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Assess the maturity of source rocks and their oil potential in greater Kirkuk and surrounding area

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Abstract

The region of Kirkuk and its surrounding areas, including (Baba, Jambour, Qara Chuq, Qaiyarah, Demir Dagh, Bai Hassan, Taq Taq, Makhul, Gilabat as well as southern Mosul and the cities of Erbil and Sulymania, are known as one of the oldest discovered oil fields in northern Iraq. This area presents a significant opportunity for further organic geochemical analysis to describe maturation zones and estimate economically generated hydrocarbons with particular reference to the Sargelu formation, to enhance hydrocarbons productivity. To assess the potential of these oil fields, it is essential to perform correlation, comparisons, and geochemical analyses of the data collected from exploration wells in the surrounding area. This approach provides key information and evidence related to the source rock precursors, maturation indices, and other physical properties. The depth of samples in this study ranges from 5,125 ft (1,562 m) to 10,866 ft (3,312 m). Notably, about 20% of these samples demonstrate Total Organic Carbon (TOC) values higher than 4%, with Rock-Eval Hydrogen indices (HI) between 100 and 600, corresponding to Tmax values within the oil generative window. The proven TOC value that has been measured is 16%, while the recorded HI value is 442, and the Tmax value of 439°C. The oil and gas accumulations of the Cretaceous and Tertiary in the Mesopotamian Basin and Zagros fold belt are overlying mature Jurassic source rocks, emphasizing the importance of vertical migrat
ion in hydrocarbon generation. Terpane and Sterane biomarker distributions as well as stable carbon isotope values were determined for oils in the region and potential Sargelu source rock extracts in order to determine dependable oil-to-source rock correlations. The remarkable API gravity, sulfur content, and biomarker ratio provide valuable insights into the source and maturity of various reservoirs. The high sulfur content and wide range of API gravity, from extra heavy to light, are achieved within the range of 8.5–43.3 API.

Keywords: Source rocks; Jurassic period; Maturation indices; Sargelu formation; Total petroleum system API°.

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1- Introduction

The Middle Jurassic Period is a significant era that is characterized as a period of extensive hydrocarbon production. During this era, major source rocks were deposited in an euxinic marine environment, forming good oil prone source rocks that contributed to hydrocarbon generation in the Middle East [1, 2]. PetroMod simulation model (transformation ratio) refers to the Sargol formation in Jabal Kand-1 Well, located in northern Iraq, which has been actively generating oil for the past six Ma [3]. Additionally, the Sargelu formation, which can be found in Qara Chuq-1,2, Makhul-2, and Melih Tharther-1 in northern Iraq, has reached thermal maturity for oil production [3]. A new 1 x 1 km 3D basin model of Kirkuk and the nearby region has been developed as shown in Fig. 1, which includes:

- 23 depth surfaces,
- Lateral variations in source rock quality, thickness, and maturity,
- All surface and seismically mapped anticlines and drainage areas,
- Generated petroleum volume for each field,
- Timing of structuration, maturation, and HC migration

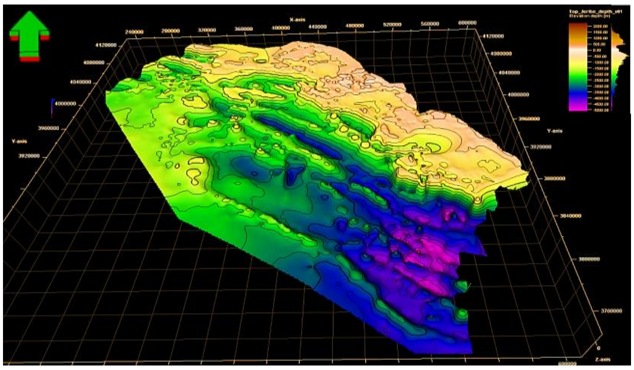

Fig. 1. Location Map of studied oil wells (modified following authorization) [6]

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It is also rich in amorphous organic materials that originate solely from the ocean. According to Jassim and Al-Gailani [4], the Jurassic, Cretaceous, and Tertiary petroleum systems are the most significant hydrocarbon deposits in Iraq. The Jurassic period generates the majority of Iraqi oil. The hydrocarbons that are produced by one of the two primary source rock formations in the Kirkuk region are comparable to one another. Kerogen type II–III is the predominant type of Kerogen material. In Iraq, the Jurassic, Cretaceous, and Tertiary petroleum systems are considered to be the most significant [5]. This is due to the widespread distribution of rock formations in the Kirkuk region Fig. 2. The novelty in this study is to determine the most promising maturation zones to enhance oil and gas field estimation, and to open horizons for more specific studies to serve the economic approaches.

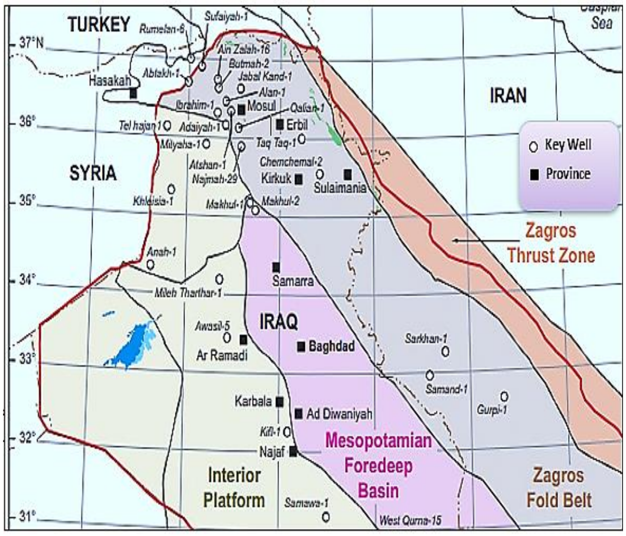

Fig. 2. Key wells within Zagros Fold Belt (modified following authorization) [6]

2- Geological setting

The study region encompasses the Zagros Fold Belt, located in the primary faulting zone of the Mesopotamian Foredeep. It is characterized by a geosynclinal flank and is surrounded by the east Zagros thrust zones. The Khlesia uplift, a Mesozoic stable shelf, surrounds it in the west. The direction of its structures clearly identifies and declares the structural evolution of the Zagros Fold Belt. The Zagros Fold Belt, which is physically complex, was defined by a linear NW-SE fold and fault pattern imposed by Palogene and Neogene tectonism. The current level of seismic activity suggests that the Zagros fold belt continues to exhibit tectonic activity [7, 8]. The faults that originated due to Zagros tectonics, which is widespread in the area of study, are major conduits that channeled petroleum flow from the source to the Miocene, and younger traps also seal fracturing that exceeds vertical petroleum flow. Sediment loading in the Zagros fore-deep caused a northeast change in a regional structural dip, which led to a shift in petroleum migration from a local to a regional flow pattern. Our field trips revealed additional oil accumulation along fault traces. Recently and according to the several studies document the stratigraphy and sedimentology [9-12] focused on the Jurassic source rocks and cancelled via screening the Cretaceous source rocks for being less than 0.5% Total Organic Carbon (TOC) and the palynological studies [1, 3] also support essential data to arrange the materials straight forwards, in addition to concentrated study of the Total petroleum system (TPS) that includes the study of generation, migration and accumulation [1].

3- Types of organic matter

It is necessary to identify different forms of kerogen in order to understand how the quantitative features of kerogen evolution differ due to organic matter. It is necessary to categorize and accurately identify the various types of particulate organic matter (POM) due to their distinct hydrocarbon production potential and products [13-15]. The majority of the samples obtained from different oil exploration wells in the Middle Jurassic Sargelu formation exhibit kerogen types II, III, and combinations of types II and III. The presence of these kerogen types indicates the existence of lacustrine and marine habitats for deposition. The majority of organic matter originates from marine algae and higher plants, making it a source that is prone to oil and gas emissions [16]. The HI vs Tmax method is frequently employed to decrease the impact of the OI in detecting the type of kerogen [17]. The disparity in outcomes is anticipated due to the prevalence of carbonates in the Lower and Middle Jurassic strata, leading to a decrease in OI. The cross plot depicting the relationship between HI and Tmax reveals the prevalence of kerogen Type II and mixed types II–III across all formations, as shown in Fig. 3. The Sargelu formation, which originated during the Middle Jurassic period, is considered a significant source rock with considerable potential for hydrocarbon generation. The source rock has reached the oil window, as indicated by a Tmax ranging from 432 to 450°C [18]. Fig. 3 illustrates source rocks that exhibit a high potential for hydrocarbon generation, ranging from good to exceptional. The source rock has reached the oil window, as indicated by a Tmax ranging from 432 to 450°C. The Sargelu formation, which originated in the Middle Jurassic period, is a significant part of the Chia Gara formations. Naokelekan formation, found in the Kirkuk and Jambur fields, is recognized as a crucial source rock [18, 19]. The peak oil generation in the Zagros Fold Belt zone during the Late Miocene and Pliocene has been observed in lower source rocks [20]. The lithological composition of Sargelu is closely associated with its richness, characterized by the presence of thin to medium-bedded black bituminous calcareous, dolomitic limestone, and thick-bedded black papery shale with black chert beds in the higher region.

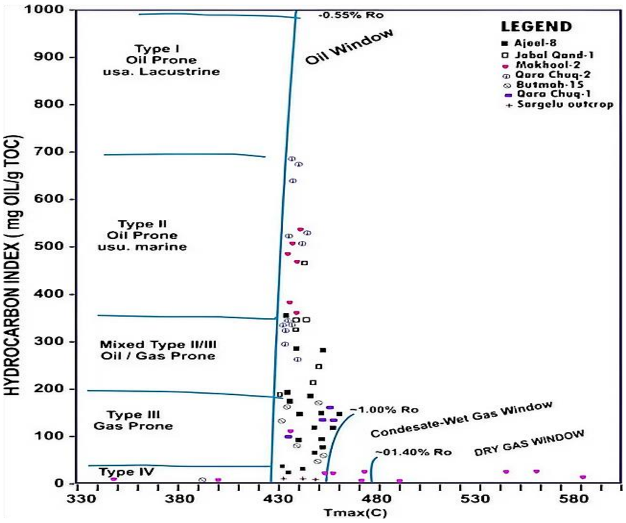

Fig. 3. The cross plot of HI versus Tmax indicates dominance of kerogen Type II and mixed types II-II

4- Middle Jurassic petroleum system

Many decades have seen the discovery of hydrocarbons in various Jurassic reservoirs in the greater Kirkuk region. The evaporites from the Kimmeridgian Gotnia and Barsarin formations provide the regional seal for the Jurassic (Sargelu-Naokelekan) petroleum system. Evidence suggests that oil has made its way from reservoirs in the Cretaceous period all the way up to the Jurassic period [20]. The principal Jurassic source intervals are located inside the Sargelu (Bathonian-Bajocian-Callovian), Naokelekan Callovian-lower Kimmeridgian, and Chia Gara (Tithonian-Valanginian) formations. The efficacy of this source system has been verified; however, there may be an additional petroleum system based on organic-rich layers in the Upper Triassic Baluti and Butmah formations that charge the Lower Jurassic reservoirs sealed by the Alan anhydrite seal. Conversely, source rocks from the Middle-Upper Jurassic or late Triassic may supply hydrocarbons to the Mus, Adaiyah, and Butmah formations situated in the Lower Jurassic. The Sargelu formation's fractured basinal carbonates and the Najmah formation's dolomitized shelf carbonates are the primary reservoir candidates in this sequence in northern Iraq. Shale layers and interbedded laminites, along with the Gotnia and Barsarin (Kimmeridgian) evaporites situated above, create a seal encasing the Sargelu. The Najmah formation is similarly encased by dense carbonates and evaporites. Fig. 4 shows that the Sargelu formation normally has a thickness ranging from 100 to 200 m (328 to 656 ft) along the Zagros fold belt [20], while the Naokelekan formation's heavily compressed part has a thickness ranging from 5 to 45 m (16 to 148 ft) or less. The HI measurements in low-maturity organic-rich samples, which range from 300 to 600 mgHC/gTOC, suggest the presence of oil-prone type II organic matter. Values are usually open marine because the present-day HI decreases quickly with increasing thermal maturity.

The hydrogen indices of the oil and gas-prone source rock intervals (pyrolysis S2 yields from 0.62 to 1.83 mgHC/gTOC and HI mainly 95, with an average of 237 mg HC/g TOC for complete samples show that these intervals have the potential to produce oil and/or gas. Hydrogen indices (HI) range from 95 to 367, with an average of 268 mg HC/g TOC, and pyrolysis S2 generates 0.62-1.83 mg HC/g rock, indicating that the mixed-prone Sargelu source rock intervals have an intermediate to high potential to produce oil and gas. Plotting S2 vs TOC allows one to identify the components of various organic substances [21]. To establish dependable correlations between oil and source rock, the distributions of Terpane and Sterane biomarkers, stable carbon isotope values, and oil samples from the region were examined. The petroleum potential of an immature source rock or the residual potential of a previously productive source rock can be assessed by analyzing its total organic carbon (TOC) content and S2 values, defined as mgHC/grock derived from kerogen during pyrolysis [22-25]. The Sargelu, Naokelekan, and Chia Gara formations of the Jurassic period contain source rocks of good to outstanding quality. Despite the current limitations of the Triassic data set, it has been found that the Kurra Chine and Geli Khana formations have source rock horizons that are fair to good. It should be noted that these Triassic samples do not represent the quality of the original source rock because they have already reached maturity in the mid-oil window. Abeed and Al-Ahmed are cited as sources of data in Fig. 5. The geochemical similarities between Terpane and Sterane are sufficiently supported by the data in Fig. 6.

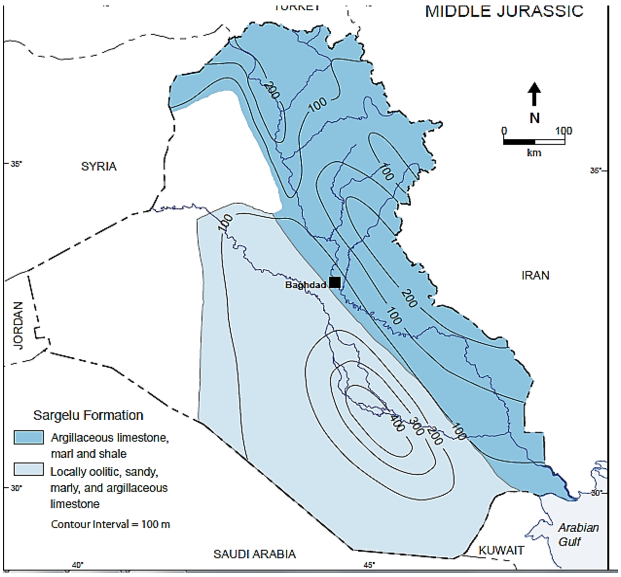

Fig. 4. Map showing isopach contours and lithofacies for the Sargelu formation [20]

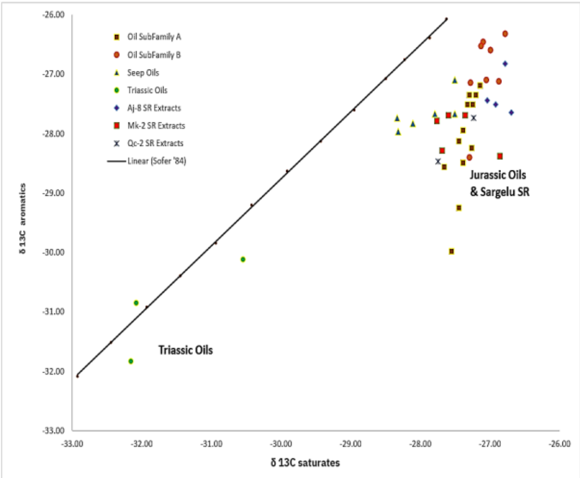

Fig. 5. Jurassic oils and Sargleu SR, oil subfamilies (A and B), oil seeps and Triassic oils [1]

Graphing the temperature of peak hydrocarbon generation during pyrolysis (T max) against the hydrogen index (HI) provides a clear depiction of the organic matter type and maturity of a source rock. The hydrological index (HI) of the Sargelu and Naokelekan samples, characterized by low maturity and high organic matter content, varies from 400 to 800 mgHC/gTOC. Correspondingly, the HI recorded in the low-maturity Chia Gara samples varies from 300 to 600 mgHC gTOC. The findings indicate that the source rocks contain type II organic matter conducive to oil generation. The current Hydrogen Index diminishes swiftly with increasing thermal maturity, leading to generally low Hydrogen Index values.

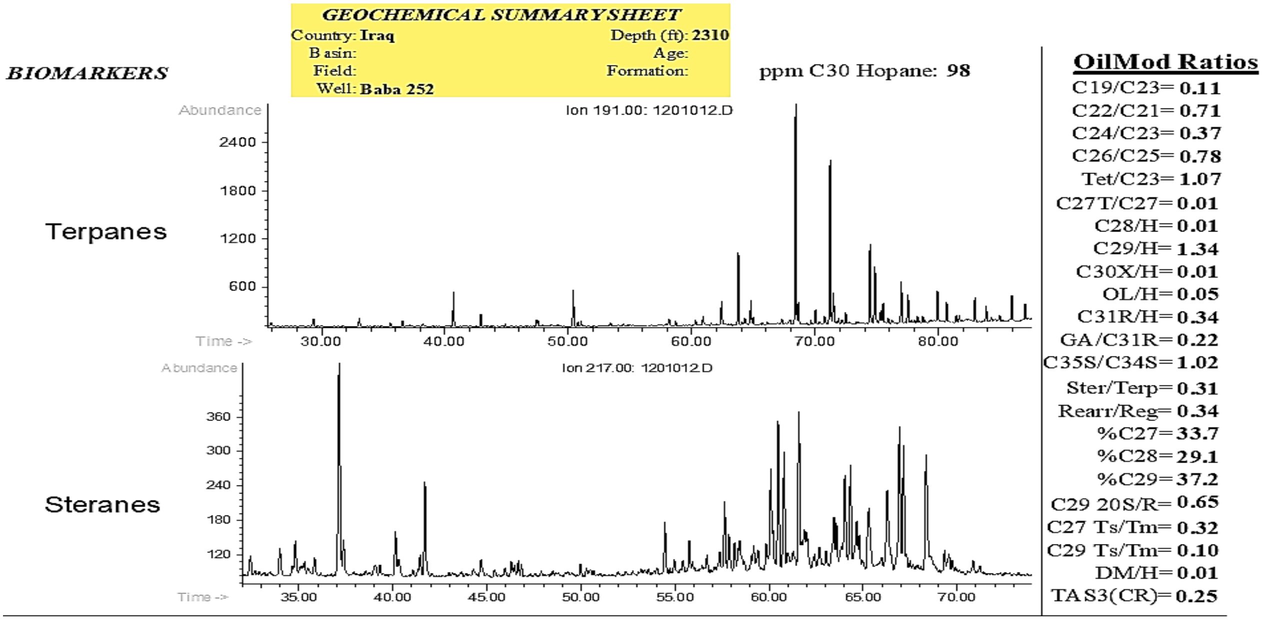

Fig. 6. Biomarker indicates Terpanes and Steranes Baba-252 [3]

5- Thermal maturity levels

The thermal maturity levels (Immature, Mature, and Ove rMature) for the oil window are determined by the type o f organic matter [26]. These levels range from 0.55 to 1.00% in vitrinite reflectance (Ro) [27]. The studied area has different levels of maturation indices, and the temperature at which hydrocarbon generation reaches its maximum rate during S2 evolution (Tmax) is between 435 and 470°C. The parameter of production index (PI) is a metric used to assess maturity, often ranging from 0.15 to 0.70, which is commonly linked to the generation of oil. The estimation of thermal maturity can be approximated by examining the plot of HI vs Tmax. A significant proportion of the samples exhibit thermal immaturity or are in the early stages of maturation. The pyrolysis Tmax values vary from 422-431°C, while the PI value is less than 0.15. The elevated PI value suggests that the organic matter falls within the oil window range, yet this contradicts the low Tmax results. The observed disparity may be attributed to the existence of kerogen Type II-S, which exhibits a reduced thermal decomposition rate compared to conventional Type-II kerogen [28]. Sargelu formation also holds heavy oils within the fractured parts, especially where the Gotina seal is absent [29]. Sargelu is a source for most of the hydrocarbons accumulated in the north, including Damir Dagh, Gilabat Oil Fields. The maturity of Jurassic succession in Sangaw North-1 Well is high and ranges from 1.34 to 2.10 Ro%, and the maturity of Sargelu mainly increases from the west to the east. The thickness and maturity of the source rock may vary laterally within the fetch area. The variation of maturity is also controlled by the lateral geometry of geological structure. The variables hydrocarbon volumes are dependent upon are interdependent, and such dependency is controlled by the geometric shape of the structure surfaces.

Lateral variations in Sargelu, Naokalekan, and Chia Gara source rock quality, thickness, and maturity. Drainage areas and generated petroleum volume for each field and tectonic zone generated volume 1160 – 2050 BBOE Timing of structuration, maturation, petroleum generation, and HC migration. Fig. 7.

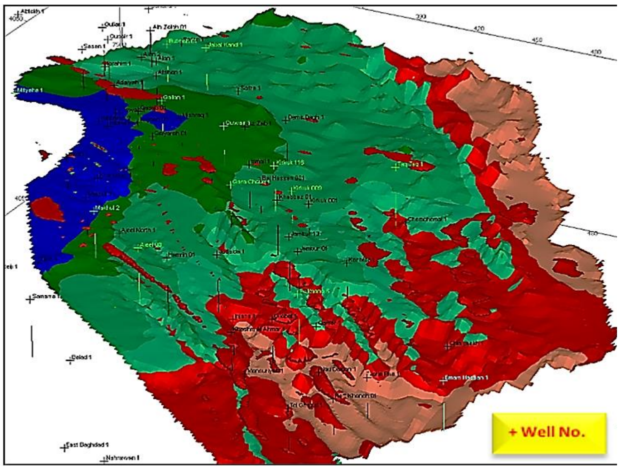

Fig. 7. A new 1 x 1 km 3D basin model of north Iraq [6]

6- Source rock maturation

Modeled vitrinite reflectance at the top of the Middle Jurassic source rock in the Zagros Fold Belt is shown in Fig. 8. The model simulations indicate that source-rock maturity varies across the region. At present-day, there is a systematic decrease in thermal maturity from east to west across the fold belt. Paralleling the trend in regional structure, which indicates that source rock maturation was predominantly controlled by burial. Jurassic source rocks have high maturity (indicate range in maturity) near the surface in the thrust zone. These maturities provide evidence that uplift and erosion took place after source rock maturation, and are consistent with studies that have documented an early oil phase generated and expelled in the thrust belt prior to late Cenozoic tectonics.

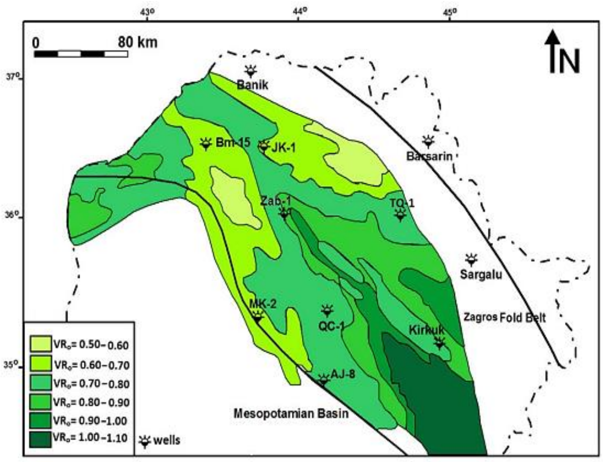

Fig. 8. Generation of petroleum, Millton/km^2 and HC kitchen by Sargelu formation [6]

Most of the oil prone bounded between 430 to 480 °C, and almost all oil fields are determined in the oil zone based on production index and maturity based on T max Fig. 9.

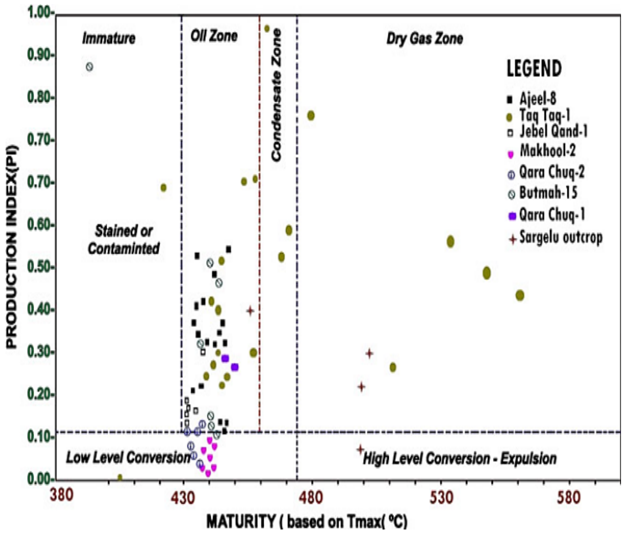

Fig. 9. Production index vs. maturity

7- The evidence of maturation indicated by API gravity and sulfur content

Significant variation was noted in the API gravity of the oil samples, ranging from 11.8 to 43.3. Similarly, the seepage samples exhibited a range of 8.5 to 9, indicating a significant divergence. This data can be classified based on the weight of the oils, ranging from very heavy to light. The light oil originates from the Jambour oil field, which is located in the early Cretaceous reservoir known as the L. Sarmord formation. On the other hand, the heavy oil is sourced from the Qaiyarah field, which is situated in the early Miocene and belongs to the Euphrates formation. The selected fields are classified as "sour" crude oil types (>0.5% S) due to their elevated sulphur content ratio. The sulphur content in the seepage samples ranges from 1.02 to 7.8, with values above 4. The depositional environment is mostly influenced by the nature of the oil, namely whether it originates from terrestrial or marine sources [17]. With the exception of the samples from the Bai Hassan and Khabbaz fields Fig. 10, there is no clear correlation between the API and sulphur level. When considering the age of the reservoirs, it is observed that the Avanah, Bai Hassan, and Khabbaz oil fields have greater API and lower sulphur content values during the Tertiary period compared to the Cretaceous period. However, there is no distinct demarcation between the two, particularly in the Baba and Jambur fields.

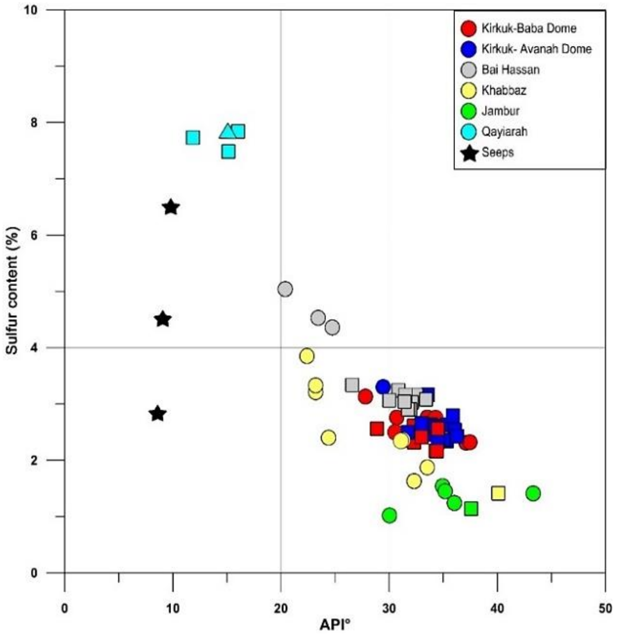

Fig. 10. Sulfur content vs. API gravity allows a further characterization

8- Conclusion

The results of the analyzed nine oil fields were classified into two main reservoir epochs, predominantly distinguished by high sulfur concentrations. This indicates that the oil originates from marine and lacustrine environments. Furthermore, it suggests that the entire study area possesses considerable potential for hydrocarbon generation. The established oil fields have been producing oil for several decades due to the various maturation regions identified in this study.

Evidence indicates a convergence between carbonate marine and nonmarine rocks within the source rocks. The Kirkuk Region comprises carbonate-rich source rocks from the Jurassic to the Late Cretaceous period. The Sargelu formation is the principal verified source rock. The m/z of Terpane is 191 amu, whereas the m/z of Steranes is 217 amu. The oil samples from Cretaceous reservoirs display low Pr/Ph ratios, signifying their derivation from a source rock predominantly comprised of marine organic material. This source rock was deposited in reducing conditions, exhibiting minimal biodegradation and an advanced stage of formation. The oil samples predominantly comprise carbonate rocks from the Sargelu and Naokelekan formations, originating from the Middle and Upper Jurassic epochs.

The majority of seeps in the study area are ascribed to the tectonic movement of the regional anhydrite cap rocks of the Fatha formation. The shallow depth of the Oligocene deposit facilitates these seeps. The biomarkers terpane and sterane were analyzed via gas chromatography-mass spectrometry. The distributions and stable carbon isotope values of oils in the region, along with probable Sargelu source rock extracts, were determined to establish reliable correlations between the oil and the source rock. The application of API gravity, sulfur content, and biomarker data alongside models offers credible evidence for improving the understanding of the origin and age of different reservoirs. The product exhibits elevated sulfur content and a broad spectrum of API gravity, varying from 8.5 to 43.3 API°.

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التعرف على نضج الصخور المصدرية وإمكانات النفط في كركوك والمناطق المجاورة

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الخلاصة

على الرغم من كونه أحد أقدم حقول النفط المكتشفة في شمال العراق، إلا أن تحديد مناطق النضج والمناطق المولدة للنفط في كركوك والمناطق المحيطة بها (بابا، جمبور، إلخ) لا يزال يمثل تحديًا. تؤكد هذه الدراسة على الحاجة إلى مزيد من التحليلات الجيوكيميائية، خاصة بالنسبة للتطورات في تقييم تكوين ساركلو لتقييم إمكانية توليد الهيدروكربون وتوجيه استراتيجيات تعزيز الإنتاج. تاريخياً، أعاقت ندرة البيانات عن صخور المصدر الجوراسي وخصائص المكامن تقييم المكامن النفطية في حوض بلاد ما بين النهرين وحزام طية زاغروس. يتطلب التقييم الفعال عملية المظاهاة ومقارنة البيانات الجيوكيميائية من آبار الاستكشاف الموجودة داخل منطقة الدراسة. تعد المؤشرات الجيوكيميائية الحرجة مثل دلائل النضج وأدلة العلامات الحيوية كنتائج منجزة ومثبتة أمرًا بالغ الأهمية لتحديد سلائف الصخور المصدر.

أظهرت عينات الآبار التي تم تحليلها سابقًا أعماقًا تتراوح من ١٥٦٢ مترًا إلى ٣٣١٢ مترًا. والجدير بالذكر أن ٢٠% من العينات تمتلك إجمالي الكربون العضوي (TOC) يتجاوز ٤%، مع قيم مؤشر الهيدروجين الصخري (HI) بين ١٠٠ و٦٠٠، بالتزامن مع قيم Tmax لنافذة النفط. يصل الحد الأقصى للقيم المسجلة إلى ١٦% TOC، و٤٤٢ درجة حرارة عالية، و٤٣٩ درجة مئوية Tmax.

إن وجود تجمعات النفط والغاز في العصر الطباشيري والثلاثي التي تغطي صخور المصدر الجوراسي الناضجة في حوض بلاد ما بين النهرين وحزام طية زاغروس , يعزز أهمية الهجرة العمودية. انتشار التربين والاستريين كادلة احيائية بجانب تحليل نظائر الكاربون المستقر,تم استخدامها بشكل موسع في النفوط المستخلصة من توليد تكوين ساركلو كصخرة مصدرية لعمل مظاهاة بين النفط والصخورالمصدرية الصخور ومصدر النفط. توفر جاذبية قيم ونسب معهد البترول الامريكي ومحتوى الكبريت ونسب الادلة الاحيائية يوفر رؤى وافكار مهمة حول اختلافات المصدر والنضج في المكامن المختلفة. ومن الجدير بالذكر أن محتوى الكبريت يختلف بشكل كبير، وتتراوح جاذبية API من مستوى منخفض يبلغ ٨,٥ درجة إلى حد أقصى يبلغ ٤٣,٣ درجة (النفط الثقيل جدًا إلى الخفيف).

الكلمات الدالة: الصخور المصدرية، العصر الجوراسي، مؤشرات النضج، تكوين سارجيلو، نظام البترول الكلي.