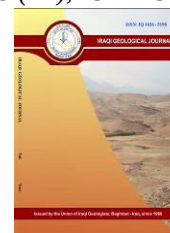




Iraqi Geological Journal

Journal homepage: <https://www.igi-iraq.org>



Structural Interpretation of Seismic Reflection Data of the Tanuma Formation in the East Baghdad Oil Field, Central Iraq

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Received:
13 April 2026
Accepted:
19 July 2026
Published:
31 August 2026

Abstract

This study includes a structural interpretation of the Tanuma Formation using 3D seismic survey data from the South-2 region of the East Baghdad oil field in central Iraq, south of the Diyala River. The research aims to define the subsurface structural framework of the formation and identify the main geological features influencing it. The data were loaded in SEG-Y format using the GeoFrame system. A check-shot survey was applied for the calibration of the time curve with depth using sonic and velocity logs, for the purpose of correcting the time values of the sonic log according to the field velocity survey, and a synthetic seismogram was generated for well EB-15 to establish a reliable time–depth relationship and ensure accurate well-to-seismic correlation. The results show a good match between the synthetic seismogram and seismic sections, allowing precise identification of formation boundaries. Structural interpretation based on seismic sections, two-way time map, velocity map, and depth map indicates that the structural picture of the field is characterized by an open structural nose trending northwest. The structure is influenced by normal faults parallel to the structural direction and also by transverse faults extending east–west, contributing to the formation of multiple structural closures. Seismic attributes, including the Variance Attribute and Instantaneous Phase, were used to identify faults and reflector continuity. The geological complexity of the region provides favorable conditions for the migration and accumulation of hydrocarbons.

Keywords: Tanuma Formation; East Baghdad oil field; Structure interpretation; Seismic attributes; Depth map

1. Introduction

The East Baghdad Oil Field is one of the most important oil fields in central Iraq and constitutes an important part of the Mesopotamian Basin petroleum system. Due to its economic significance and complex geological setting, the field has attracted considerable attention from researchers and exploration companies. Numerous geological and geophysical investigations have been carried out to improve the understanding of its subsurface architecture and hydrocarbon potential. Seismic reflection studies have been widely employed in the East Baghdad Oil Field for both structural and stratigraphic interpretation. Several seismic studies have been conducted to understand the structural framework, fault systems, structural closures, and stratigraphic geometry of different reservoir units of the East Baghdad Oil Field (Khorshid and Kadhm, 2015; Darweesh et al., 2017; Khorshid et al., 2017; Al-Sadi, 2021). The Tanuma Formation is considered one of the important Upper Cretaceous units within the petroleum system of central Iraq. Several investigations have addressed different aspects of the

DOI: <https://doi.org/10.46717/igj.2026.59.2B.8>

formation, including source-rock characteristics, sedimentology, microfacies, diagenesis, petrophysical properties, and rock-physics applications (Al-Ameri, 2011; Al-Majid, 2021). These studies have provided valuable information regarding the geological characteristics and petroleum significance of the formation. However, despite the large number of seismic interpretation studies conducted in the East Baghdad Oil Field and the various geological investigations carried out on the Tanuma Formation, detailed seismic structural studies specifically targeting the Tanuma Formation remain limited. Consequently, the structural configuration and fault architecture of the formation are still not fully understood within the study area. Therefore, the current study aims to delineate the structural framework of the Tanuma Formation using seismic reflection data and to examine the relationship between the structural configuration of the formation and hydrocarbon accumulation in the East Baghdad Oil Field.

2. Location of the Study Area

The East Baghdad Oil Field is located in central Iraq, approximately 20 km east of Baghdad City (Fig. 1). The field lies south of the Diyala River within the eastern part of the Mesopotamian Basin. Geographically, it extends in a northwest–southeast direction and is commonly subdivided into six sectors: North Extension, Al-Taji, Al-Rashdiya, Urban, South-2, and South-1. The present study focuses on the South-2 sector, which occupies the southern part of the field. The study area is situated within the Arabian Plate and forms part of the Mesopotamian Foredeep Basin (Jassim and Goff, 2006). Table 1 illustrates the UTM coordinates of the study area.

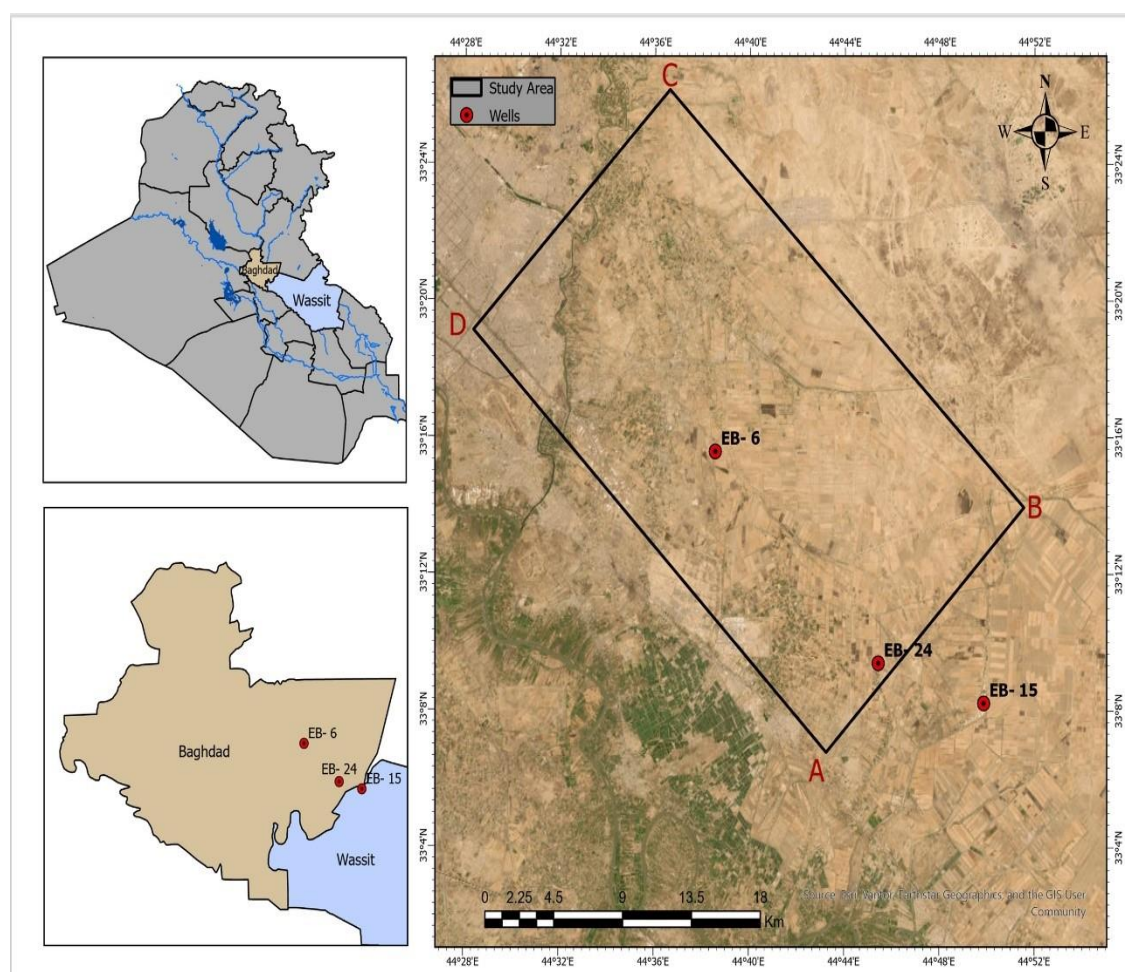


Fig. 1. Location map of the study area

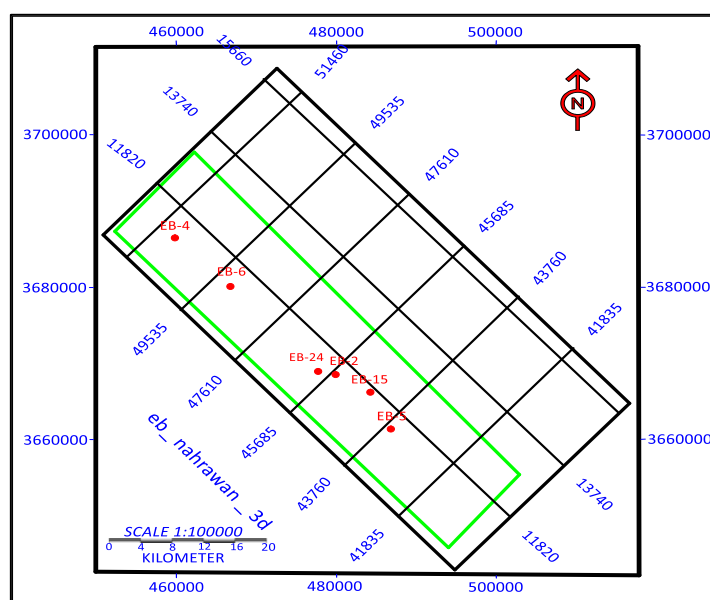
Table 1. The UTM coordinates of the study area

Point	Northing(m)	Easting(m)
A	3666013.355	471688.611
B	3678991.931	484590.887
C	3686705.372	450873.453
D	3699683.514	463775.04

3. Materials and Methods

An interactive workstation, a high-powered computer with specialized software, was used to interpret the seismic data accurately and efficiently. In the current study, the following data were utilized and uploaded to the GeoFrame/IESX system:

1. The 3D seismic data for the southern East Baghdad Oil Field (South-2 area) were loaded in SEG-Y format into the interpretation system. This step involved defining the inline and crossline boundaries and grid cell dimensions.
2. Data from the EB-15 well were loaded as a primary reference for establishing a dependable time–depth relationship. Well data included records (formation tops, check shots, sonic log, and density log).
3. A base map was constructed (Fig. 2) illustrating the study area boundaries.
4. Due to the low quality of the Two-Way Time (TWT) map and velocity map, a reprocessing procedure was carried out. The map was digitized using Didger software to accurately extract spatial data. After that, the digitized data were processed and re-plotted using Surfer software to produce high-resolution contour maps, and the depth map was created using Petrel software.

**Fig. 2.** Base map of the study area

3.1. Check-Shot Survey

GeoFrame/IESX was used to create the synthetic seismogram for well EB-15 by importing and calibrating the acoustic and velocity logs to establish a dependable time–depth relationship. Table 2 from the IESX system shows the dependent depth and time values derived from formation logs, field

survey velocity, and processed depth values referenced to sea level, penetrating formations. This serves as a reference surface for the 3D data of the study area.

Table 2. The marker information of well EB-15

Name	Borehole Name	Type	MD (m)	TVD (m)	TWT (ms)	TVDSS (m)	Source
Tanuma	EB_15	Strat_Marker	2455	2455	1566.98	2420.5	Gal Loader
Khasib	EB_15	Strat_Marker	2547	2547	1614.79	2512.5	Gal Loader
Kifl/Rumaila	EB_15	Strat_Marker	2661	2661	1677.31	2626.5	Gal Loader
Chak(1)	EB_15	Strat_Marker	2792	2792	1725.61	2757.5	Gal Loader
Ahmadi	EB_15	Strat_Marker	3066	3066	1827.02	3031.5	Gal Loader
Mauddud	EB_15	Strat_Marker	3081	3081	1832.4	3046.5	Gal Loader

Calibration is an important step in aligning well log data and seismic reflections to achieve a better match. The current study's results showed that the calibrated sonic data and the seismic response were quite similar. This improved seismic interpretation accuracy and facilitated the identification of formation boundaries (Fig. 3).

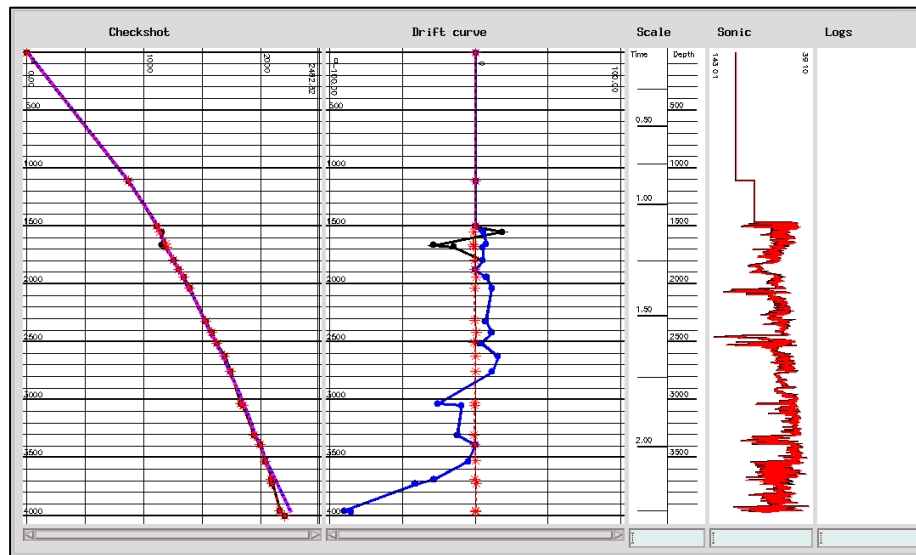


Fig. 3. The time-depth curves after calibration of check-shot curves for East Baghdad Well-15

3.2. Synthetic Seismogram Generation

Synthetic seismograms were generated for East Baghdad Well-15 using the GeoFrame software package. Synthetic seismograms are referred to in Lindseth (1979) and Sheriff and Geldart (1995) as involving the following main steps for their generation, which are:

1. Calculate the acoustic impedance by using following equation

$$Z = \rho \times v.$$

Where:

Z :Acoustic Impedence

v: Seismic velocity.

ρ : Is density measured using density logs

2. Calculating the reflection coefficients of vertically incident waves on reflectors separated by time intervals (i) and (i+1), with acoustic impedance values ($\rho_i \cdot v_i$) and ($\rho_{i+1} \cdot v_{i+1}$), respectively. The wavelet used to produce the synthetic seismogram was chosen experimentally. The sonic log data were

compared to the well velocity survey, which is a direct approach for measuring the geological velocity (average velocity) of geological layers. The synthetic seismogram traces for the East Baghdad well EB-15 were constructed using IESX software (synthetic programs). These programs derive the relationship between time and depth functions at the well site. This relationship is critical in defining the seismic section and the synthetic trace's reflection on a time axis against the well's required bed. The sonic logs were translated from the depth domain to the time domain using the given check shots, and synthetics were generated using the calculated reflectivity series by convolving these coefficients with a chosen source wavelet. After that, calibration was performed on the synthetic seismic section (Fig. 4). The figure shows an excellent match between the seismic section and the synthetic seismogram. The continuity of reflectors in the seismic section (Fig. 5), which passes through well EB-15, matches the synthetic trace. The synthetic seismogram generated for well EB-15 indicates that the Tanuma Formation is characterized by a peak reflection on the synthetic seismogram (Fig. 4). This behavior is attributed to the variation in physical properties between the limestone and shale units, particularly the difference in acoustic impedance, which leads to a positive reflection coefficient at the interface.

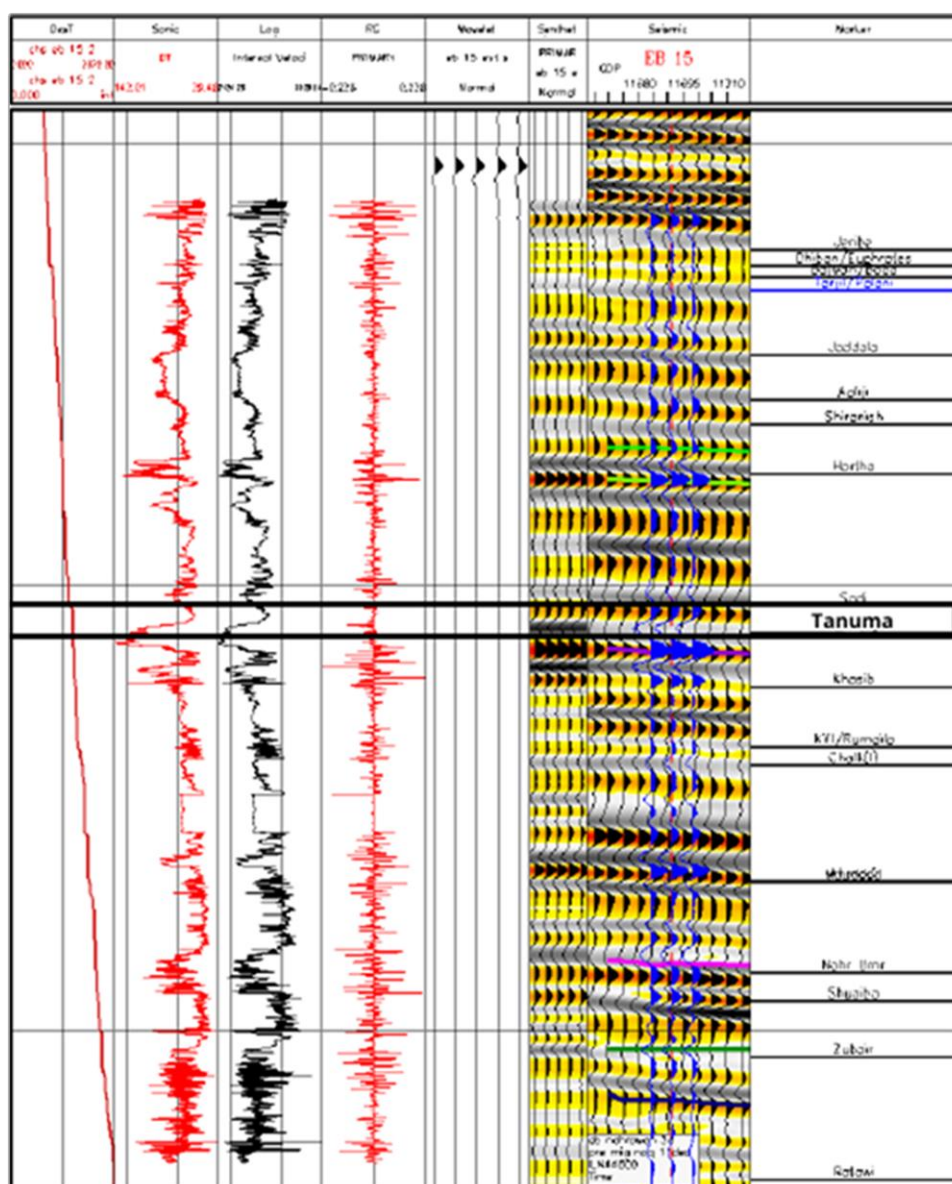


Fig. 4. Synthetic seismograms of the well EB-15

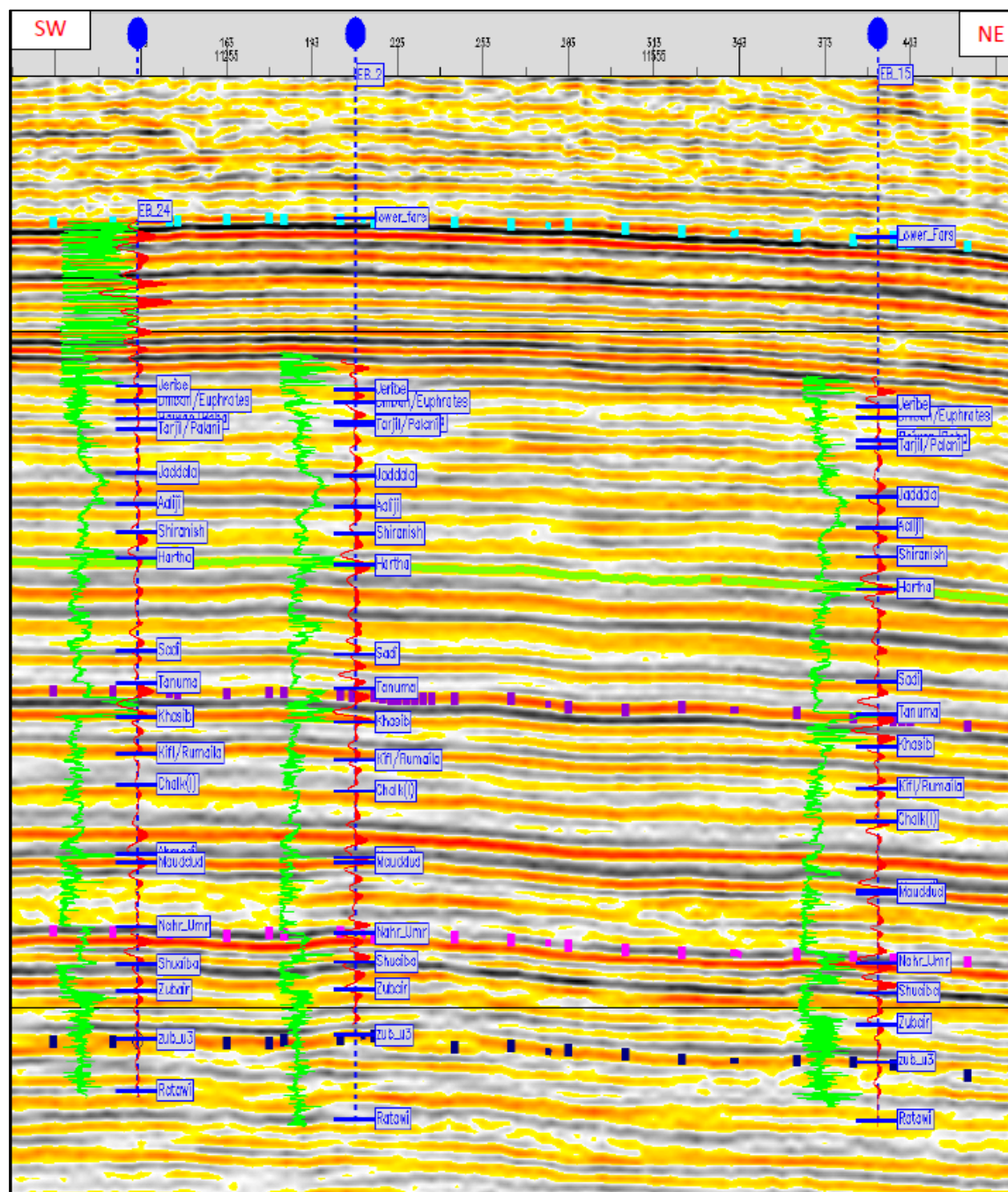


Fig. 5. Seismic section illustrates the continuity of reflectors across wells EB-15 and EB-2, which corresponds perfectly with the synthetic trace

4. Results and Discussion

4.1. The Two-Way Time (TWT) Map

The two-way time (TWT) map for the upper Tanuma Formation was prepared at a scale of 1:100,000 using a specialized mapping program (CPS-3), with a contour interval of 10 milliseconds, and sea level was used as the reference datum (Fig. 6). The map shows lower values of TWT (1440 ms) toward the northwestern part of the study area, indicating a structural high, whereas higher values of TWT (1650 ms) occur toward the east and northeast of the study area, reflecting gradual regional dip trends in that direction. The TWT map suggests that the structural image of the formation is an

asymmetrical anticline trending in a NW–SE direction, which is consistent with the regional structural style of the Mesopotamian Basin and reflects the influence of the regional tectonic framework generated by the convergence between the Arabian and Eurasian plates (Jassim and Goff, 2006). The structure is affected by several normal faults (N1–N13) and transverse faults (T1–T3), which disrupt the continuity of the reflector and divide the field into structural blocks. These faults are interpreted as tectonic features related to basement reactivation and regional deformation, and they likely influenced hydrocarbon migration and trap development within the field.

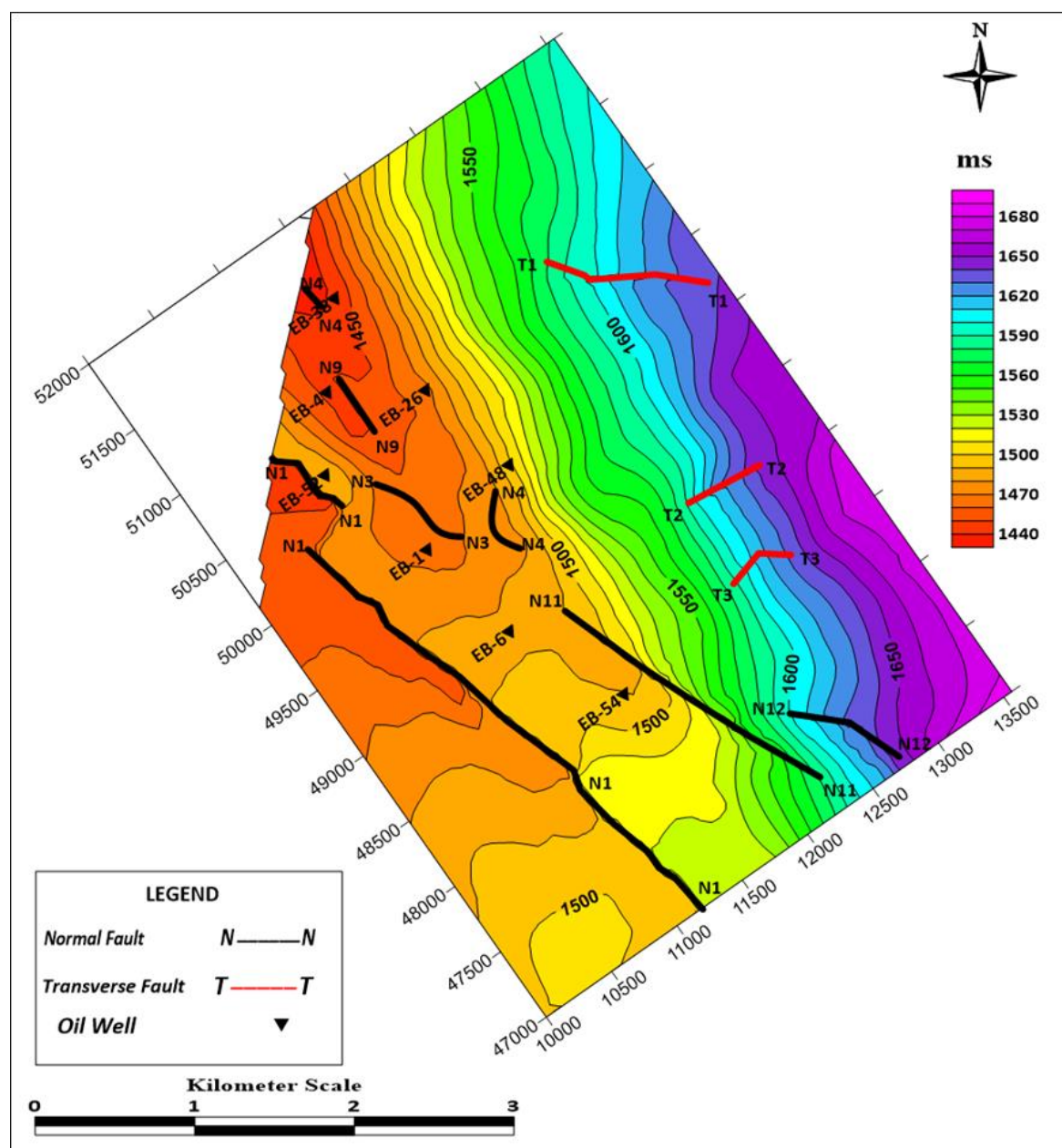


Fig. 6. Two-Way Time map for the upper Tanuma Formation generated after digitizing the original map using Didger software

4.2. Velocity map

The critical parameter for the conversion of two-way time maps to depth maps is average velocity. According to McQuillin et al. (1984), it is considered the most accurate velocity type in seismic methodologies and is directly determined through well velocity surveys (check-shots). The velocity map

for the upper Tanuma Formation was prepared at a scale of 1:100,000 with a contour interval of 50 m/s, referenced to mean sea level (Fig. 7). The average velocity map shows higher velocity values exceeding 3150 m/s concentrated in the central part of the field, while lower velocities characterize the surrounding area. The observed velocity distribution reflects the lateral variations in rock properties and structural position. The increase in seismic velocity is interpreted to result from reduced porosity due to compaction, cementation, and diagenetic alteration within the Tanuma Formation. Similar relationships between seismic velocity and rock properties have been documented in carbonate rocks (Mavko et al., 2009; Al-Awsi et al., 2021). In addition, fault-controlled fluid circulation may have contributed to localized diagenetic alteration and velocity variation.

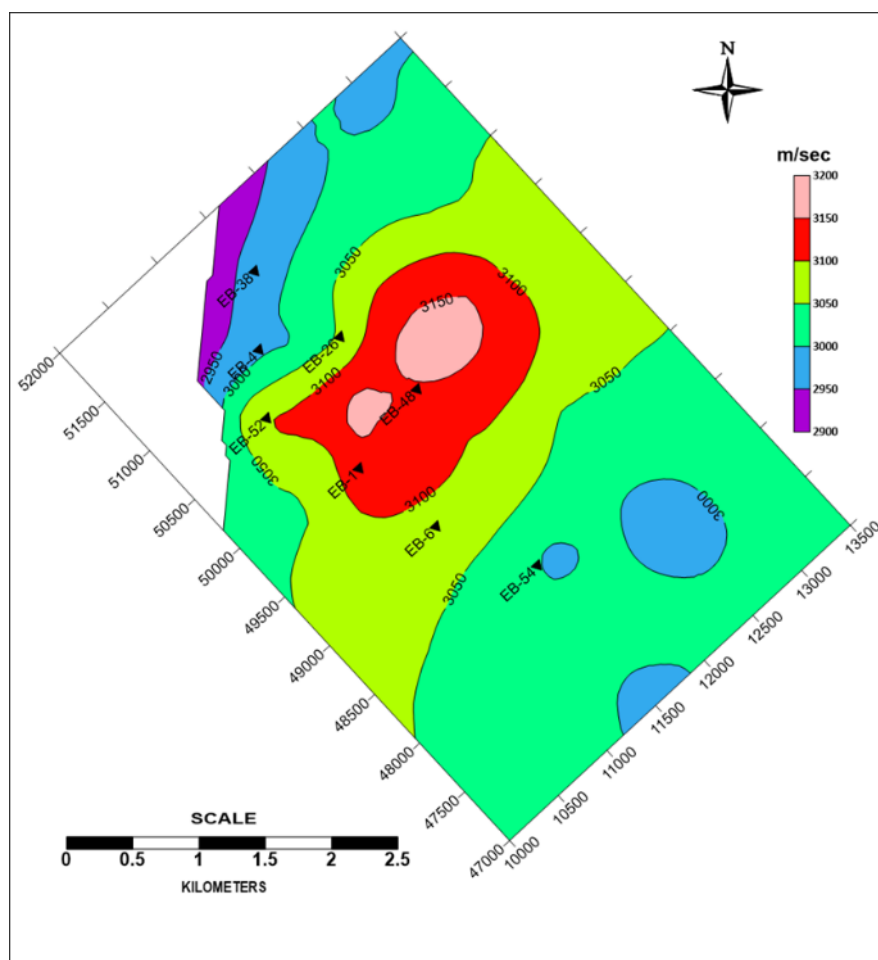


Fig. 7. Average velocity map of the top of the Tanuma Formation generated after digitizing the original map using Didger software

4.3. Depth Map

The depth map of the upper Tanuma Formation, prepared at a scale of 1:100,000 with a contour interval of 20 m, was constructed using the equation below, based on the time map and average velocity map described above.

Depth at any point = one-way time $\times$ average velocity at this point

The depth range of the top of the Tanuma Formation in the study region is between 2220–2700 m. The map shows that the formation takes the form of an open structural nose trending northwest–southeast (Fig. 8). The depth map confirms the structural framework identified on the TWT map. The upper Tanuma horizon becomes deeper toward the eastern part of the field, whereas shallower depths occur in the northwestern part. This geometry defines an asymmetrical anticline with a relatively gentle

western flank and a steeper eastern flank. The map also indicates the presence of several local transverse faults trending east–west and northeast–southwest, which cut across the normal faults and affect the lateral continuity of the formation. Such fault systems are common in central Iraqi oil fields and play an important role in controlling reservoir architecture and hydrocarbon accumulation.

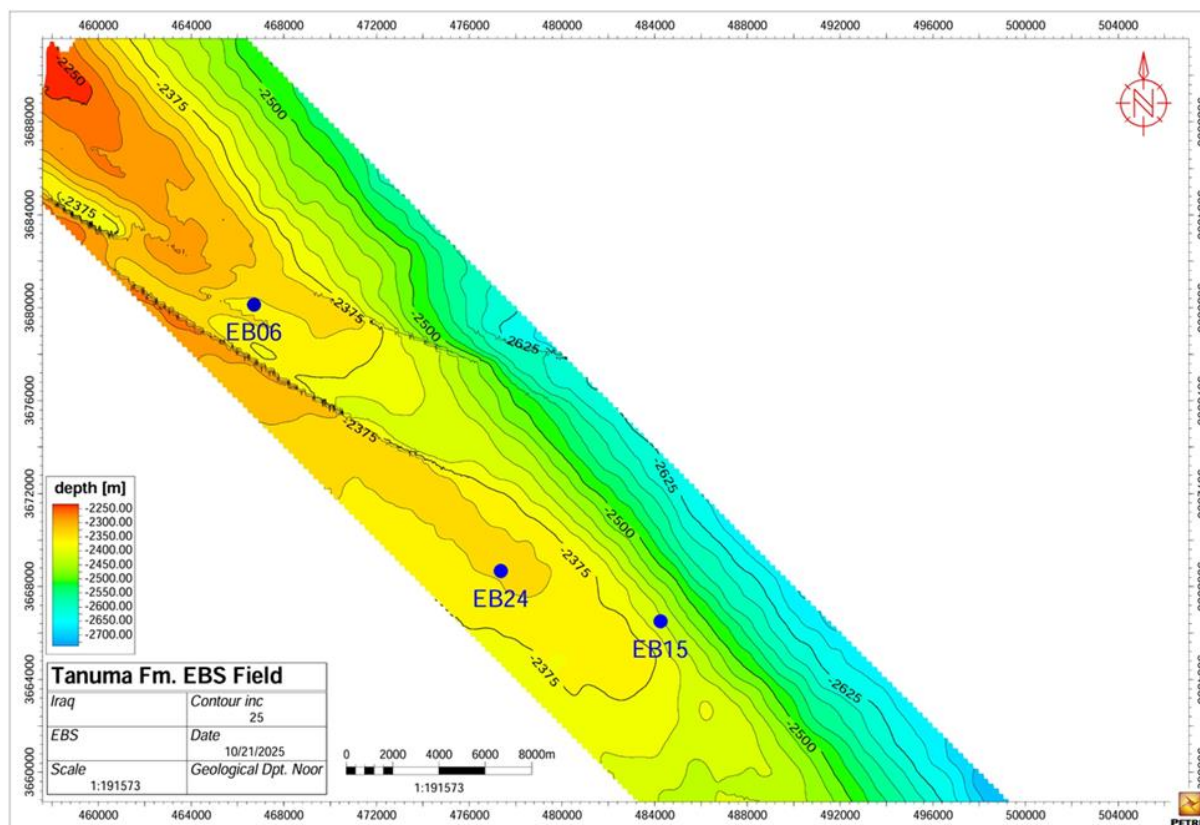


Fig. 8. Depth map of the top of Tanuma Formation

4.4. Seismic Attributes

Only two seismic attributes provided by the Oil Exploration Company, namely the Variance and Instantaneous Phase attributes, were applied to support the structural interpretation of the Tanuma Formation, as follows:

4.4.1. Variance attribute

The variance attribute was applied to a two-way travel time (TWT) slice at 1444 ms for the Tanuma Formation (Fig. 9). This attribute effectively highlights discontinuities and abrupt changes in seismic reflectors caused by fault displacement, allowing for clearer identification of fault patterns within the study area. The variance map reveals several major longitudinal faults trending northwest–southeast, which extend across large portions of the study area and represent the dominant structural elements within the Tanuma Formation. These faults display good lateral continuity, indicating significant tectonic influence during or after the deposition of the formation. In addition, a set of transverse faults with east–west and northeast–southwest orientations is clearly observed, particularly concentrated in the northeastern part of the study area. These transverse faults segment the longitudinal faults into distinct structural blocks, resulting in a complex fault network.

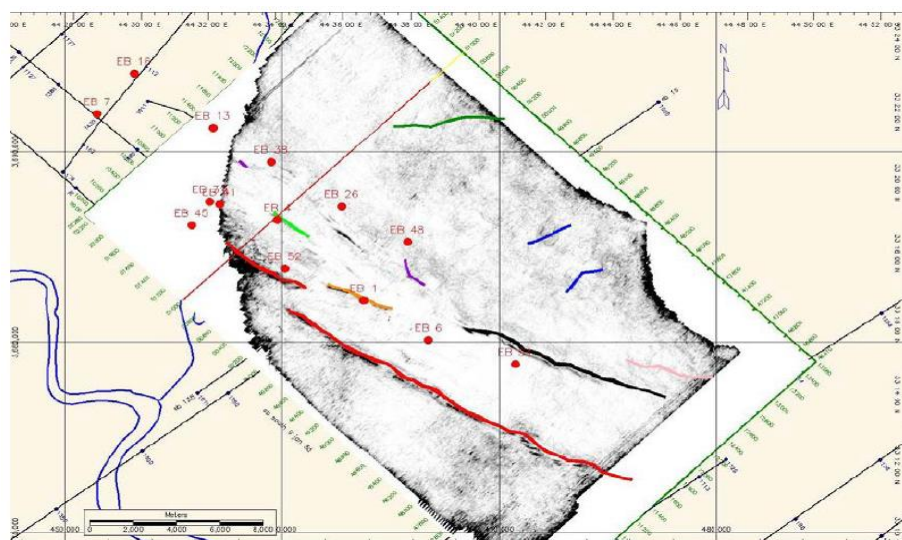


Fig. 9. Variance attributes at 1444 milliseconds for the variance attribute of the top surface of the Formation of Tanuma

4.4.2. Instantaneous phase

Measured in degrees ($-\pi$ to π), instantaneous phase is independent of amplitude and shows the continuity and discontinuity of events, as well as excellent bedding. In theory, the phase along a horizon should not vary, but it may if there is a picking issue or if the layer shifts laterally as a result of sinkholes or other events (Taner and Sheriff, 1977). The instantaneous phase sections of the Tanuma Formation show clear lateral continuity of seismic reflectors across most of the section, where the events appear relatively parallel and consistent. The upper and lower boundaries of the formation are distinguished by noticeable changes in phase values and reflector patterns at the contacts with the overlying Sadi Formation and the underlying Khasib Formation (Fig. 10). The instantaneous phase sections also reveal localized zones of discontinuity and distortion within the Tanuma Formation, particularly near major faults, where abrupt phase changes and disruption of reflector continuity assist in accurately identifying fault locations.

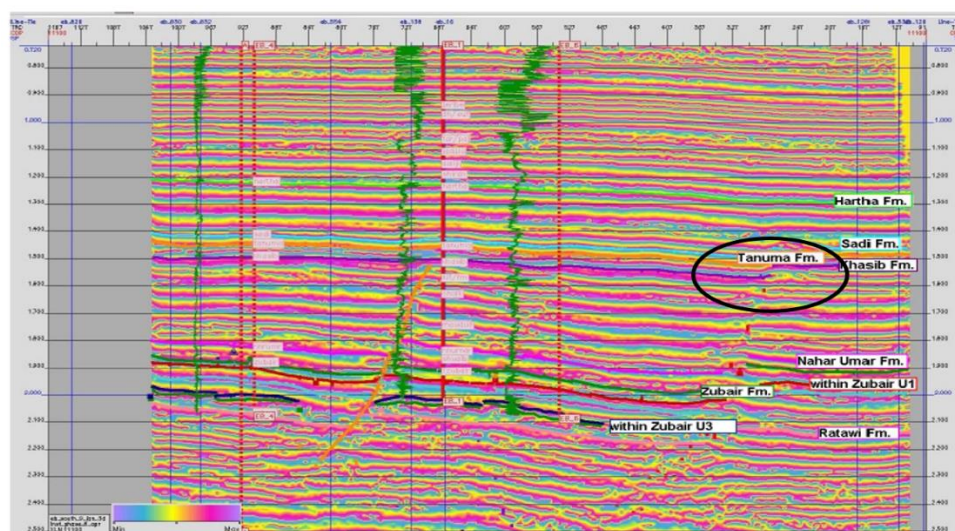


Fig. 10. Vertical section of line 11100 for the seismic attribute Instantaneous Phase, passing through wells EB-4, EB-1, and EB-6. The section shows changes in phase at the level of the reservoir units.

5. Conclusions

The Tanuma Formation represents an Upper Cretaceous succession deposited within the Mesopotamian Basin. The structural interpretation of seismic data indicates that the upper Tanuma Formation in the East Baghdad Oil Field is represented by a northwest–southeast trending elongated asymmetrical anticline affected by several normal and transverse faults. This anticline structure is consistent with the regional structural style of the Mesopotamian Basin and reflects the influence of the regional tectonic framework generated by the convergence between the Arabian and Eurasian plates, where subduction of the Arabian Plate beneath the Eurasian Plate has occurred. The structure becomes deeper toward the eastern part of the field, whereas shallower depths occur in the northwestern part.

The average velocity map shows an irregular velocity distribution, with higher velocities concentrated in the central part of the field, while lower velocities characterize the surrounding area. The observed velocity distribution reflects the lateral heterogeneity of carbonate Tanuma Formation rock properties and structural position. The increase in seismic velocity is interpreted to result from facies variation, reduced porosity due to compaction from possible overburden effects, cementation, and diagenetic alteration within the Tanuma Formation.

The structural framework of the Tanuma Formation is influenced by normal and transverse faults that interrupt the continuity of the reflector. Seismic attributes further support this interpretation. The variance attribute effectively highlights reflector discontinuities, making fault patterns more distinguishable, while the instantaneous phase sections show reflector continuity and highlight changes in phase around faulted zones and at formation boundaries. These faults appear to have influenced the development of the structure and may have played a role in controlling hydrocarbon migration and accumulation.

Declaration of Competing Interest

We declare that the authors have no competing financial interests or personal relationships that could have influenced the work reported in this study.

Acknowledgments

The authors express their gratitude to the Ministry of Oil and the Oil Exploration Company for providing the necessary data and reports required to complete this study. The authors extend their sincere thanks to the Department of Petroleum and Mineral Geology for supporting this research. The authors are also grateful to the editors and reviewers for their efforts in revising this manuscript and for providing constructive comments, which have significantly improved the clarity and quality of the work.

Funding sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sector.

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