

## Geometry and Tectonic History of West Qurna-1 Structure, Southern Iraq, Mauddud Carbonate Reservoir as Case Study

Maysaa A. Abdulhameed<sup>1</sup>, Fahad M Al-Najm<sup>2</sup> and Maher M Mahdi<sup>2\*</sup>

1 Basra Education Directorate, Basra, Iraq

2 Department of Geology, College of Science, University of Basra, Basra, Iraq

\* Correspondence: [maher.mahdi@uobasrah.edu.iq](mailto:maher.mahdi@uobasrah.edu.iq)

Received:  
23 January 2024

Accepted:  
9 March 2024

Published:  
31 May 2024

### Abstract

West Qurna 1 is a portion of the supergiant anticline that extends more than 120 km. This elongated anticline contains, from north to south, West Qurna 2, West Qurna 1, North Rumaila, and South Rumaila. The Mauddud reservoir in the West Qurna 1 oilfield has only been subjected to very few studies, as the vast majority of the studies were concentrated on the main reservoir, which is the Mishrif reservoir, in addition to the Zubair and Yammama reservoirs. The current study attempts to incorporate all available data to better understand the subsurface structure of the Mauddud reservoir in West Qurna I. First, the well tops for each unit within the Mauddud reservoir have been picked from 25 wells that were well dispersed over the entire study area. All data, including well tops and 3D seismic interpretation reports, were used to build structural maps for each unit including: Upper Mauddud A, Upper Mauddud B, Lower Mauddud A, Lower Mauddud B, Lower Mauddud C, and Top of Nahr Umer Formation. Finally, the study concludes that the Mauddud structure in West Qurna 1 was classified as a gentle, approximately asymmetrical, anti-form, horizontal, non-cylindrical, brachy anticline. The structures within the Zubair subzone were formed due to multiple geological factors, including the Alpine orogeny resulting from the collision between the Arabian and Eurasian plates, salt tectonics associated with the Infra-Cambrian Hormuz Formation, and movements of basement rocks. The development of subsurface structures is collectively influenced by the interplay of various factors, including the Alpine orogeny, basement faults affecting anticlines, and salt tectonics shaping salt structures.

**Keywords:** Fold classification; West Qurna 1 Oilfield; Geometric analysis; Structural analysis, Iraq

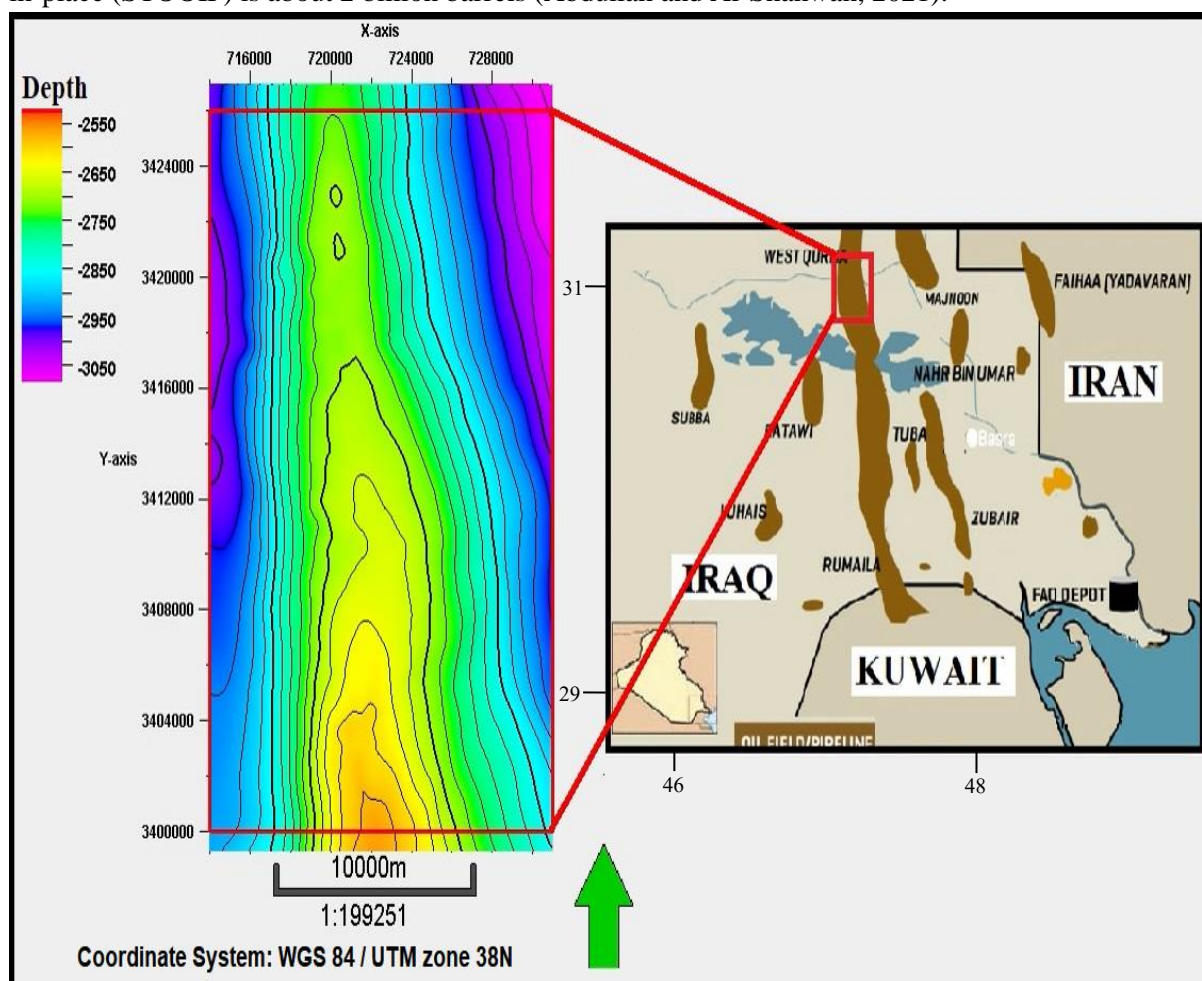
### 1. Introduction

The West Qurna 1 (WQ1) oilfield is considered one of the supergiant oilfields in Mesopotamia hydrocarbon province, Southern Iraq (Abdullah et al., 2018). According to World Oil and Journal of Petroleum Technology, the West Qurna Oil Field (southern Iraq) has a potential of 21 billion barrels of oil reserves within the Cretaceous units (Mahdi et al., 2022). The potentiometric map in the West Qurna oilfield indicated high potential sites that are of great importance for migration and accumulation (Awadh et al., 2019). West Qurna 1 oilfield is geographically located approximately 50 km Northwest of Basra city (Fig.1). The study area covered approximately 442 km<sup>2</sup>. Clay and alluvial sediment covered most of the study area (Abdullah et al., 2022). The field presents the dome that extend with Rumaila oilfield direction, although the third dome is currently delineated as West Qurna oilfield, from a structural perspective, it is inherently connected to the northern Rumaila anticline (Al-Kaabi et al.,

DOI: [10.46717/igi.57.1E.15ms-2024-5-26](https://doi.org/10.46717/igi.57.1E.15ms-2024-5-26)

2023). The main trend of the field is N–S, with the western limb being steeper than the eastern limb (Mahdi et al., 2023).

Several oil reservoirs have been discovered within the West Qurna 1 oilfield in the Cretaceous Period, from the oldest to the youngest: Yammama, Zubair, Mauddud, Khasib, and Sa'adi (Aqrawi et al., 2010; Lazim et al., 2023). Fig. 2 illustrates the stratigraphic column in the West Qurna 1 oilfield. After the 2D seismic survey in 1972, then the first exploration was drilled in 1973, while drilling of appraisal and development wells has continued to until this day. A (3D) seismic survey was performed in 2012–2013 by Western Geco Company. Production commenced in WQ1 in 1990 from Mishrif, Zubair, and Sa'adi reservoirs (Abdullah et al., 2018). The Mauddud reservoir in the West Qurna 1 oilfield is considered a tight carbonate reservoir. The porosity units in the Mauddud reservoir is approximately 10-25%, with a permeability range between 1-100 mD, and the stock tank oil originally in-place (STOOIP) is about 2 billion barrels (Abdullah and Al-Shahwan, 2021).



**Fig.1.** Location map of the study area, West Qurna 1 structure, Southern Iraq

The latest tectonic classification of Iraq, as outlined by Fouad (2015), situates the study area within Mesopotamia's Outer Platform. The predominant component of the Zagros foreland basin is the foredeep, characterized as a predominantly flat terrain overlaid with marine and continental deposits from the Miocene to the Holocene epochs. The Mauddud tight carbonate Formation is part of the Albian-Early Turonian Sequence (Wasi'a Group), which is considered the upper part of the Late Tithonian-Early Turonian Megasequence (AP8) (Jassim and Goff, 2006). The studied formation extends across Iraq, Kuwait, and Saudi Arabia including the Late Tithonian-Early Turonian Megasequence (AP8). The upper contact of the Mauddud Formation represents a conformable (gradation) contact with overlying

Ahmadi Formation, and the contact of the Mauddud Formation represents a conformable (gradation) contact with underlying Nahr-Umer Formation (Fig. 2). (Strohmenger et al., 2006), however described the Mauddud sequence stratigraphic framework, where the lower part of Mauddud Formation represents the Transgressive Systems Tract (TST), while the upper part of Mauddud Formation represents the Highstand Systems Tract (HST), and they are separated by the Maximum Flooding Surface (MFS).

Age		Formation	Lith.	WQI
Period	Epoch			
Cretaceous	L Miocene-Recent	Dibdibba		
		Fatha		
	E-M Miocene	Ghar		
		Dammam		Aquifer
	Paleocene-Early Eocene	Rus		
		Umm-Er-Radhuma		Aquifer
		Tayarat		Aquifer
	Late Cretaceous	Shiranish		
		Hartha		
		Sa'adi		Reservoir
Tanuma				
Khasib			Reservoir	
Mishrif			Reservoir	
Middel Cretaceous	Ahmadi			
	Mauddud		Reservoir	
	Nhr Umr		Aquifer	
	Shuaiba			
Early Cretaceous	Zubair		Reservoir	
	Ratawi			
	Yammam		Reservoir	
Jurassic	U-Jurassic	Sulaiy		

Fig.2. Stratigraphic column in the West Qurna 1 Oilfield (Abdullah, 2021)

Numerous fold classifications could be utilized to define a single fold (Al-Kubaisi and Lazem, 2016). To achieve the classification in this study, specific geometric characteristics were used. The geometric parameters that employed in this work are fold dimensions, fold symmetry, fold orientation, fold tightness, and fold facing. Fig. 3 shows the geometric parameters of the fold.

In the context of earlier research, comparable studies have been conducted in different domains, as evidenced by works such as those by Al-kubaisi and Lazim, 2016; Jafar, 2018 and Al-Kaabi et al., 2023. However, it's noteworthy that a distinctive study by; Abdullah and Al-Shahwan, 2021) specifically focuses on the same field, albeit targeting a distinct formation—the Khasib Formation. This study is pioneering in its objective to comprehensively unravel and categorize the intricate structural facets of the West Qurna Dome. It aspires to delve into every nuance of the structural features.

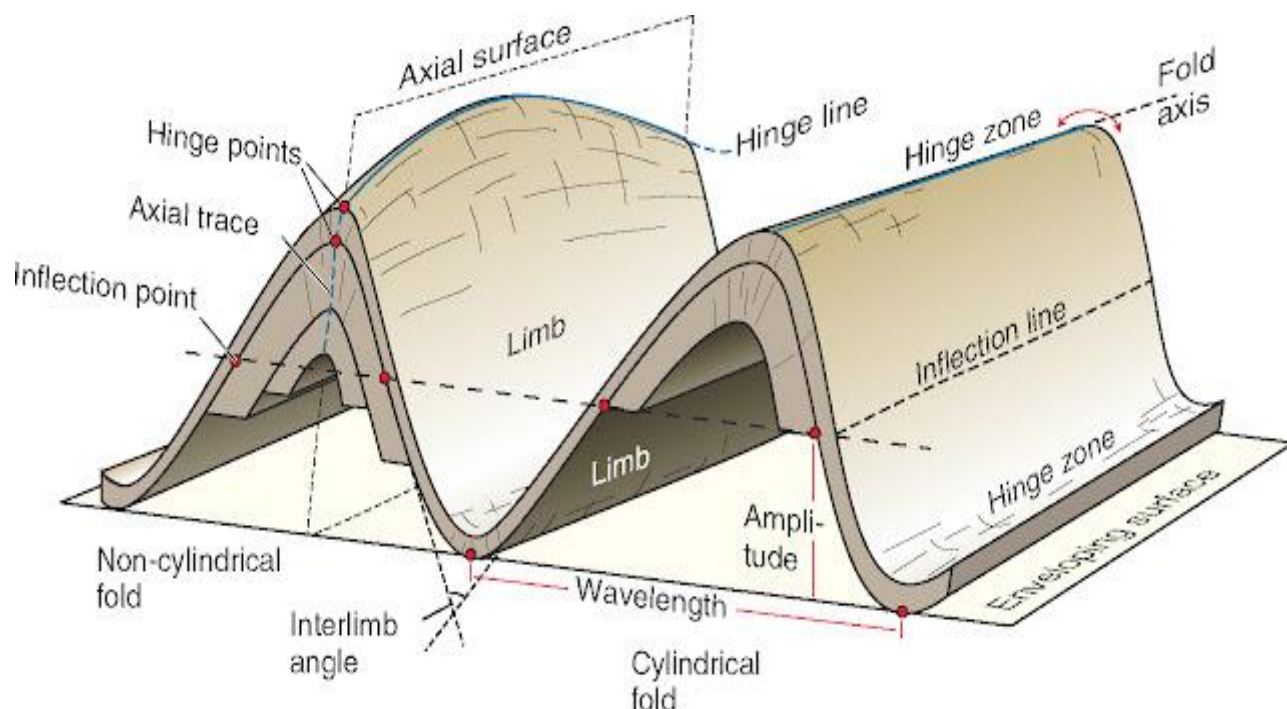
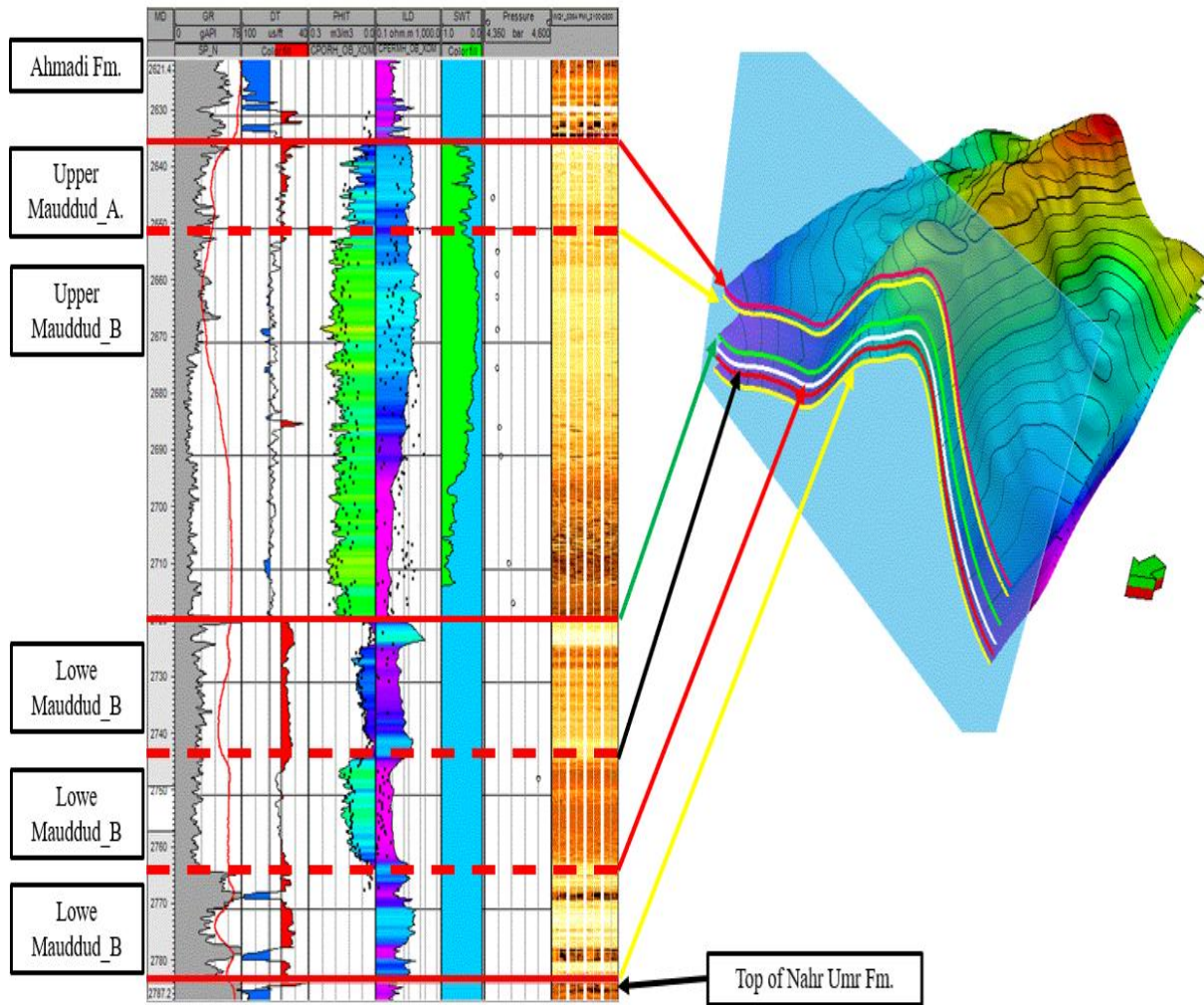


Fig.3. Geometric parameters of the fold Fossen, 2010)

## 2. Methodology

Information was extracted from a total of 25 wells strategically positioned across the crest regions of the fold and along the peripheries of the field. However, the specific locations and identities of these wells have been kept confidential as the Basra oil company lacks the authorization to disclose such information. Different sources of data have been analyzed to subdivide the Mauddud Formation into various units. According to the open-hole logs response, cutting description, and core description, the Mauddud Formation has been divided into two members, which are Upper Mauddud and Lower Mauddud. The Upper Mauddud is subdivided into Upper Mauddud\_A and Upper Mauddud\_B, as well as the Lower Mauddud, which is also subdivided into Lower Mauddud\_A, Lower Mauddud\_B, and Lower Mauddud\_C. Fig. 4 illustrates the different units within the Mauddud Formation. To build an accurate structural framework, structural contour maps have been created using Petrel software for all rock units within the Mauddud Formation in addition to the top of the underlying formation (Nahr-Umer Formation). A lot of data was uploaded to the Petrel software, such as well tops, well logs, well headers, well deviation, and model boundaries. First of all, the well tops have been determined from the well logs which available in all wells that have been used in this study, and then some data editing must be done; therefore, stratigraphic well correlations are used to make little adjustments to the well tops. The structural maps were built using different geostatistical algorithms that are available in Petrel software, such as Gaussian, Kriging, Convergent Interpolation, Minimum Curvature, Moving Average, etc., and then the unique geostatistical algorithm (convergent interpolation) was applied to create Petrel surfaces. These surfaces (3D structure maps) could be used to analyze the structure of the study area.



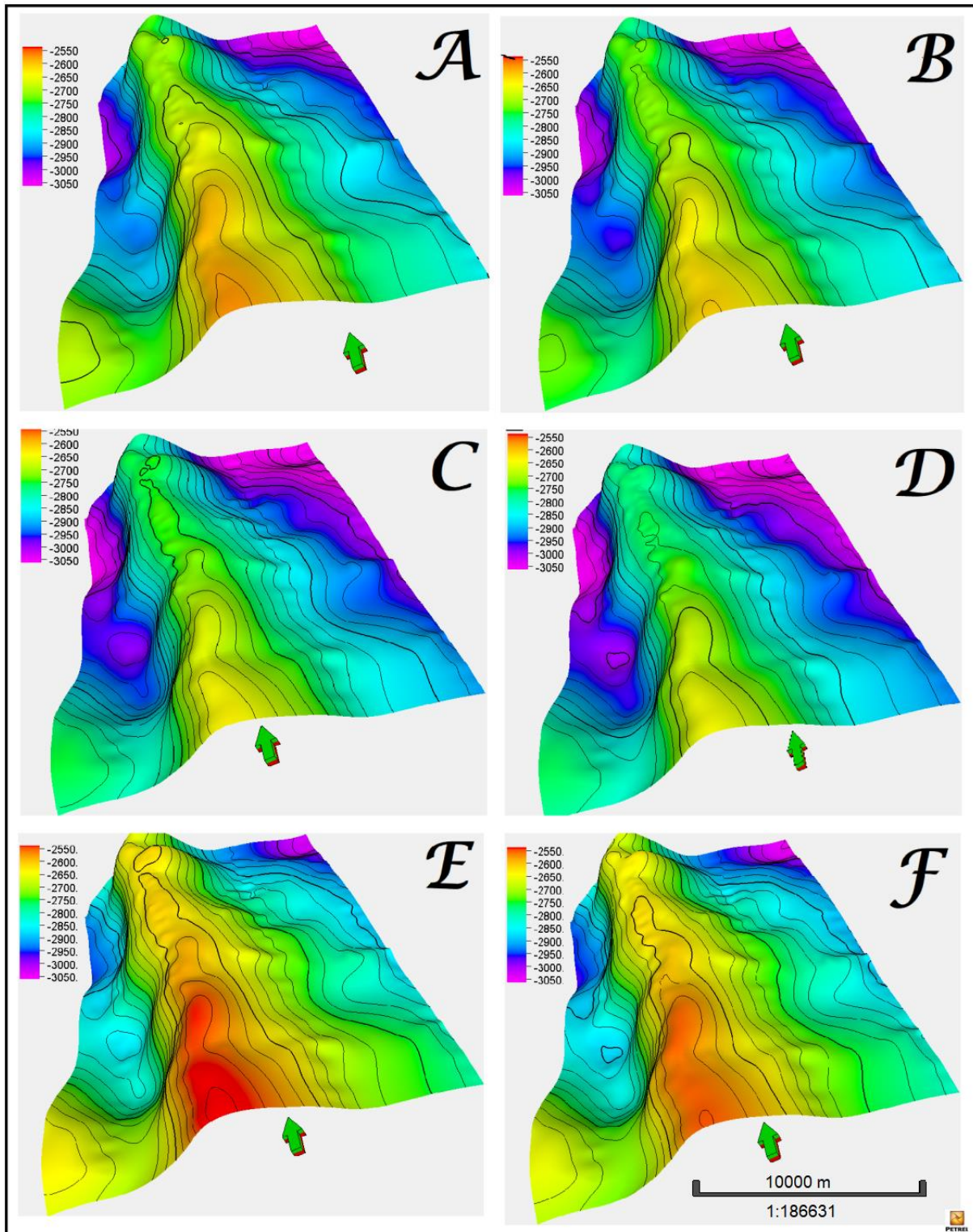
**Fig.4.** Maaddud Formation subdivisions in WQ1

### 3. Results

All available data has been used to build six precise structure maps using Petrel software. Fig. 5 shows the structure maps for all units. The 3D structure maps of the top for Upper Maaddud\_A (UM\_A), top of Upper Maaddud\_B, top for Lower Maaddud\_A (LM\_A), top of Lower Maaddud\_B (LM\_B), top for Lower Maaddud\_C (LM\_C), and top of Nahr-Umer Formation can be utilized to study the structural geometry analysis of the Maaddud fold in the West Qurna 1 oilfield.

#### 3.1. Fold Classification

To describe any specific fold, several fold classifications could be used. Each classification can have certain geometric parameters to implement the fold classification (Abdullah and Al-Shahwan, 2021). In this study, the Maaddud fold classifications were done according to the following geometric parameters: Fold dimensions, Fold tightness, Fold symmetry, Fold orientation, and Fold facing.



**Fig.5.** 3D Structural Maps, WQ1, A) Top of Upper Mauddud-A, B) Top of Upper Mauddud-B, C) Top of Lower Mauddud-A, D) Top of Lower Mauddud-B, E) Top of Lower Mauddud-C, F) Top of Nahr - Umer Formation

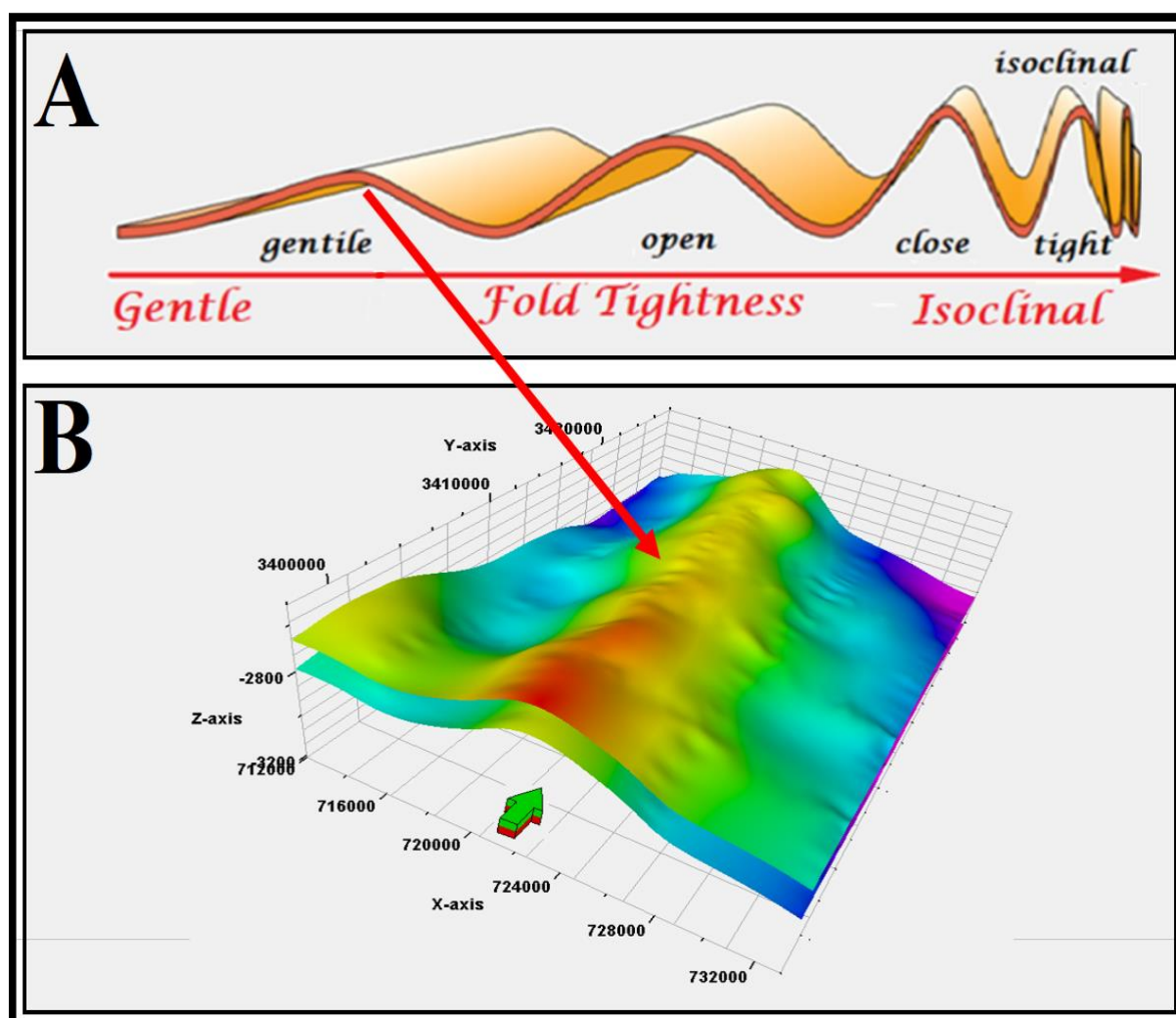
### 3.1.1. Classification based on the fold dimensions

According to Jaafer, 2018, the folds can be classified using the structure length (L) / the structure width (W) value into three types. 1) domes and basin fold when L/W value less than 2, 2) brachy fold

when L/W value more than 2, 3) liner fold when L/W value more than 5. Therefore, the Mauddud structure is liner fold, because West Qurna 1 oilfield is part of the major fold extends approximately 120 Km (Abdullah et al., 2022) and its width approximately 10 km according to the Structural map of the oilfield (Fig. 5).

### 3.1.2. Classification based on the fold tightness

The inter-limb angle is the magnitude of the angle between the fold's limbs (as measured tangential to the folded surface at the inflection line of each limb). The inter-limb angle is used to describe the Openness/Tightness of the fold, which in turn can be an effective tool for fold classification. Six classes can be defined according to the inter-limb angle. By comparison between the fold of the West Qurna 1 structure in the cross section (Fig. 6B) and the classification based on the fold tightness for Fluety (Fig. 6B), the fold can be classified as a gentle fold whereas the inter-limb angle of Mauddud fold is too wide (more than  $120^\circ$ ) as illustrated in Fig. 6.



**Fig.6.** A) Classification according to the fold tightness B) The classification of Mauddud Formation as Gentle Fold, WQ1

3.1.3. Classification according to the fold symmetry

The Mauddud structure in the West Qurna Oilfield 1 is called an asymmetrical fold because the two limbs in West Qurna 1 are not equal. Fig. 7 shows the West Qurna 1 cross-sections that obviously indicate that the western flank is shorter than the eastern flank, while Fig. 8 obviously shows that the dip angle of eastern and western limbs are not equal in all three structure maps (Top of Upper Mauddud\_A, Top of Lower Mauddud\_A, and Top of Nahr-Umer Formation). The dip angle of the western limb approximately ranges between 1.2 and 2.3 degrees, while the dip angle of the eastern limb approximately ranges between 2 and 3.5 degrees.

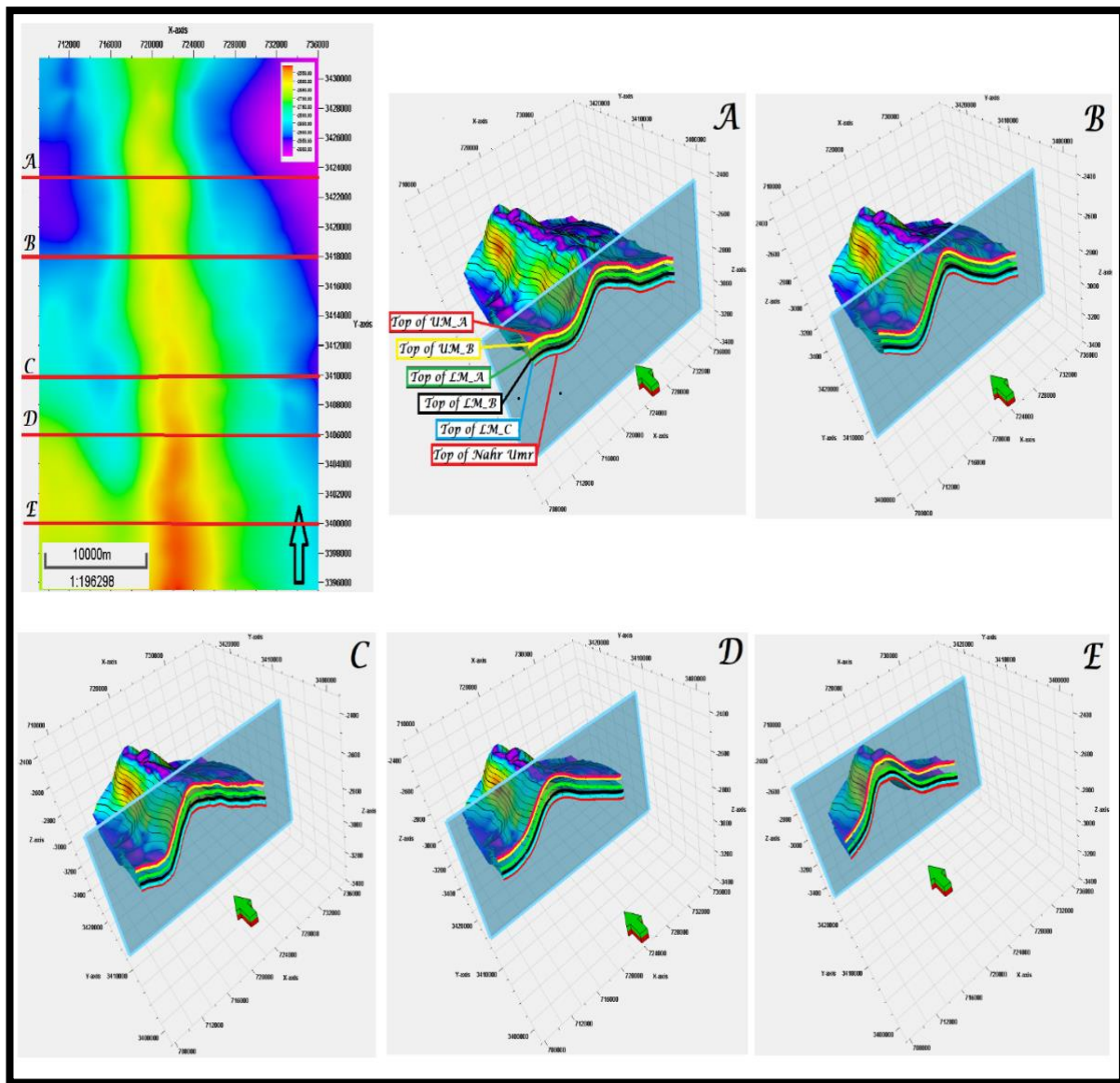
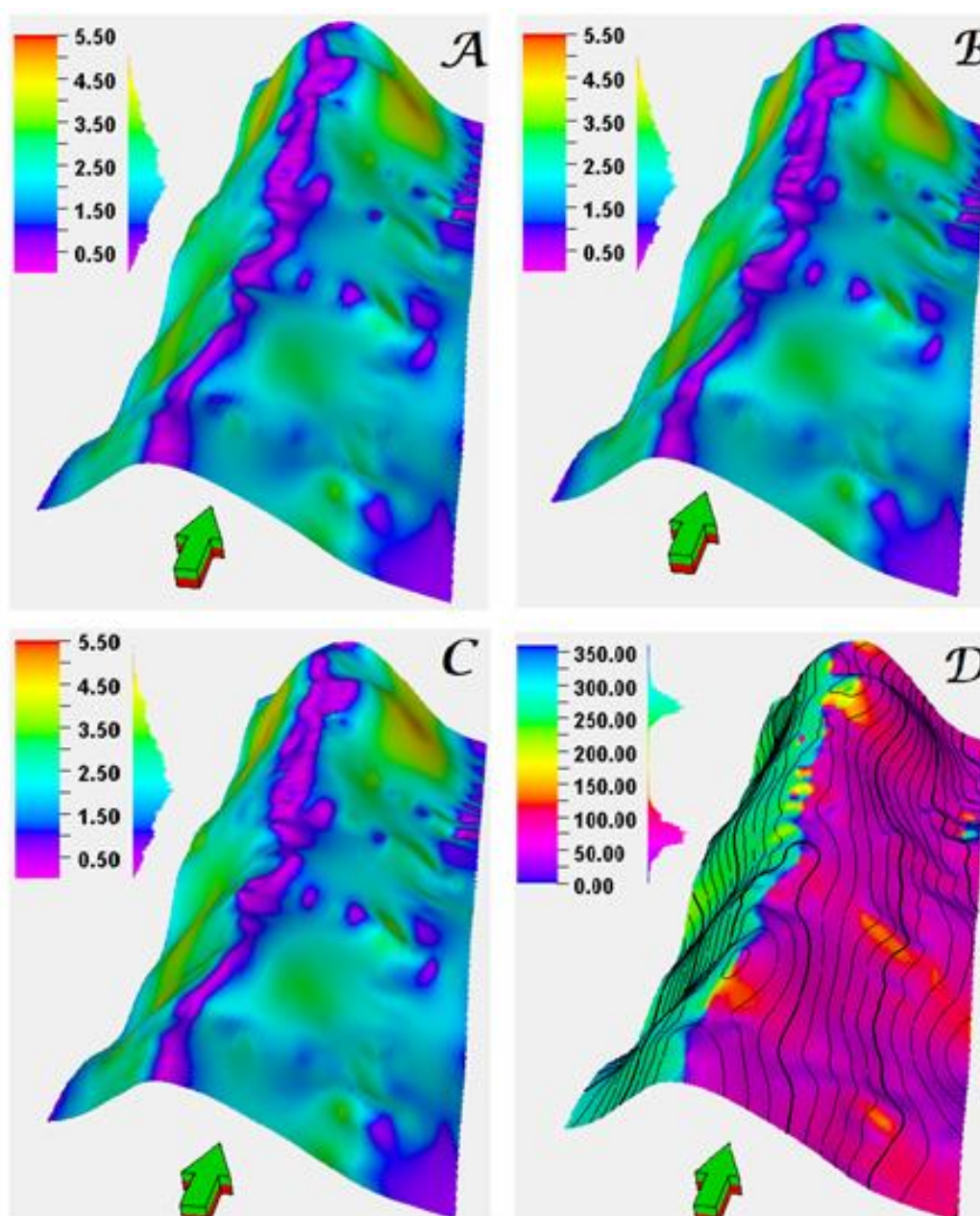


Fig.7. East-West cross sections of Mauddud Formation for each layer (A to E) in WQ1

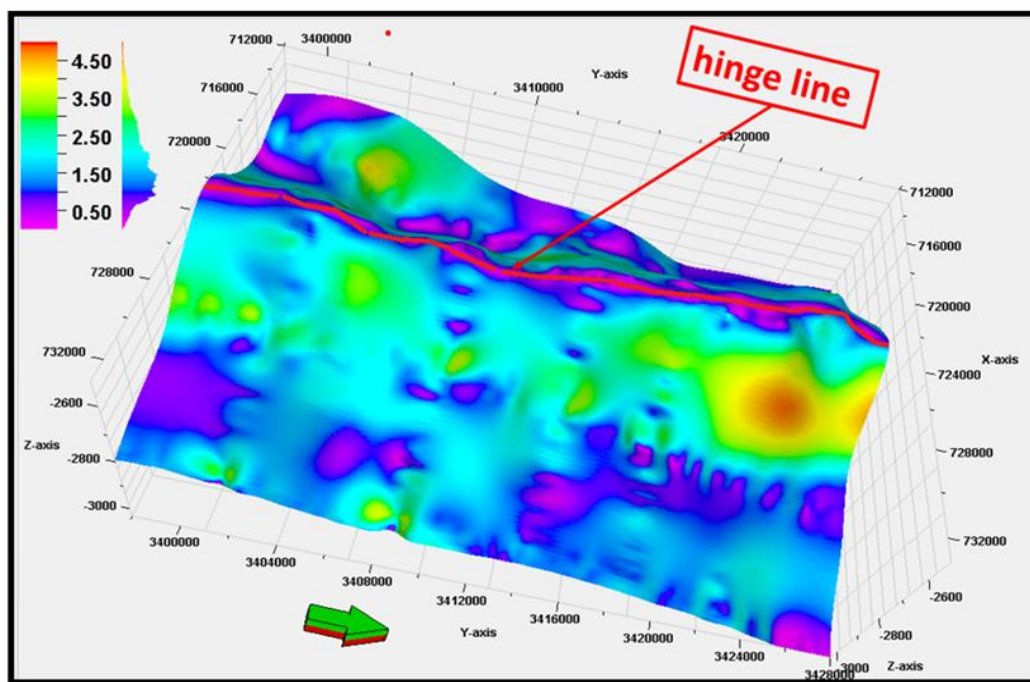




**Fig. 8.** Maaddud Dip Angle and Azimuth, WQ1 A) Dip angel of Top of Upper Maaddud\_A. B) Dip Angel of Top of Lower Maaddud\_A. C) Dip Angle of Top of Nahr Umer Formation

#### 3.1.4. Classification according to the cylindricity

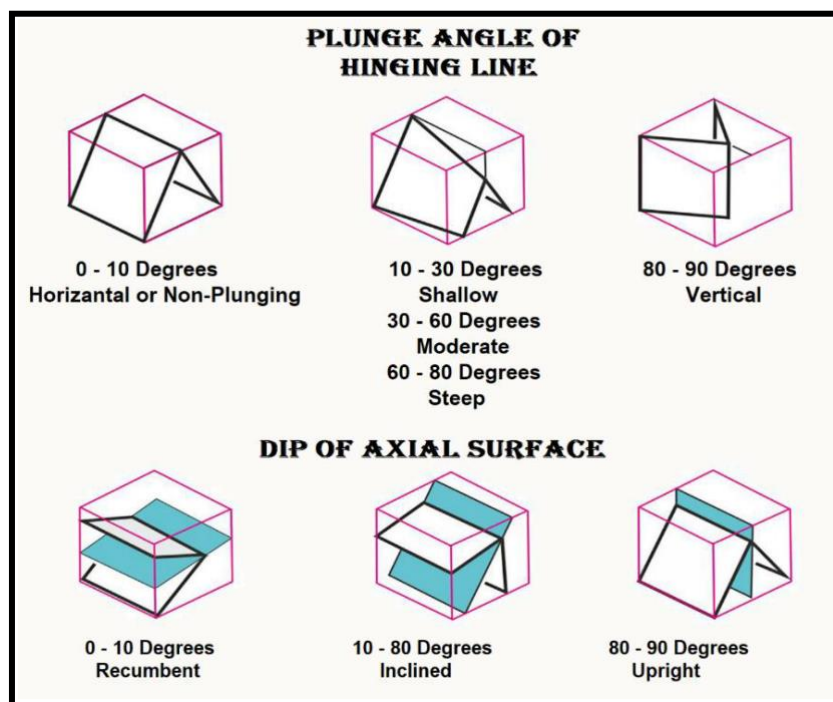
The fold can be classified according to the fold facing into cylindrical and non-cylindrical. When the hinge line of the fold is straight, it is called a cylindrical fold and when the hinge line is curvy, the fold is called a non-cylindrical fold. Thus, the folds can be classified according to the fold facing into synform and antiform. When the hinge line is at the base of the structure, it is synform; when it is at the top, it is antiform (Fossen, 2010). According to the Fig. 9, the Maaddud structure in the West Qurna 1 oilfield is an antiform, non-cylindrical fold.

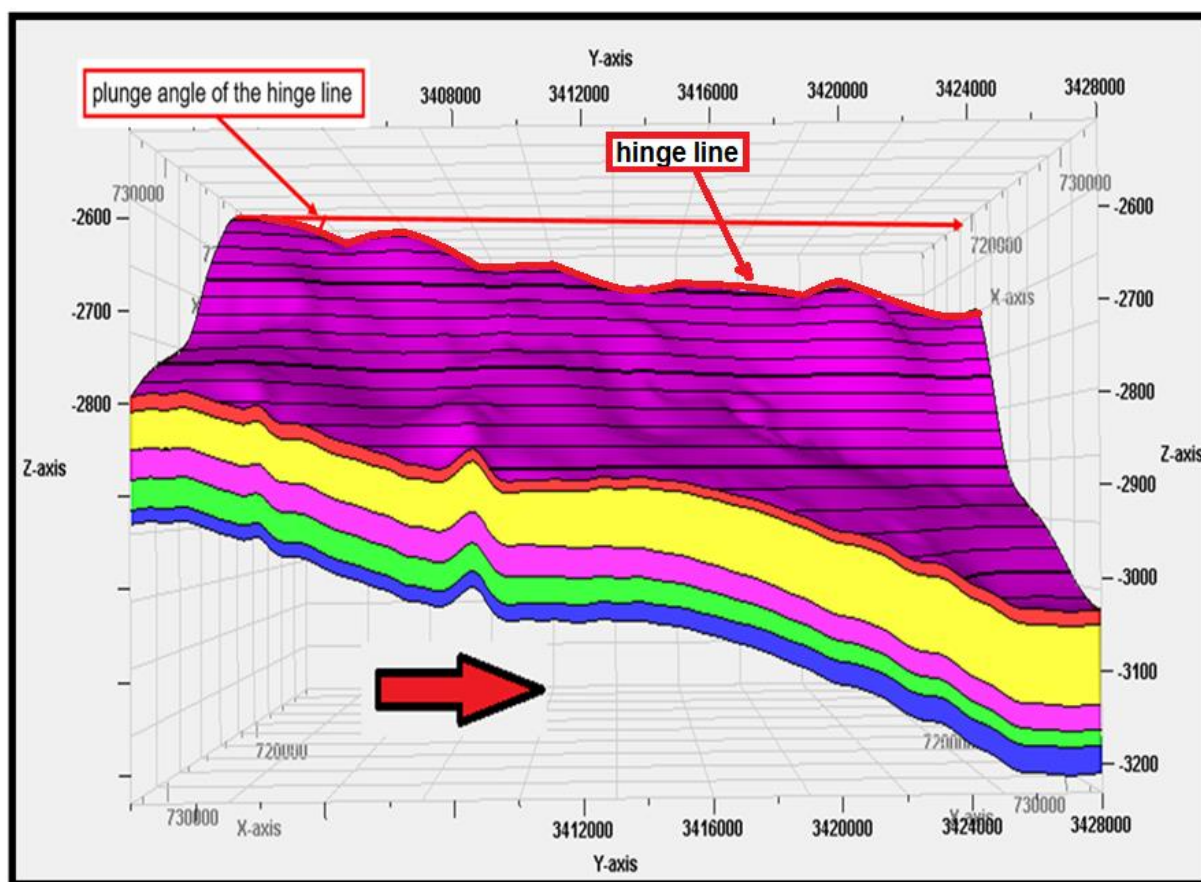


**Fig. 9.** Non-Cylindrical Maaddud Structure as classification according to fold facing, WQ1

*3.1.5. Classification of Folds*

Based on the axial surface dip angle, folds are divided into three categories: recumbent, inclined, and upright. Folds are divided into five groups based on the hinge line's plunge angle: vertical, steep, intermediate, shallow, and horizontal folds. Fig. 10 shows the classification of folds according to the plunge angle of hinge line and the dip angle of the axial surface respectively. According to Fig. 11, the Maaddud structure in West Qurna 1 oilfield can be classified as an approximately upright fold with horizontal hinge line.



**Fig. 10.** Folds classification according to (modified by Lisle, 2020)**Fig. 11.** The plunge angle of the hinge line of West Qurna 1 structure

#### 4. The Tectonic History of Maaddud Structure

During the Albian stage of the Cretaceous period (approximately 113 to 100 million years ago), when the studied formation was deposited, several tectonic events took place in the Arabian Plate, including Iraq. Here are some significant events (Numan, 1997; Jassim and Goff, 2006; Al-Mutury and Al-Asadi, 2008; Frizon et al., 2011; Berra and Angiolini, 2014; Handhal, and Mahdi, 2016; Al-Kaabi et al., 2023):

a. Iraq shelf passed through a stage called pre-collision, subsequent to this, a unique phase in plate tectonics is identified during the Turonian, Coniacian, Santonian, and Lower Campanian periods.

b. Foreland Basin Formation: The tectonic collision between the Arabian Plate and the Iranian Plate during the Late Cretaceous resulted in the formation of the Zagros Fold Belt. This collision led to the development of a foreland basin system on the Arabian side, including parts of Iraq. The sediments deposited in this basin record the tectonic events and associated deformation.

c. During the Aptian, Albian, and Cenomanian periods, there was a process of ophiolite obduction, involving formations such as the Penjwin-Shlair Complex, the Khwakurk Series (comprising volcanics and radiolarites), and the Qulqula Radiolarites.

d. Development of Petroleum Systems: The Albian period in Iraq witnessed the development of several oil-rich sedimentary basins, including the Mesopotamian Basin and the Zagros Fold Belt. The tectonic activities during this time, such as faulting and folding, contributed to the formation and preservation of hydrocarbon reservoirs.

e. Accretion of Terranes: The Albian period witnessed the accretion of various terranes (smaller crustal blocks) onto the Arabian Plate, leading to the formation of the Iraqi Plateau. Terranes such as the Sanandaj-Sirjan Zone were amalgamated during this time, contributing to the tectonic complexities of the region.

While (Numan, 2000) asserted that Iraq experienced a shift in the regional tectonic regime during the Cretaceous period, transitioning from extensional to compressional tectonism, this led to elevating the shelf of the Mesopotamian passive-margin basin above sea level could potentially result from uplift. The structures within the Zubair subzone have originated from the Alpine orogeny resulting from the collision between the Arabian and Eurasian plates, the salt tectonics associated with the Infra-Cambrian Hormuz Formation, and the movements of basement rocks. These factors collectively govern the development of subsurface structures (Al-Kubaisi and Ahmed, 2018). Anticlines are primarily influenced by the Alpine orogeny and basement faults, while salt structures are predominantly shaped by salt tectonics. The interplay of salt mechanisms, basement uplift, and the Alpine orogeny has collectively contributed to the configuration of the examined subsurface structures. The shear stress induced by the rotation of the Arabian Plate in the Zubair subzone leads to the formation different types of folds as West Qurna field, these reasons led to the shape and direction (N-S) of this studied field.

## 5. Conclusions

A. The study presents a method for creating precise 3D structure maps of specific reflectors in the Mauddud Formation and the Nahr-Umer Formation using well tops from a distributed set of wells.

B. Various classifications of Mauddud folds are conducted based on engineering parameters like dimensions, tightness, symmetry, facing, and orientation.

C. The study concludes that the Mauddud structure in West Qurna 1 is characterized as a gentle, linear, approximately asymmetrical, non-cylindrical, antiform, upright, and horizontal fold, influenced by factors including Alpine orogeny, basement faults, and salt tectonics.

## References

- Abdullah, R. A., Al-Shahwan, M. 2021, Structural geometry analysis of Khasib Formation in West Qurna I and II supergiant oilfields, Southern Iraq. *Iraqi Geological Journal*, 54(1E), 54–66.
- Abdullah, R., Al-Shahwan, M. F., Abdulhameed, M. A., 2022. Structure analysis of Sa'adi Reservoir in x supergiant oilfield, Southern Iraq. *Journal of Petroleum Research and Studies*, 12(4), 1–15.
- Abdullah, R. A., Al-Jorany, K., Mohsin, F., Imad, A., Abdulrazaq, M., 2018. Edge water breakthrough in each of the major zones within Mishrif reservoir in West Qurna phase 1. *Journal of Petroleum Research & Studies*, 20.
- Al-Kaabi, M., Hantoosh, D., Neamah, B., Almohy, H., Bahlee, Z., Mahdi, M., Abdalnaby, W., 2023. The structural analysis of the oilfields in Zubair subzone, Southern Iraq. *Journal of African Earth Sciences, Africian Journal Earth Science*, 197, 104770.
- Al-Kubaisi, M. S., Ahmed, M. M., 2018. Development of Ratawi Oil Field, Southern Iraq. *Iraqi Journal of Science*, 59(1B), 329-336.
- Al-kubaisi, M. S., Lazim, A. A., 2016. Structural study of Nahr Umer Oil Field in Southern Iraq. *Journal of Petroleum Research and Studies*, 6 (2), 27-46.
- Al-Mutury, W.G., Al-Asadi, M.M., 2008. Tectonostratigraphic history of Mesopotamian passive margin during mesozoic and cenozoic, South Iraq. *Kirkuk Journal of Science (J. Kirkuk Univ)*, 3, (31-50).
- Awadh, S. M., Al-Mimar, H. S., Al-Yaseri, A., 2019. Potentiometric salinity mapping of Mishrif Oilfield waters in (Iraq's) southern oil fields, *Advance in Science, Technology and Innovation*, 49-52.
- Berra, F., Angiolini, L., 2014. The evolution of the Tethys region throughout the Phanerozoic: A brief tectonic reconstruction. *American Association of Petroleum Geologists (AAPG), special volume*, 1-27.
- Aqrabi, A. A, Goff, J.C, Horbury, A. D., Sadooni F. N., 2010. *The Petroleum Geology of Iraq*. Scientific Press Ltd, Beaconsfield, 424.

- Fossen, H., 2010. Structural geology. Cambridge University Press.
- Fouad, S. F., 2015. Tectonic Map of Iraq, scale 1: 1000 000, 2012. Iraqi Bulletin of Geology and Mining 11 (1), (1-7).
- Frizon, de Lamotte, D., Raulin, C., Mouchot, N., Wrobel-Daveau, J. C., Blanpied, C., Ringenbach, J. C., 2011. The southernmost margin of the Tethys realm during the Mesozoic and Cenozoic: Initial geometry and timing of the inversion processes. *Tectonics*, 30(3).
- Handhal, A., Mahdi, M., 2016. Basin modeling analysis and organic maturation for selected wells from different oil fields, Southern Iraq. *Model Earth Systems Environ.* 189 (2), 1-14.
- Jaafer, H. M., 2018. Structural Geology of Rumaila Oilfield in Southern Iraq from Well Logs and Seismic Data. M. Sc. Thesis, Department of Geology, College of Science, University of Basrah.
- Jassim, S. Z., Goff, J., 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Berno, 332.
- Lazim, A. A., Ismail, M. J., Mahdi, M. M., 2023. High resolution sequence stratigraphy of the Mishrif Formation (Cenomanian-Early Turonian) at Zubair oilfield (Al-Rafdhiyah dome), southern Iraq. *Petroleum Research*.
- Lisle, R. J., 2020. Geological Structures and Maps. A Practical Guide. Butterworth-Heinemann.
- Mahdi, M., Ismail, M., Mohammad, O., 2022. The integration of wireline logs and sedimentological data to predict sequence stratigraphic framework in carbonate rocks: an example from Rumaila Formation (Cenomanian), West Qurna Oil Field, Southern Iraq. *Stratigraphic Geological Correlation*, 30 (5), 360e377.
- Numan, N. M. S., 1997. A plate tectonic scenario for the Phanerozoic Succession in Iraq. *Journal of the Geological Society (Journal Geological Society)*. Iraq 30 (2), 85–110.
- Numan, N. M. S., 2000. Major cretaceous tectonic events in Iraq. *Rafidain Journal of Science*, 11 (3), 32–52.
- Strohmenger, C. J., Mitchell, J. C., Feldman, H. R., Lehmann, P. J., Broomhall, R. W., Patterson, P. E., Al-Ajmi, N., 2006. Sequence stratigraphy and reservoir architecture of the Burgan and Maudud formations (Lower Cretaceous), Kuwait. *American Association of Petroleum Geologists*, 213-245.