University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.jcoeng.edu.iq

Volume 32 Number 1 January 2026

The 2D Seismic Evaluation of Petrophysical Characters of Yamama Reservoir in Nasiriyah Oil Field, Southern Iraq

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ABSTRACT

Since seismic reflection data produce comprehensive subsurface images that reveal geological structures likely to contain minerals, oil, and gas, they are essential for resource exploitation. When paired with well logs, these data enable seismic and petrophysical assessments that lower drilling risks and boost efficiency. Wireline logs from five wells and seismic coverage of the Nasiriyah oil field (Dhi-Qar Governorate), processed with Schlumberger software, were used to characterize the Yamama reservoir. Synthetic seismograms connected reservoir tops to seismic data; however, resistivity and gamma logs helped with correlation and sequence delineation. Wells' correlation described the migration routes of hydrocarbons and reservoir carbonates.

Potential sweet spots were found using models that showed heterogeneity and anisotropy in the reservoir's lateral and vertical variations. Units YB3 and YC were defined as the primary production layers, based on borehole data analyzed in Techlog, Petrel, Kingdom, and Didger. Results confirm seismic methods enhance exploration success and guide future hydrocarbon recovery.

Keywords: Yamama reservoir, Synthetic seismogram, Seismic interpretation, Petrophysical Characterization, Gamma ray log.

1. INTRODUCTION

Many oil wells have been drilled in the Nasiriyah Field based on previous studies confirming significant hydrocarbon reserves. Recent data from the Iraqi Oil Production Company indicate that crude oil production reached approximately 4.3 billion barrels in 2020, highlighting the field's major contribution to Iraq's petroleum output **(GEMP, 2020)**. The field is located in Dhi-Qar Governorate, southern Iraq, near Nasiriyah City and east of the Euphrates River, within the southern Mesopotamian Basin, characterized by complex stratigraphic and structural settings that host multiple productive formations.

Among these, the Yamama Formation represents the second-largest oil-bearing carbonate reservoir in southern Iraq. Deposited during the Lower Cretaceous (Valanginian–Early

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2026.01.10

Article received: 30/09/2025
Article revised: 27/11/2025
Article accepted: 10/12/2025
Article published: 01/01/2026

Hauterivian) as part of a retrogressive marine cycle, it consists of heterogeneous limestone units with distinct petrophysical and depositional characteristics **(Budy, 1980)**. The Yamama reservoir, along with other Lower Cretaceous formations such as Zubair, Ratawi, and Shuaiba, records alternating shallow-marine depositional cycles that significantly influence reservoir quality and continuity.

Assessing both seismic and well data remains essential for improving understanding of the reservoir's structural framework, lithological variability, and fluid-flow behavior. According to **(Lake and Carroll, 1986)**, petrophysical characterization provides a quantitative approach to describing reservoir properties, while **(Coffen, 1984)** emphasized the role of porosity, permeability, and sealing capacity in hydrocarbon accumulation.

In this study, data from five oil wells (NS-1 to NS-5) penetrating the upper Yamama units were integrated with 2D seismic interpretation to delineate formation geometry and reservoir zones. The workflow utilized Petrel 2024v and Techlog 2024v software to correlate well logs (particularly gamma ray, density, and sonic) with seismic facies and identify impermeable barriers and productive layers.

The objective of this study is to seismically evaluate the Yamama Formation within the Nasiriyah Field using an integrated seismic–petrophysical approach to characterize reservoir heterogeneity, identify productive intervals, and map structural features influencing hydrocarbon accumulation. The integration of well-log and seismic data aims to enhance the accuracy of reservoir modeling and depositional interpretation, providing a reliable basis for future development and production optimization in southern Iraqi carbonate systems.

2. LOCATION AND STRUCTURE OF NASIRIYAH OIL FIELD

The field is situated in the unstable Mesopotamian Basin zone, 38 km northwest of the city of Nasiriyah. The region is not structurally complex, as strong structural movements did not significantly affect the stratigraphic column, and it is located in a region of the Mesopotamian Basin that is unstable **(Budy, 1980)**. The Miocene age witnessed the formation of the Nasiriyah structure in eastern Iraq, resulting from lateral movement associated with the Alpine orogeny. This movement caused the structure to evolve and its capacity to rise **(Aqrawi et al., 1998).** The central locations of oil aggregation in the field are the Yamama and Mishrif formations. At the summit of every reservoir unit, the Al-Nasiriyah oil field anticline structure's long axis, which trends NW-SE, is roughly 22 km long and 10 km wide, and it passes close to the Euphrates Boundary Fault and parallel to it.

The Yamama Formation, deposited in the Early Cretaceous at the base of the mega-sequence AP8 (Tithonian–Early Turonian), is one of the primary reservoirs in the Nasiriyah oil field. It is laminar between the Sulay Formation in the lower transitional contact and contains argillaceous limestone, hard recrystallized limestone, and limestone with periodic shale interbeds **(Jassim and Goff, 2006)**, see **Fig. 1.**

The field is located in the Dhi-Qar Governorate. The coordinates of the oil field are (31°26'53") N and (45°58'0") E, as shown in **Fig. 2.**

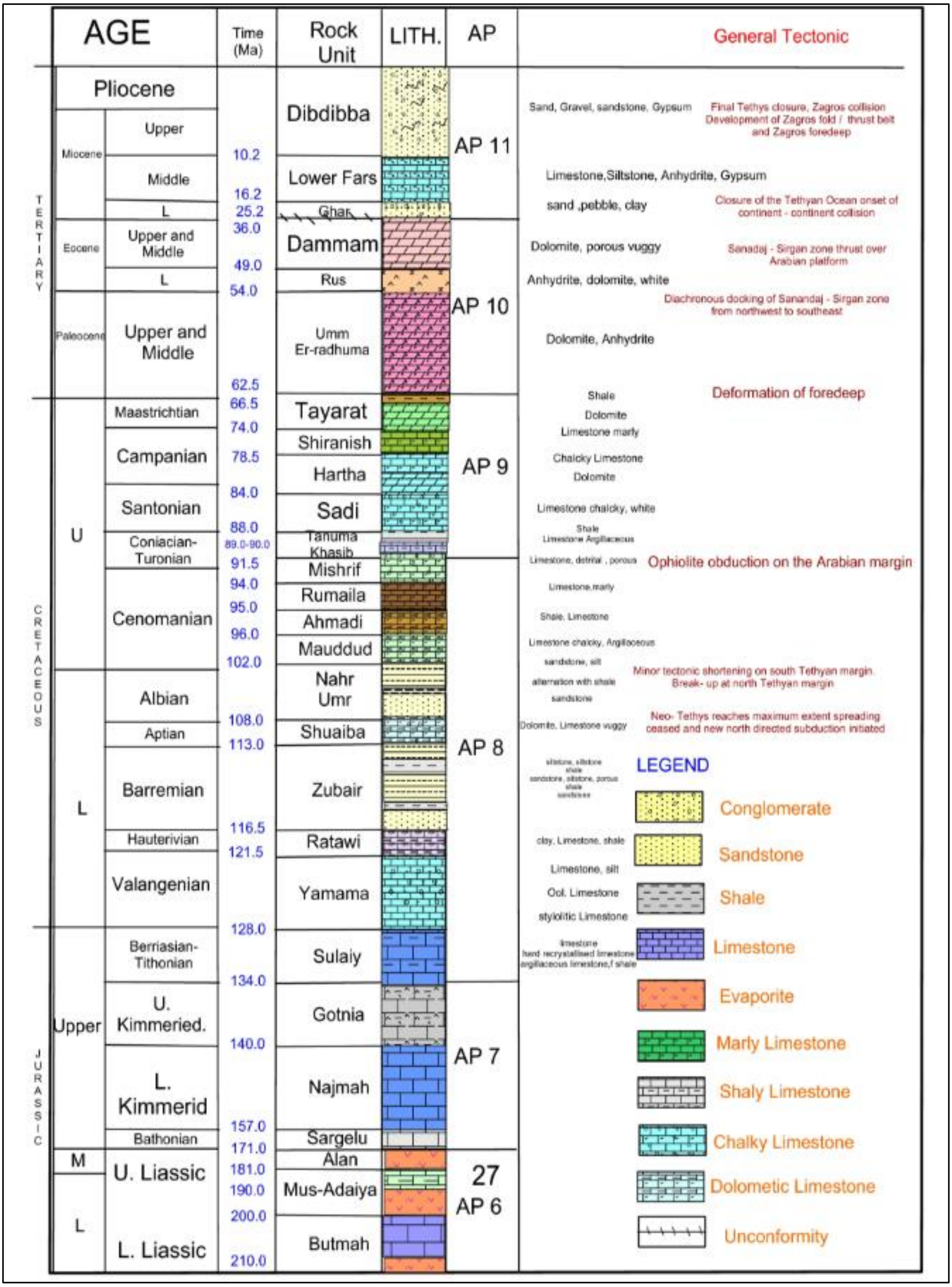

Figure 1. The geological setting of the Yamama formation and its stratigraphy, modified after **(Al-Iessa and Zhang, 2023)**.

Figure 2. The satellite map shows the location of the field.

3. MATERIALS AND METHOD

3.1 Software Workflow and Data Processing

For accurate interpretation and integration of the geological, petrophysical, and seismic datasets, several specialized software packages were used throughout the study. Each program played a specific role in processing, analyzing, and visualizing the data for the Yamama Formation in the Nasiriyah oil field:

- **Didger 3 Software:**
  Used for digitizing and georeferencing base maps and cross-sections. Didger ensured spatial consistency between well locations, seismic lines, and geological boundaries before importing the data into Petrel for 3D modeling.
- **Kingdom Suite:**
  Utilized for seismic data processing and horizon correlation. The software supported the conversion of seismic time data to depth, well-to-seismic ties, and validation of structural features identified in Petrel.
- **Petrel 2024 (Schlumberger):**
  Used for seismic interpretation and 3D structural modeling. Petrel facilitated the correlation of seismic horizons with well tops, fault interpretation, and the generation of structural contour maps. It also allowed integration of well log data to create a unified geological model of the reservoir.
- **Techlog 2024 (Schlumberger):**

Applied for petrophysical analysis and well-log interpretation. Techlog was used to evaluate porosity, permeability, water saturation, and lithological composition based on gamma-ray, density, and sonic logs. These analyses provided key inputs for identifying reservoir and non-reservoir zones.

The integration of these software platforms allowed a comprehensive workflow from data preprocessing and quality control to detailed seismic interpretation and petrophysical evaluation. This process ensured consistent interpretation of the Yamama Formation's structural and stratigraphic framework before proceeding to detailed data analysis.

3.2 Data Analysis

Petro-interpreters can construct faults and horizons along lines, crosslines, random lines, and slices using the seismic interpretation process. Horizons can be automatically tracked on horizontal slices and vertical seismic displays. Seismic interpretation maps are then generated using advanced horizon-tracking algorithms, in addition to user-interpreted faults and fault polygons. A reduction in reflection amplitude is commonly recognized as a standard indicator of faulting within seismic sections **(Bjørlykke, 2010)**.

A two-dimensional geological cross-section's seismic response can be investigated using a similar methodology. These models are frequently used to assess the seismic response of various fluid types, such as oil, gas, or brine, within a possible reservoir, as well as the resolution of thin beds **(Hodgetts and Howell, 2000)**. These cross-sections can also be used to test alternative structural geometries. In constructing a cross-section, density and seismic velocity values are assigned to each layer. These parameters may be constant within individual layers or vary systematically both vertically and horizontally across the model.

In the Nasiriyah field, 32 wells have been drilled, but only five reached significant penetration into the Yamama Formation. These wells were selected due to the availability of borehole sensors and are distributed across both the crest and the flanks of the field.

This study integrates seismic data with well-log information, applying seismic stratigraphic analysis to the Yamama Formation, which lies at an approximate depth of 3 km. The analysis involved correlating seismic reflection profiles with well-log data from the wells (NS1–NS5). The well data comprised resistivity, spontaneous potential, and gamma-ray logs, and the 2D seismic profiles covering 58 km^2 with 25 m spacing. **Fig. 3** displays the base map of a Nasiriyah oil field, which displays the coverage of the seismic dataset and the spatial distribution of the study wells.

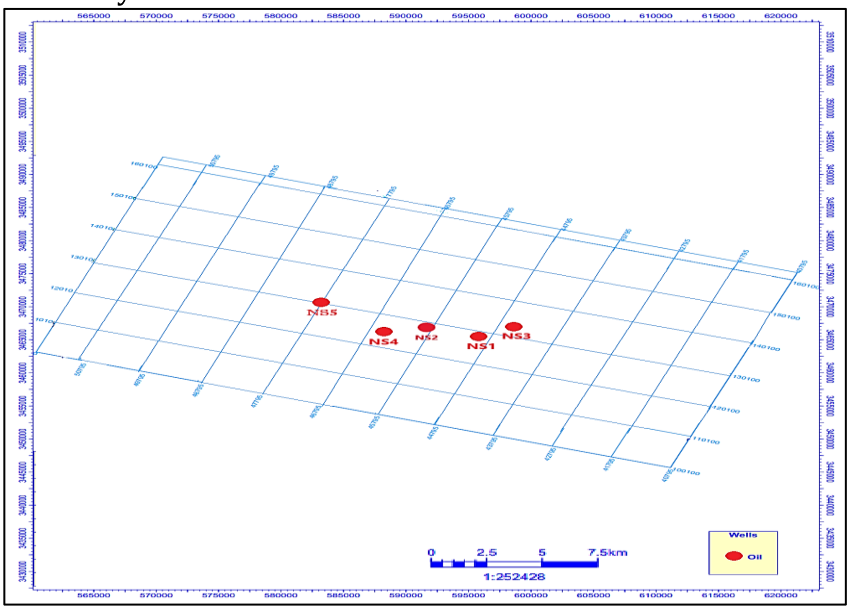

Figure 3. Base Map of Nasiriyah Field.

Check shot data were used to establish the depth-to-time relationship at the well locations. Density and sonic logs were then combined to produce logs of acoustic impedance and reflectivity. A seismic wavelet that was taken straight from the seismic data was convolved with the reflectivity log to construct the synthetic seismogram. In cases where limited well control is available, statistical wavelet extraction is commonly applied **(Edgar and Van der Baan, 2011)**.

Surface seismic data provide the most comprehensive dataset for reservoir characterization and development. However, their primary limitation is that seismic reflections, which delineate seismic sequences and interfaces, are recorded in two-way travel time rather than in depth. To overcome this, velocity calibration was performed using control wells, allowing for a reliable time-to-depth conversion of seismic images. This calibration ensured that seismic reflections could be tied to stratigraphic horizons in depth, a critical step for accurate reservoir volume estimation.

Synthetic seismic traces were generated at each well location using sonic and density logs in combination with the extracted wavelet. These synthetics established the link between seismic reflections and stratigraphy. As part of the quality control process, only sonic logs corrected for drift using check shot calibration were employed. Seismic-to-well calibration was conducted at two control wells (NS1 and NS3), which provided accurate depth positioning of geologically significant horizons before mapping **Fig. 4.**

The synthetics indicated that the top of the reservoir is expressed seismically as a trough. To validate this calibration, resistivity and gamma-ray logs were overlaid on the seismic section. Although both the seismic quality and sonic logs posed challenges, cross-correlation between real and synthetic traces confirmed the final extracted wavelet. The wavelet, as expected, was band-limited in the frequency domain, reflecting the inherent loss of very low and very high frequencies in seismic data. The synthetic seismograms demonstrated that the top of the Yamama Formation corresponds to reduced reservoir quality with increasing depth. At the same time, higher resolution and productivity are associated with the third reservoir unit.

All available data were subsequently loaded into Petrel software V. 2024 for seismic interpretation and modeling. This included 2D seismic lines extracted from the 3D seismic volume, well logs, and synthetics. The synthetic traces were matched to seismic data at each well location to evaluate the seismic response of the reservoir and to highlight hydrocarbon migration pathways. The seismic reflections in **Fig. 4** illustrate a gentle dip towards the northwest and southeast, ranging from one to two degrees. The reflections across wells NS1 and NS3 reveal continuous extensions of the lower Yamama reservoir layers.

At the basin margin, the lower units of the Yamama Formation, specifically YC and YB, are characterized by intense, continuous, and well-defined reflections. In contrast, the upper unit (YA) displays relatively weak seismic responses. This pattern indicates that the reservoir's most laterally continuous and seismically resolvable intervals occur in the lower part of the formation. Reflection characteristics further suggest that carbonate shoreline facies developed predominantly along the basin margins, with reflection strength and frequency increasing from the basin margins toward the basin center. Well log data support this interpretation, showing a progressive increase in dip from the northwest to southeast across the Yamama sequences, consistent with folding along the structural boundary of the Nasiriyah field.

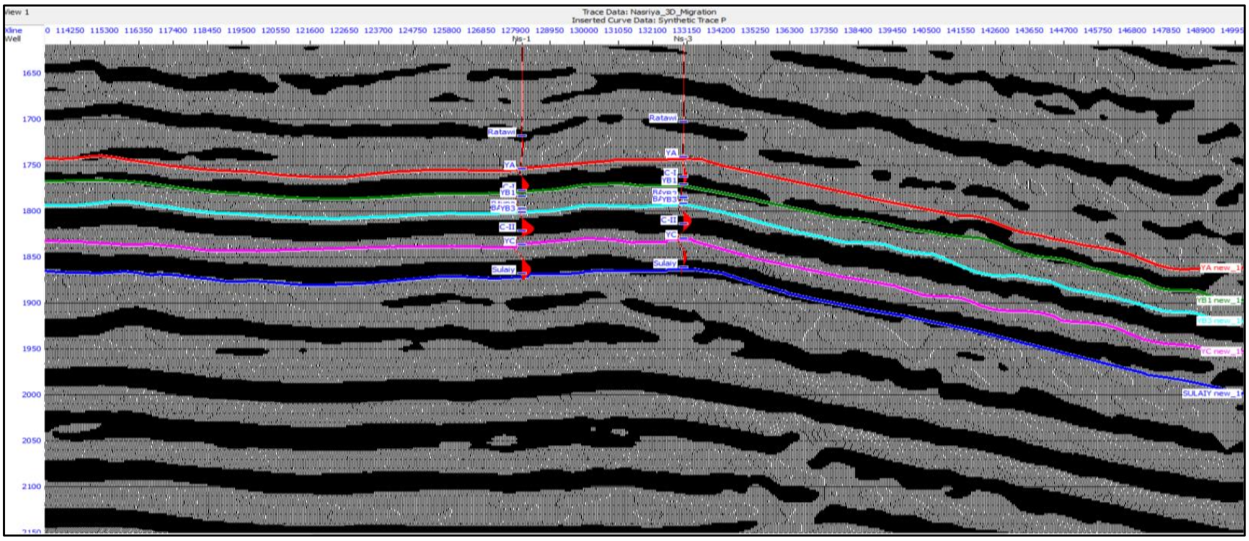

Figure 4. Yamama Reservoir's seismic properties and aggradation model graph in the Nasiriyah oil field.

Acoustic information can be extracted from seismic traces using a technique called seismic inversion. Seismic traces do not contain information at low or high frequencies because source wavelets are band-limited. Deterministic seismic inversion, which produces a smooth inversion result, thus presents a significant challenge when applied to actual data. Well log data provides the low-frequency component; however, a difficulty arises when combining well log and seismic data, dependent on the measurement support scale. While seismic data represent low details in the vertical direction, well-log data have a high vertical resolution.

3.3 Correlation of Formation's Intervals

Since correlation imposes fundamental limitations on recognizing the reservoir architecture, it is an essential component needed to construct a petroleum reservoir model. To maximize the recovery of our diminishing hydrocarbon supply, the reservoir's correlation as a limestone formation is crucial. The primary method for oilfield correlation is still biostratigraphy, as well as the analysis of seismic and geophysical logs **(Jones and Simmons, 1999)**.

Correlation of formation intervals with 2D seismic sections serves as the bridge between well control (depth, geology) and seismic reflection data (time, structure), ensuring that what is seen on seismic actually represents the real subsurface formations. This enables more reliable interpretations, maps, and drilling decisions.

The seismic section in **Fig. 5** displays five wells (Ns1 to Ns5) tied to the seismic line, with correlated formation tops after digitizing and arranging the data using an Excel sheet to represent the top and bottom of layers (YA, YB1, YB2, YB3, YC, Sulay). Several key horizons are mapped across the section, following strong reflectors that represent stratigraphic boundaries, so structurally, the section shows faulting and flexures, particularly around wells Ns1, Ns2, and Ns3, with possible downthrown blocks or graben features, while stratigraphically, the horizons YA–YB3 appear laterally continuous, indicating relatively uniform sedimentation; local thickness variations suggest changes in depositional conditions. From a reservoir perspective, intervals such as YB1, YB2, YB3, and YC represent potential reservoir units, with structural highs near Ns5 and Ns1 as possible hydrocarbon traps.

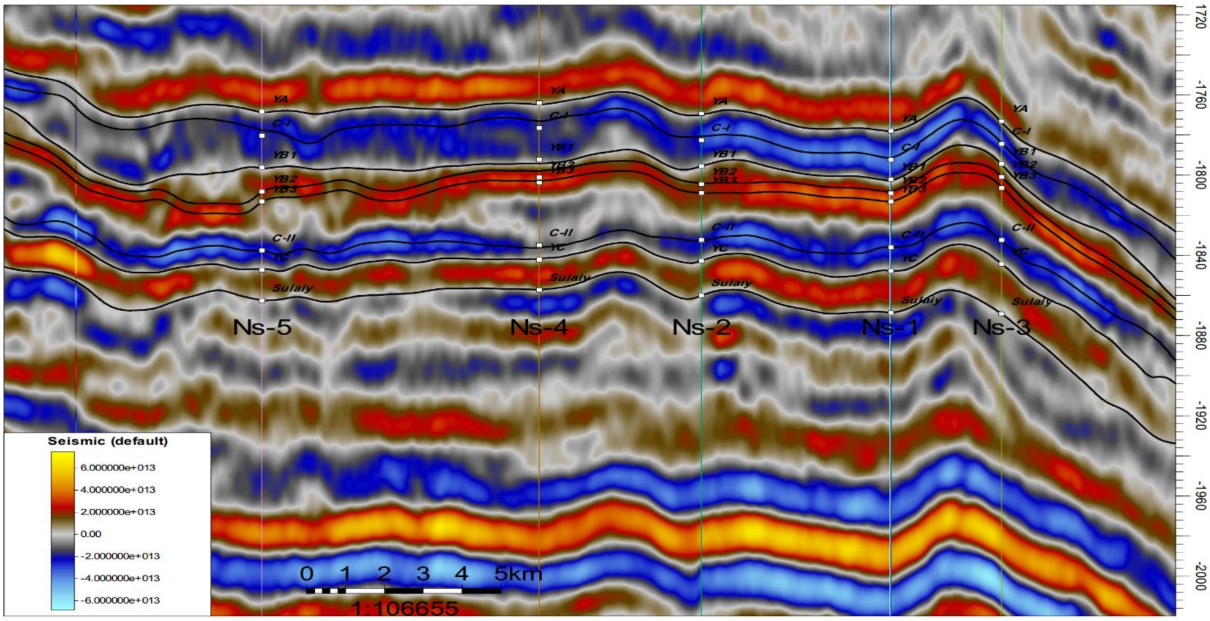

Figure 5. 2D seismic inline from the 3D cube showing structural features, well correlations (NS1–NS5), and key stratigraphic horizons of the Yamama Formation.

Using the gamma-ray index (IGR) to calculate the V shale was mainly determined **(Larionov, 1969)**. Both the gamma-ray response and the V shale values are used to designate the five zones: YA, YB1, YB2, YB3, and YC, which are separated by four barriers. The data comprised seismic sections, a base map, a structure map, and digital suites of well logs that were loaded into the interactive Techlog program.

The current objectives are to determine the seismic features of the Yamama Formation and to investigate the diagenetic development and its impact on reservoir parameters. Remarkably, compared to other rock packages, the Shale, a significant component of the Yamama Formation, has greater radioactivity values. Thus, gamma-ray logs are typically employed to show the volume of shale (V shale) in the lithology and successions.

The aim is to connect well log interpretation (gamma ray) with seismic interpretation. Gamma-ray logs are essential for identifying lithology and estimating shale volume (V shale) within successions, where high gamma values indicate shale-rich intervals and low values reflect cleaner sandstones or carbonates. When tied to the seismic section, these log-derived formation tops provide the calibration needed to connect well-scale lithology to seismic reflectors. The horizons picked on the seismic section (YA, YB1–YB3, YC, Sulay) correspond to lithological boundaries observed on the gamma-ray logs. Clean reservoir-prone intervals, such as the YB units, can thus be traced across the seismic line, while high gamma intervals, such as Sulay, act as regional seals. This integration ensures that seismic reflectors accurately represent actual stratigraphic boundaries, allowing for the reliable mapping of reservoir and seal intervals across the field.

Fig. 6 shows the correlation between gamma-ray log responses and the detection of interval layers in the Yamama formation, as well as the barriers between layers, and the addition of lithology properties using Didger v.3 software at each depth, according to the FGR litho-description. The study wells, trending from northwestern to southeastern, reflected gamma-ray traces with high and low amplitude values in the Nasiriyah wells. Through this response, the areas of hydrocarbon presence were determined, and by comparing the studied wells, the depth and the most productive reservoir layer were determined.

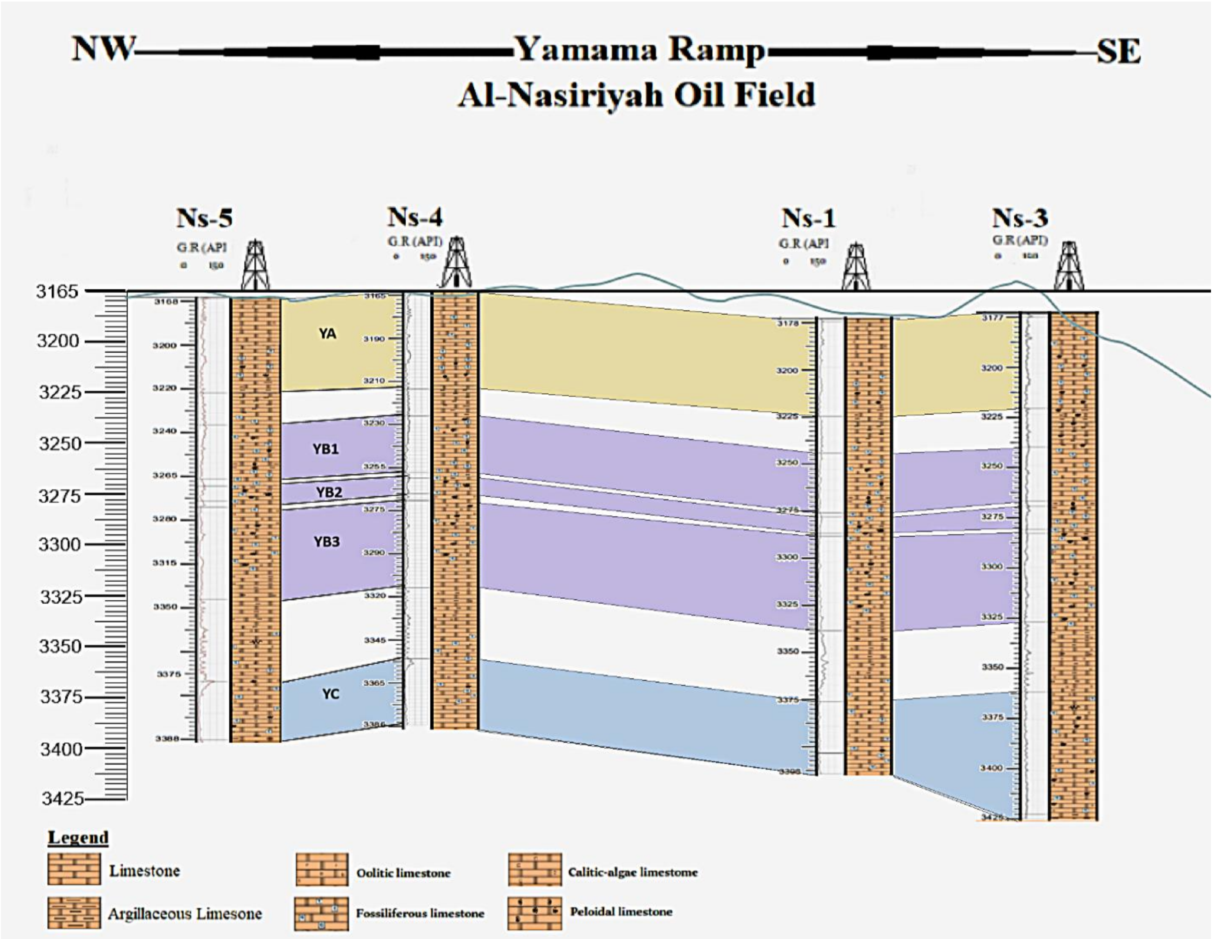

Figure 6. The Gamma Ray and Lithology strata of the study wells.

3.4 Seismic Interpretation Tools

Stratigraphic and structural changes are the two primary categories of geological changes; It is possible to divide teleseismic interpretation techniques into two main categories based on this basis. The travel-time tool and the waveform tool are the two instruments:

1. The travel-time tool uses reflection travel-time computations to identify variations in the depth of reflectors along seismic lines and to map folding and faulting.
2. The waveform tool examines how the spectrum structure of the reflection wavelet is influenced by the physical properties of the rock medium through which the seismic reflection wave has travelled. Using reflection travel-time calculations, the travel-time tool maps folding and faulting and detects changes in reflector depth along seismic lines.
3. The waveform tool analyzes the effects of the physical characteristics of the rock medium traversed by the seismic reflection wave on the spectrum structure of the reflection wavelet. The physical characteristics, lithology, porosity, and fluid content of the rock all affect the wavelet amplitude, frequency, and acoustic impedance. Stated differently, the waveform alterations are a valuable tool for stratigraphic interpretation, **Fig. 7**.

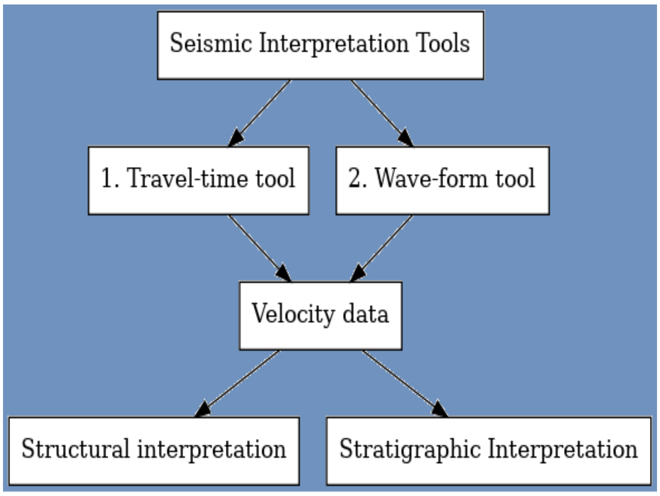

Figure 7. The Seismic Interpretation tools.

3.3.1 Interpretation of Seismic Stratigraphy

The approach described here involves analyzing the variations in the reflection waveform in contrast to the reflection travel time. Determining the various types of stratigraphic features that appear on seismic sections is the primary goal of stratigraphic interpretation. Reefs, sand lenses, facies variations, and irregularities are typical examples of these features. The traveling seismic wavelet holds the signature of each physical characteristic of its path. These alterations brought about by the various characteristics of it make it possible to think of the mineral and fluid contents (water, oil, or gas) as signals that are just awaiting interpretation and the recognition of their geological significance.
Involves combining geology and geophysics to evaluate subsurface geology using seismic data **(Mitchum et al., 1977a, 1977b; Badley, 1985; Sheriff, 1985)**. Seismic facies analysis **(Berg, 1982)** was a valuable component of the field that involved analyzing stratal architecture and reflection geometries to classify them into depositional sequences, thereby inferring seismic lithofacies and interpreting the paleoenvironment **(Mitchum et al., 1977a, 1977b; Roksandic, 1978)**.
Numerous geologists have been drawn to engage in geological research about seismic facies analysis since the birth of sequence stratigraphy. Nonetheless, it has deepened the collaboration between petroleum geologists and geophysicists. While geophysicists began using seismic characteristics in their investigations of wells, outcrops, and seismic data, petroleum geologists independently conducted sedimentological and stratigraphic examinations of these features, as well as hydrocarbon exploration.

3.3.2. Seismic Structural Interpretation

When a reflection occurs in a seismic stack section, its basic structural form is a horizontal reflection horizon free of geometric distortions. In fact, many types of structural distortions often affect reflections.
Linear, horizontal, or curved reflection horizons are all possible. Many levels of folding can impact horizons; **Fig. 5**. In seismic sections, anticlines, syntonic bends, and monotonic bends are the most often seen folding structures. Accordingly, the Yamamah reservoir has been classified as an anticline structure that shows the NW-SE trend. Folding and faulting are the most common forms of reflection horizon distortions.

3.3.3 Seismic Facies and Lithofacies Analysis

At the early stage of this research, seismic facies analysis was developed to study the kinematic and dynamic aspects of seismic imaging, allowing for the scientific inference of geologic features of interest **(Xu et al., 1990; Chopra and Marfurt, 2012**).

Once considered a breakthrough in exploration applications, it has evolved into a dynamic field due to the introduction of several new concepts and interpretive procedures. In terms of basic theory, notable developments have occurred, encompassing refinements in geological and geophysical concepts, including several enhancements to sequence-stratigraphic and facies distribution models.

Seismic facies analysis involves the description and interpretation of seismic reflection parameters, including configuration, continuity, amplitude, and frequency, within the stratigraphic framework of a depositional sequence.

Its purpose is to determine all variations of seismic parameters within third-order sequences and their systems tracts to determine lateral lithofacies and fluid type changes. Of these parameters, reflection pattern geometries are perhaps the most useful for calibration, as they are interpreted from lithofacies derived from well logs, cores, and cuttings. Through reflection characteristics such as geometry, amplitude, and continuity, seismic facies analysis provides a helpful framework for interpreting carbonate platform systems. **Fig. 8** was established by **(Huang et al., 2020)**. According to this method, Huang's descriptions of similar carbonate facies can be used to correlate the seismic facies of the Yamama Formation in the Nasiriyah oil field. The lower Yamama units exhibit continuous, parallel, high-amplitude reflections of the SF1–SF2 types, indicating deposition in a lagoonal or platform interior environment. Progradation along the platform margin and slope is reflected by sigmoidal and oblique clinoform reflectors, which are similar to SF3–SF4 facies. The SF5-like discontinuous, high-amplitude reflectors in the upper Yamama interval could be a dolomitized or karstified platform top. Mound-shaped or chaotic reflection that is locally produced

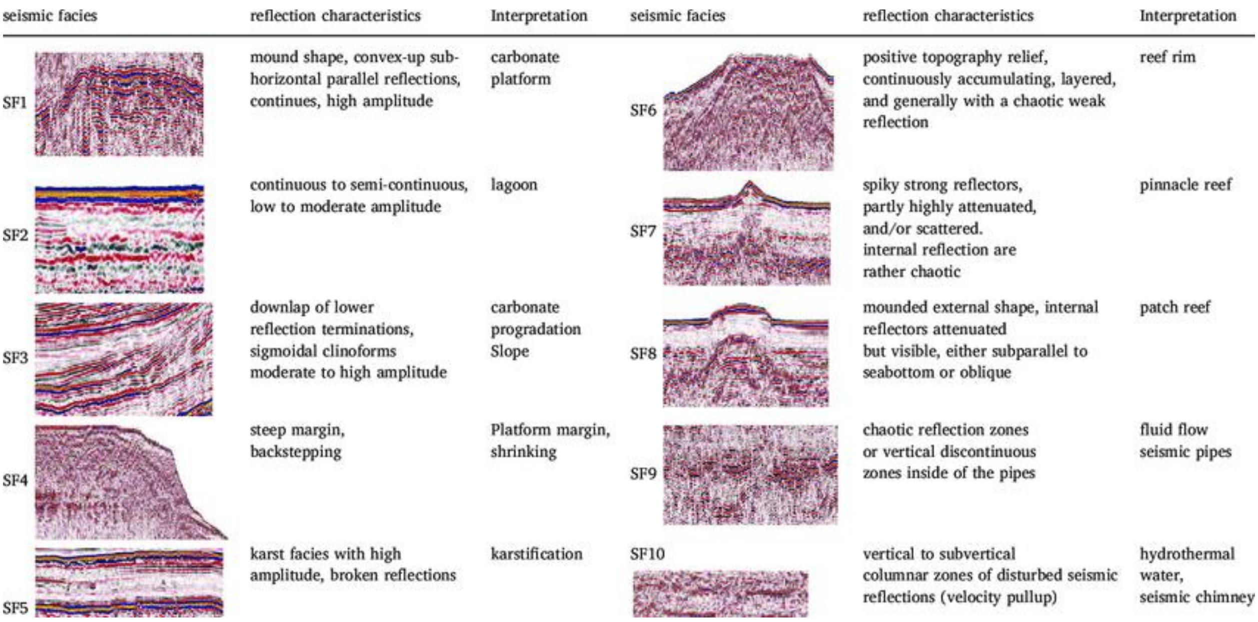

Figure 8. Diagram showing various attributes used in determining seismic facies, modified after **(Huang et al., 2020).**

4. CONCLUSIONS

Integration of 2D seismic and well-log data provided a comprehensive understanding of the Yamama Formation in the Nasiriyah Oil Field. The formation was divided into five stratigraphic units (YA, YB1, YB2, YB3, and YC), separated by impermeable barriers. Among these, units YB3 and YC exhibit the best reservoir quality, characterized by higher porosity and hydrocarbon saturation. Seismic facies analysis identified five main facies types (SF1–SF5), representing lateral variations from platform to slope environments and confirming the heterogeneous depositional nature of the formation. This facies heterogeneity directly controls reservoir distribution and fluid pathways. The integrated interpretation significantly enhances reservoir prediction, reduces geological uncertainty, and supports more effective well placement and development planning. Continued work integrating 3D seismic data and inversion modeling will further refine characterization of the Yamama reservoir and improve future exploration success in southern Iraq.

Acknowledgments

The author acknowledges the help from the Iraq National Oil Company (INOC), Department of Petroleum Engineering at the College of Engineering, University of Baghdad.

Declaration of Competing Interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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التقييم الزلزالي ثنائي الأبعاد للخصائص البترفيزيائية لتكوين يمامة في حقل الناصرية النفطي، جنوب العراق

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الخلاصة

تُعد بيانات الانعكاس الزلزالي إحدى الأدوات الرئيسة في دراسة باطن الأرض وتقييم المكامن الهيدروكربونية، نظراً لقدرتها على إنتاج صور تركيبية طبقية عالية الدقة تكشف التراكيب الجيولوجية والبيئات الرسوبية الحاكمة لحركة وتراكم الهيدروكربونات. وعند دمج هذه البيانات مع سجلات الآبار (Well Logs)، يزداد مستوى الدقة في التوصيف البتروفيزيائي والزلزالي للخزان، ما يقلل من مخاطر الحفر ويرفع كفاءة تطوير الحقول. في هذه الدراسة، تم تحليل سجلات خمسة آبار ضمن حقل الناصرية النفطي في محافظة ذي قار، بالاعتماد على تغطية زلزالية ثنائية الأبعاد ومعالجتها باستخدام برمجيات شلمبرجير المتقدمة. جرى إنشاء السيزموجرامات التركيبية لربط القمم الطبقية لتكوين اليمامة مع انعكاسات الموجات الزلزالية، فيما أسهمت سجلات أشعة غاما والمقاومة الكهربائية في تعزيز عملية الربط الطبقي وتحديد التتابعات الرسوبية الكربوناتية. أظهرت نتائج الربط بين الآبار أن اتجاهات التراكيب وممرات الهجرة تتوافق مع التغاير الطبقي lateral heterogeneity للصخور الخازنة. كما بيّنت النمذجة البتروفيزيائية والزلزالية وجود مناطق غنية محتملة (Sweet Spots) ضمن وحدات اليمامة، خصوصاً الوحدتين YB3 وYC اللتين أثبتتا كونهما الطبقات الرئيسة للإنتاج، وذلك اعتماداً على التحليل المتكامل باستخدام برامج Petrel، Techlog، Kingdom، وDidger. حيث تؤكد هذه النتائج أن دمج السجلات البئرية مع بيانات الانعكاس الزلزالي يمثل منهجاً فعالاً لرفع موثوقية النماذج الجيولوجية وتوجيه عمليات الاستكشاف والتطوير، فضلاً عن تحسين استراتيجيات إنتاج واسترداد الهيدروكربونات في الحقل مستقبلاً.

الكلمات المفتاحية: مكمن اليمامة، المخطط الزلزلي الاصطناعي، التفسير الزلزالي، الخصائص البترفيزيائية، مجس اشعة جاما