawi.

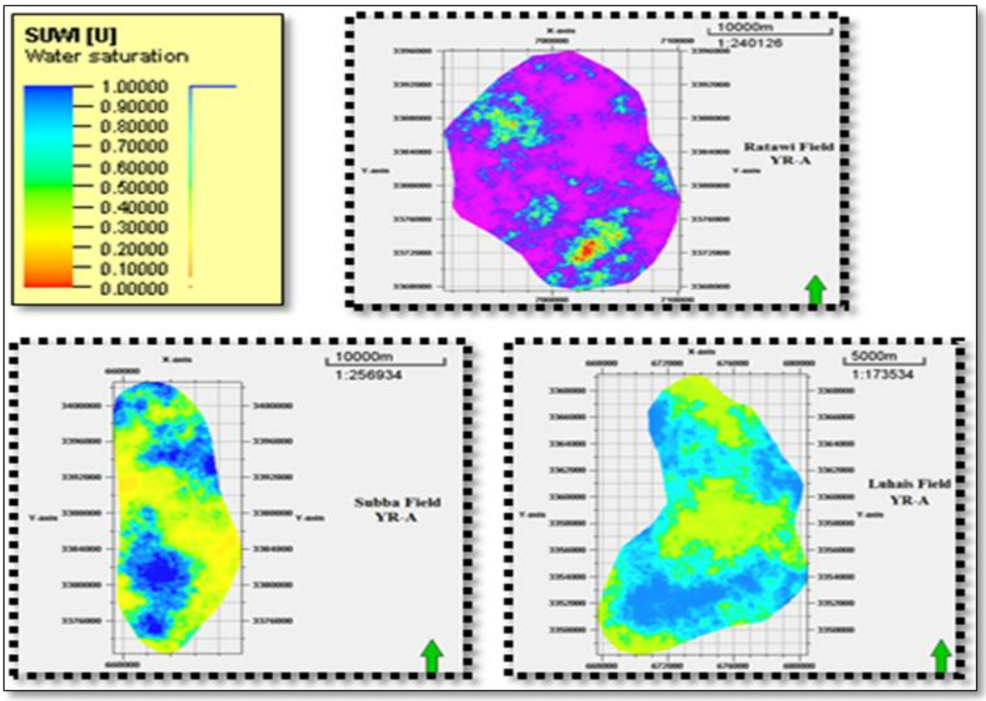

Figure 9- Map distribution of Effective Porosity of (YR-D, YR-E) in Subba and Luhais

Water Saturation (Sw)

Water saturation modeling of the reservoir rock represents one of the most important stages in a reservoir study, due to its influences extends beyond the calculation of the amount of hydrocarbons in place, but also the determination of fluid mechanics, and thus the productivity of the wells [11].

The hydrocarbon saturation is a function of the water saturation. Water saturation is also an important parameter in reservoir characterization [12].

The figures that show the distribution of water saturation models for the reservoir units of Yamama formation within the three studied fields are: Figure-10 for unit YR-A, Figure-11 for unit YR-B, Figure-12 for unit YR-C, and Figure-13 for unit D and E.

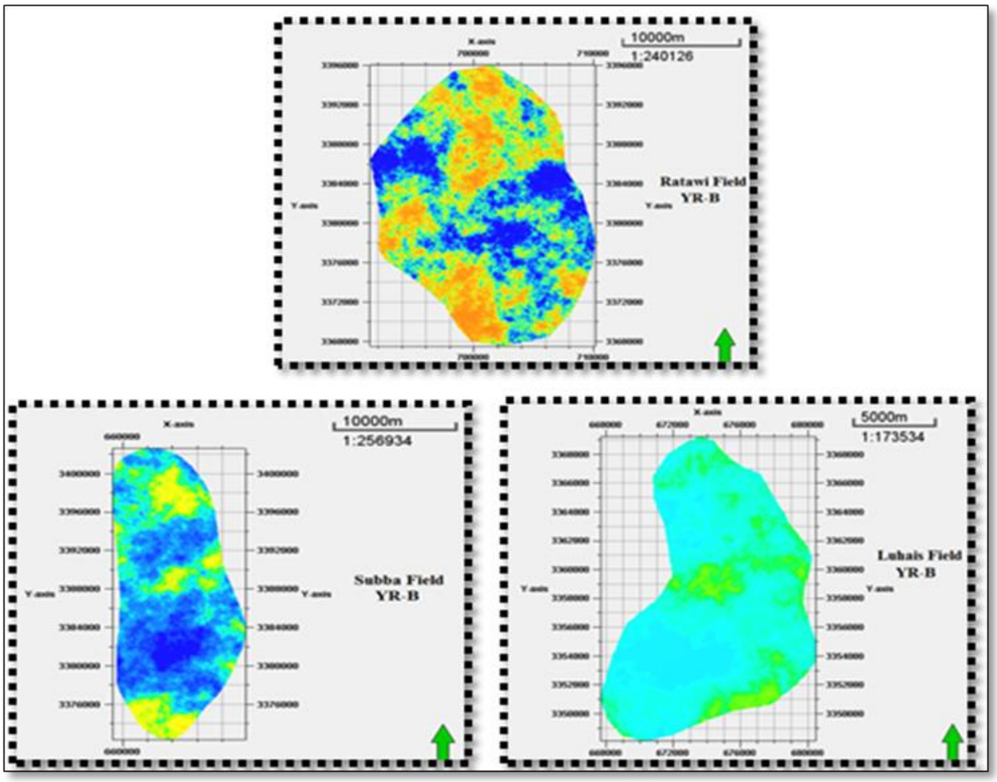

Figure 10- Map distribution of Water Saturation of (YR-A) in Subba, Luhais and Ratawi

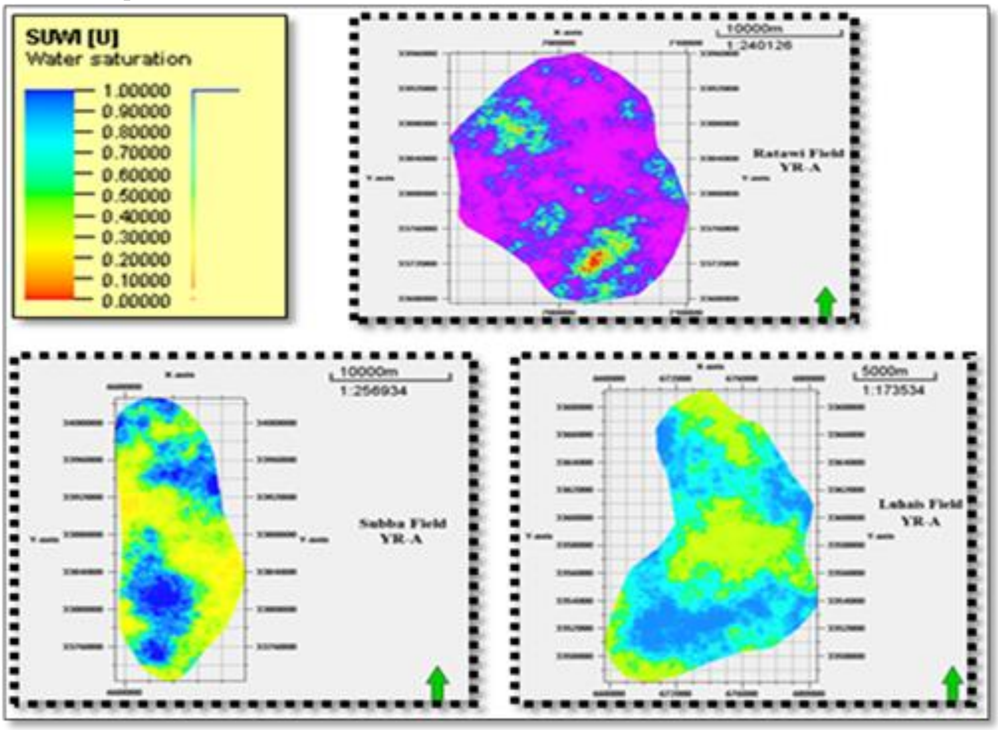

Figure 11- Map distribution of Water Saturation of (YR-B) in Subba, Luhais and Ratawi

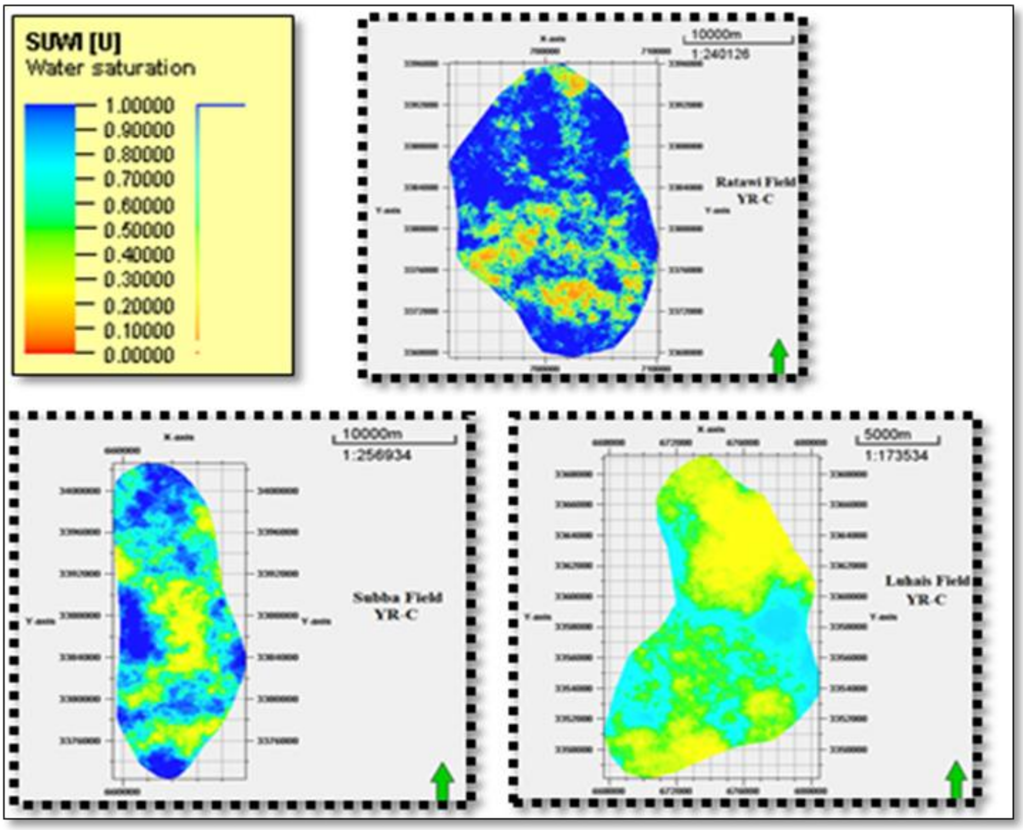

Figure 12- Map distribution of Water Saturation of (YR-C) in Subba, Luhais and Ratawi

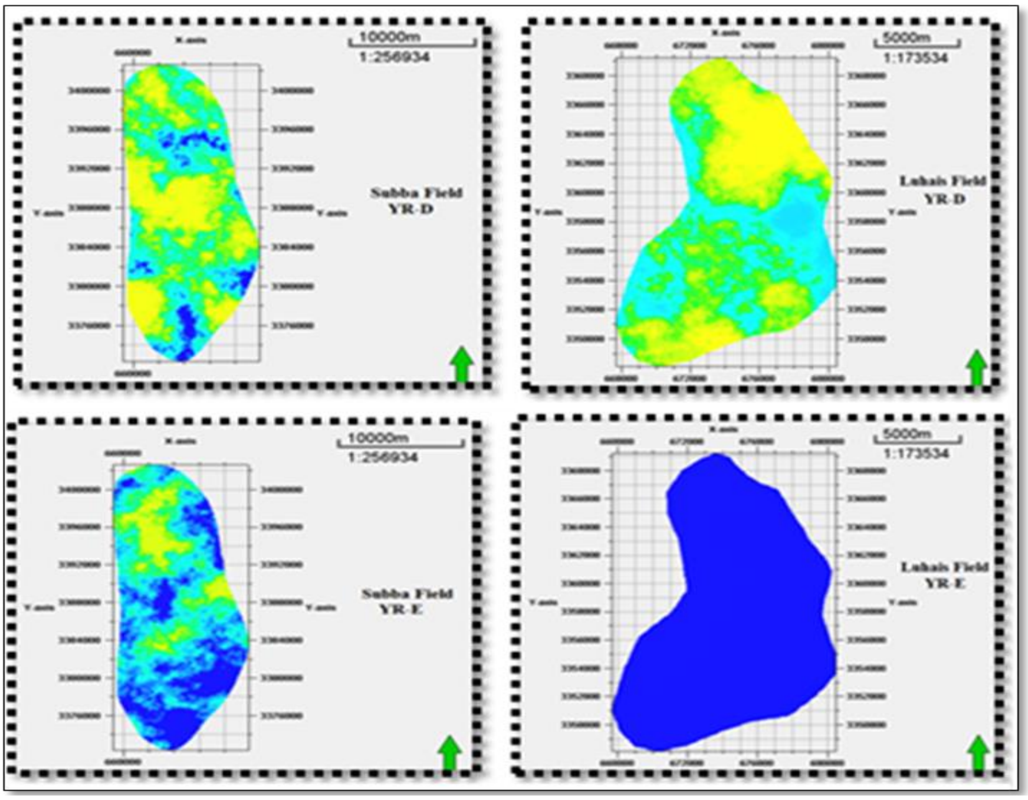

Figure 13- Map distribution of Water Saturation of (YR-D, YR-E) in Subba and Luhais

Using the resistivity logs for each of the studied wells, the water saturation computed to estimate the values for the three studied fields and was distributed across the 3-D grids, and due to its low shale volume (V_{sh}) that ranges between 7 to 14%, the formation is considered as clean formation. The calculation of water saturation for formation reservoirs ranges from 0.1-0.9. The average of water saturation is about 0.4. The water saturation is uniformly distributed such as porosity in the reservoirs. The zones of interest are with low values (yellow and red), due to its indication of a low water saturation and high hydrocarbon saturation.

Conclusions

From the porosity and water saturation models for each reservoir unit of the Yamama Formation in the three studied fields, the following points can be shown:

- In Subba oil field YR-C and YR-D considered as the best and main reservoir units within the Yamama Formation, the effective porosity value ranging between 0.13 maximum To 0.3 minimum, with water saturation value ranging between (0.9-0.2), they are interpreted as an oil-bearing, the average thickness of YR-C in the field is about 45 m, and the net pay thickness is ranging between 1.5 to 42 m.
- In the Luhais oil field the Yamama Formation has poor to moderate petrophysical properties and contains water, especially at YR-E, in most intervals the formation produces heavy oil and salt water as indicated by low resistivity log reading, and according to Drill Steam Test (DST) with the description of cutting in final geological reports, except in YR-B and YR-C that contain a low volume of oil.
- In the Ratawi oil field the all three reservoir units are oil-bearing, YR-B is considered the major reservoir unit within the Yamama formation, it's characterized by the highest porosity, lowest water saturation (1-21%) porosity, whereas the water saturation is ranging between (5-10%), the thickness ranging (81.5-93 m) and the net pay thickness is ranging between 3 to 65 m. Generally, from the petrophysical grids (porosity and water saturation) models, it can be deduced that the Yamama formation in the Ratawi field has a distinctive reservoir property at the crest of the structure reducing downward and towards the flanks of the structure.
- Figure -14 and Figure -15 shows the general intersections for Porosity and water saturation models of Yamama Formation in the three studied Oil Fields.

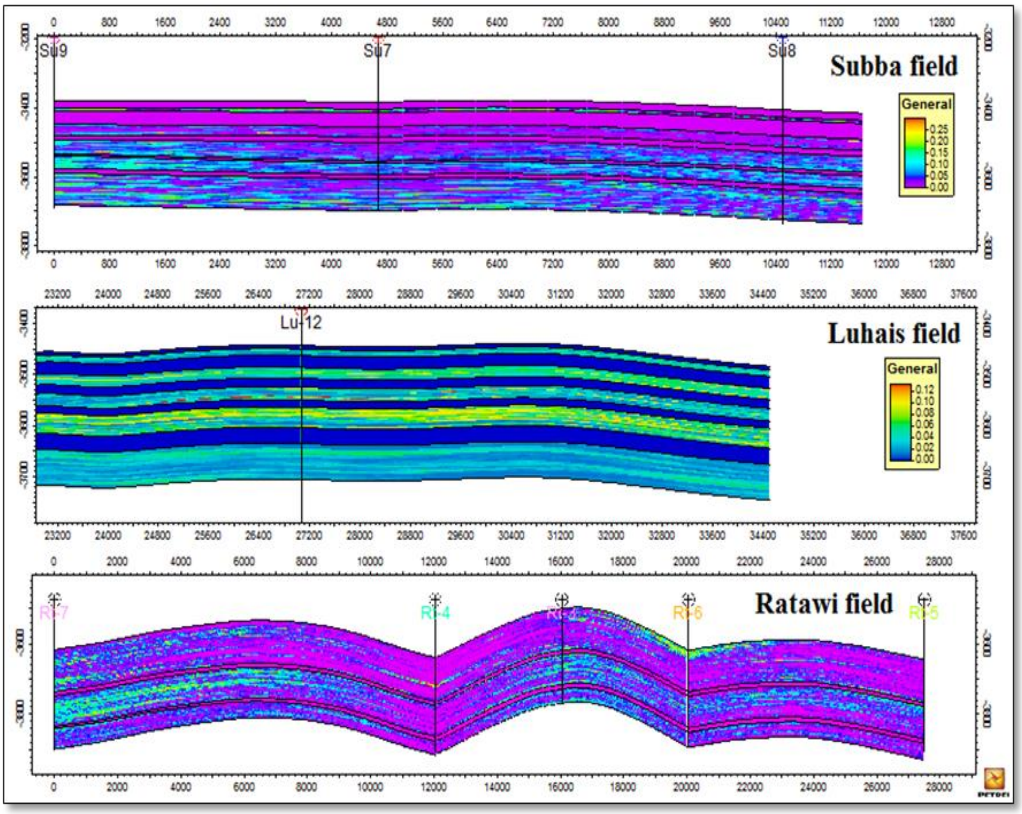

Figure 14- Comparison of Porosity sections for the three studied fields

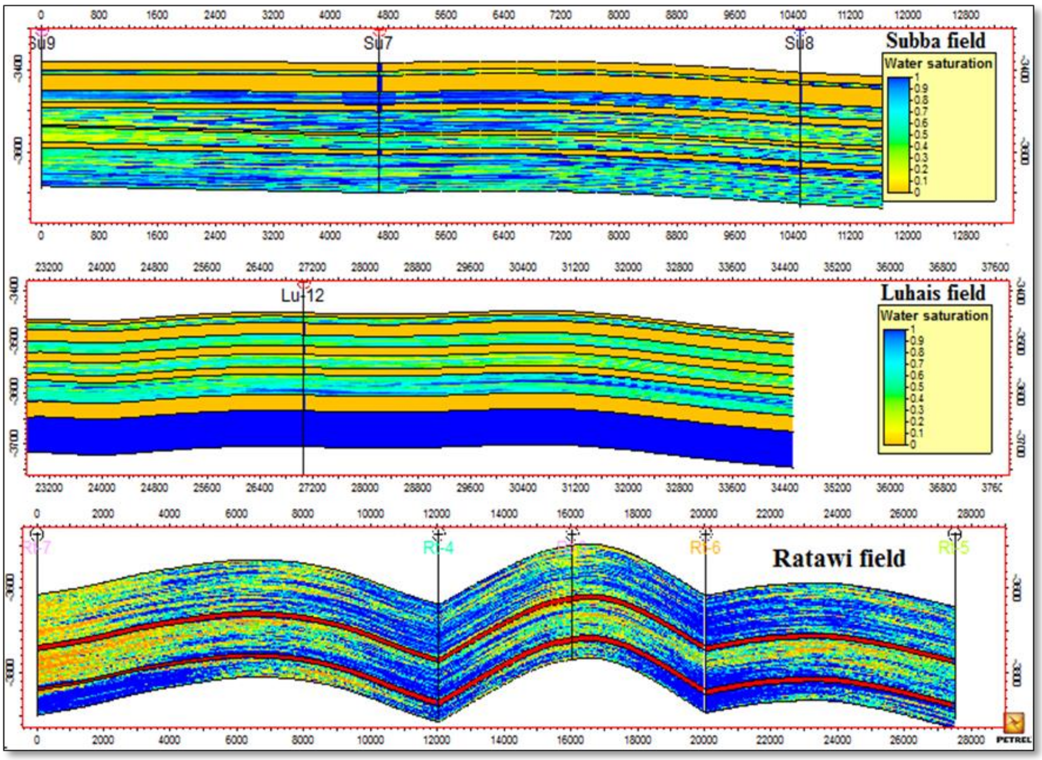

Figure 15- Comparison of Water Saturation sections for the three studied fields

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