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Geomorphological Analysis of Tectonic Activity in the Eastern Maysan Governorate

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***Abstract*:**
This study examines the geomorphological analysis of tectonic activity in the eastern part of Maysan Governorate, with a focus on structural features such as faults, fractures, folds, and their geographical distribution. The research is based on an analysis of the geological history of the region, which reveals that it has undergone two major phases of tectonic movement:

- *The first phase (older): Associated with the movement of the Arabian and Iranian plates, beginning in the Permian and continuing through the Neogene period. This phase contributed to the formation of a passive margin of an extensional basin.*
- *The second phase: Influenced by inherited basement faults during the Cretaceous and Eocene periods, which increased tectonic activity rates.*

Remote sensing data from ***LANDSAT 8*** *were utilized to analyse structural lineaments through the application of spectral and spatial digital processing techniques. The results indicated that the* ***near-infrared band (Band 4)*** *and* ***mid-infrared bands (Bands 5 and 7)*** *were most effective in detecting geological features. The study also revealed the significant role of faults in shaping morphotectonic features, such as changes in bedding dip, fold deflections, drainage pattern reversals, and modifications in alluvial fan morphology, indicating recent tectonic activity.*
Keywords: *Geomorphology, Tectonic Activity, Faults, Remote Sensing, Maysan, Arabian Plate, Spectral Bands, Geological Structures.*

1. INTRODUCTION:

This study addresses the structural analysis and major tectonic movements affecting the study area, focusing on Iraq's most recent structural classifications and the principal landforms resulting from tectonic features such as faults, fractures, folds, and the spatial distribution of geological formations. The research relied on interpreting the tectonic style of the region through an analysis of its geological history, which revealed exposure to two main phases of tectonic activity, influenced by the movements of the Arabian and Iranian plates:

- **The first (older) phase** represents a thermotectonic subsidence event that began after the rifting of the northeastern margin of the Arabian Plate in the middle Permian period and continued until the mid-Neogene. This process led to the formation of a passive margin for an extensional basin.
- **The second phase** involved local tectonic activity due to the reactivation of inherited basement faults during the Late Cretaceous and Eocene epochs, resulting in increased rates of tectonic subsidence.

Satellite imagery data from **LANDSAT 8** were utilised to identify structural lineaments, faults, and tectonic features within the region. Both spatial and spectral digital enhancement techniques were applied, and it was found that the **near-infrared band (Band 4)** and the **mid-infrared bands (Bands 5 and 7)** were most effective for geological studies and for delineating the tectonic characteristics of the area, including slope patterns and lithological structures. Both visual and digital interpretations of satellite imagery were conducted.

Furthermore, the study examined the impact of faults on surrounding geological structures, as reflected in morphotectonic features such as abrupt changes in bedding dip, deviation of anticlines, sudden shifts in drainage basin patterns, and even flow direction reversals in some streams. Alterations in the morphology of alluvial fans in the study area also suggest signs of recent tectonic activity. These findings reveal a contrast in recent and ongoing tectonic behaviour within the **foreland tectonic framework**, coinciding with the locations of contemporary seismic activity observed throughout the region.

2. Structural Characteristics of the Study Area:

Iraq's position along the northern and northeastern edge of the Arabian Plate has made it subject to various tectonic and regional changes throughout geological time. These tectonic movements contributed to the formation of both basin and uplifted regions, which played a fundamental role in shaping the country's geological framework (Al-Rawi, Diaa Youssef, 1985, p. 83). Tectonic processes lead to the activation of structural features such as anticlines, domes, and synclines, as well as fault displacements, all of which result in notable surface deformations (Al-Qaim, Basim, 1993, p. 30).

There are two main orientations of fold inclinations in the region: the first comprises folds dipping toward the northeast, while the second includes folds inclined toward the southwest. These variations are due to the shifting positions of inherited structural faults, which influenced the formation and orientation of different folds.

This phase of the study involved the collection and visual interpretation of data from selected locations using multiple satellite images at varying scales. Faults were identified and interpreted through morphotectonic evidence derived from visual analysis and field verification. These identified faults were then overlaid onto the final morphotectonic map, which included other tectonic features, contributing to the delineation of the region's morphotectonic framework.

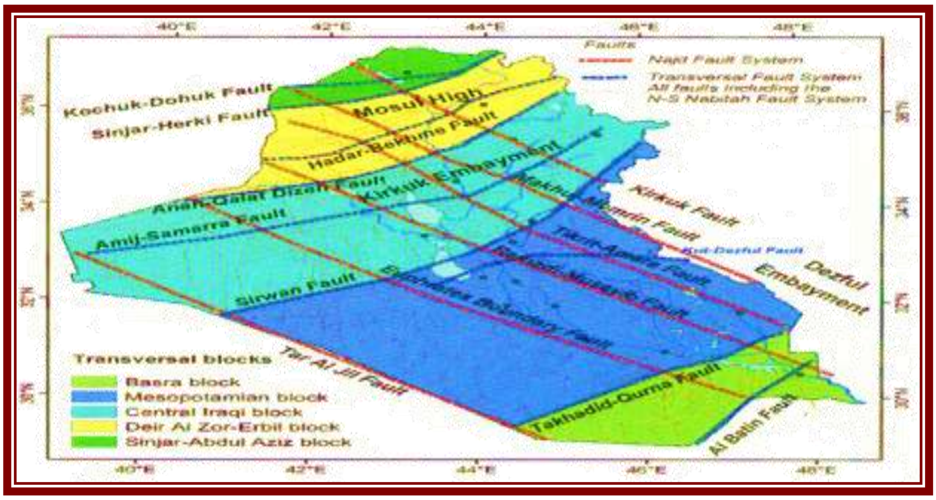
Structurally, the study area represents a broad zone encompassing many of the major geological structures present in northern Iraq. The most prominent of these include:

Morphotectonic History of the Study Area:

Fault activation in Iraq occurred during two distinct phases of geological history.

- The **first phase** took place in the **Late Cretaceous**, when the leading edge of the Arabian Plate was subjected to compressional forces due to the initial closure of the Neo-Tethys Ocean and the convergence of the Arabian and Eurasian plates. These forces pushed the Arabian Plate northward or north-eastward. The compressive stress generated during this phase (Al-Brifkani, Mohammed Jalal, 2008, p. 67) resulted in fault displacement inversions and, in some cases, the reactivation or formation of new faults.
- The **second phase** of fault formation or reactivation occurred during the **Miocene–Pliocene**, following the continental collision of the Arabian Plate. This led to intense folding of the sedimentary cover within the foreland zone and reversal of movement along some pre-existing faults. *(See Map 1).*

Map 1: Ancient fault systems located within the basement rocks of the Arabian Plate.



Source : Abdul Aziz, M. T. (1978). *Regional Geological Mapping of Dohuk-Amadiya-Ain Sifni Area* (GEOSURV Library Report No. 922). Baghdad.

This tectonic development, known as **structural inversion**, also included the activation of horizontal displacements along some of the existing faults or the formation of new faults in response to horizontal stress resulting from the continental collision (Al-Daghistani, Hikmat Subhi, 1996, pp. 85–96).

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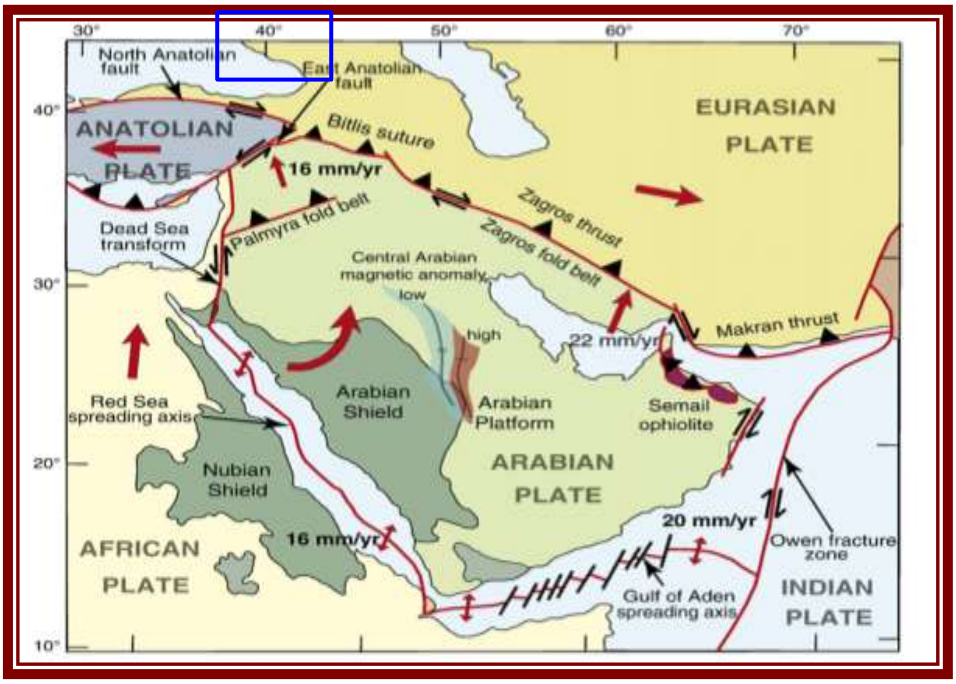
When examining the tectonic history of the regional faults within the study area, two principal fault systems can be identified:
Within the continental crust of the Arabian Plate (Iraq region), two primary fault systems can be identified:

- Najd faults, trending northwest–southeast, and
- Transverse faults, trending northeast–southwest.

The study area, which forms part of the foreland zone of the Arabian Plate, remains under compressional stress due to the ongoing convergence between the Arabian and Iranian plates. The direct effects of this plate movement are evident along the margins of the Arabian Plate, notably in the form of increased and persistent seismic activity recorded over the past twenty years—reflecting recent tectonic activity in the region (Take a look at *Map 2*).

Map 2. Rate of movement of the Arabian Plate toward the Iranian Plate.



Source: Al-Moula, Mohammed Fathi. (2002). *A Morphometric Study to Identify a Dam Site in the Wadi Tharthar Basin North of Al-Hadr Using Remote Sensing Techniques* [Unpublished Master's Thesis]. College of Science, University of Mosul, p. 91.

3. Faults

Numerous faults exist within the study area, exhibiting either vertical or oblique displacement, including normal, reverse, and strike-slip faults. These faults manifest along the limbs or hinges of folds and may run longitudinally (parallel) or transversely (perpendicular) to the fold axes, significantly affecting the morphology of folds and other geological structures.

Morphotectonic Analysis of Faults

The morphotectonic analysis of faults in the region reveals that compressional lateral stress from the collision between the Arabian and Iranian plates has led to the development of right-lateral strike-slip faults along the Zagros Fault system, contributing to the northward movement of the Arabian Plate. This has resulted in horizontal deformations, manifested as zones of alternating lateral displacement.

Fault System:

Variations in drainage patterns on either side of structural rock units are among the best indicators for identifying linear features and faults. Structural influences are also suggested by topographic patterns such as linear alignment of lakes, depressions, and alluvial fans (Al-Kubaisi, Manal Shaker Ali, 2000, p. 126).

Some faults extend east to west, while others trend northwest to southeast. These features play a significant role in increasing rock permeability, transforming otherwise impermeable rocks into highly porous and permeable units.

Fractures of various types, including faults, joints, and cracks, act as planes of weakness that can reduce rock strength, resulting in landslides. These brittle deformations, which form under stress, are often unstable.

Faults are a specific type of fracture along which observable displacement has occurred. They can be identified by the presence of slickensides, nearby fractures, feather structures, rock debris along fault planes, or stratigraphic dislocations. Iraq contains numerous surface and subsurface faults and fractures (*take a look at Image 1*).

Given the continued north-eastward movement of the Arabian Plate, tectonic stress remains active, impacting geological structures in the foreland zone and promoting continued fold development. Consequently, the reactivation of faults along fold axes remains likely.

Folds located within shear zones between parallel faults can experience clockwise rotation, affecting regional structure (Hays, Masoud Murai, 1989, p. 129).

Tectonic stresses may induce fold rotation, as evidenced by joint analysis and the presence of normal faults in the area.

Description of Faults

Morphotectonic features, such as fault scarps and their influence on fold morphology, have been identified, along with evidence of stream offset and changes in alluvial fan geomorphology. The study area exhibits signs of brittle deformation in the overlying sedimentary cover, particularly in areas where subsurface faults exist especially in the central and eastern portions of the study area.

Image 1. Impact of faults in the region

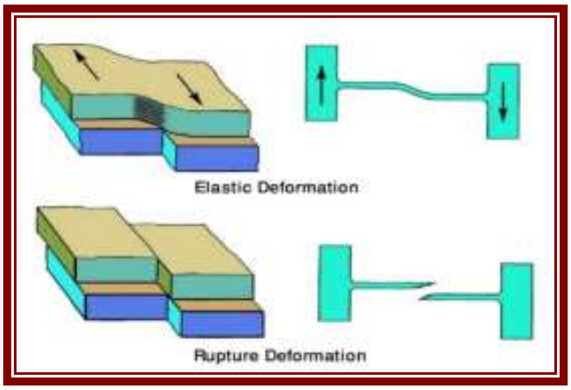


Figure (1): Deformations affecting the rock layers

Source: Hijazi, Bassam Mohammed. (1996). *Hydrochemistry of the Upper Part of the Dibdibba Aquifer and Geochemistry of Clays* [Unpublished Master's Thesis]. College of Science, University of Baghdad, p. 119.

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Table (11): Characteristics of Major Faults in the Study Area

Fault	Length (km)	Location	Orientation
Main Fault 1	26.61	Ali Al-Gharbi	East–West
Main Fault 2	15.53	Ali Al-Gharbi	East–West
Main Fault 3	32.83	Amarah	East–West
Main Fault 4	12.10	Amarah	East–West
Main Fault 5	24.72	Amarah	East–West
Main Fault 6	36.00	Amarah	East–West
Main Fault 7	10.65	Amarah	East–West
Main Fault 8	27.56	Ali Al-Gharbi	North–South
Main Fault 9	42.86	Amarah	North–South
Main Fault 10	36.13	Amarah	North–South

Source: Based on *Map (3)*

Main Fault 1 in Ali Al-Gharbi

This fault appears along the boundary between the study area and Wasit Governorate, extending in a nearly parallel manner from the eastern part of the study area westward, in Ali Al-Gharbi district near Wasit, in the northern part of the study area. Its length is approximately 26.61 km (take a look at Table (1) and Map (3)). The fault intersects a subsurface fold in the same area (northern part of the study area) and extends westward toward the Tigris River, specifically near Hor (Sarout). The following morphotectonic evidence confirms the existence and type of this fault:

At the intersection point, a tributary valley meets the main valley (Wadi Al-Jifta) forming a right angle, northeast of the city of Ali Al-Gharbi. This indicates that the tributary valley has responded to recent tectonic activity along the fault or possibly resulted from it.

This morphotectonic response is evident in the fault's northern strike, where tectonic reactivation has led to vertical incision in multiple valleys and to changes in the morphology of the region. This includes the deflection of valley shapes in response to fault displacement. The valley crossing the fault bends westward in line with the direction of fault movement, indicating reactivation.

Similar morphotectonic features are observed elsewhere in the study area. At the northern end of the fault, several nearly parallel first-order valleys exhibit high erosion rates and nearly equal catchment areas, forming distinct geomorphological structures that further indicate the presence of a fault.

Main Fault 2

This fault is located near Wadi Al-Tayyib in the northern part of the study area, extending until it intersects with Main Fault 1. It trends from northeast to southwest in Ali Al-Gharbi district and has a length of 15.53 km (take a look at Map (3) and Table (1)).

It is a strike-slip fault with left-lateral displacement, identified based on the noticeable offset on the southern limb of the fold and its linear extension. The fault cuts across part of the fold limb and diminishes as it intersects the fold hinge.

The fault also affects the eastern side of the area, especially some valleys located north of the study area. It alters the morphology of the valley's origin, deflecting it southeast in response to the fault's displacement, which confirms the fault's tectonic activity.

Main Fault 3 – Abu Hadiriya Area

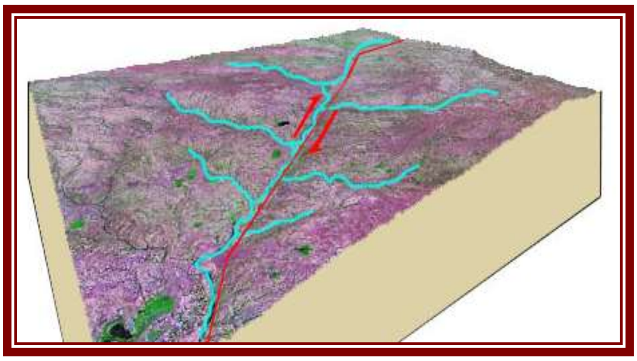
This fault is associated with a group of anticlinal structures located east of the study area near the Abu Hadiriya region. It extends toward the Tayyib alluvial fan in the Amarah district. Its length is approximately 32.83 km (take a look at Map (3) and Table (1)).

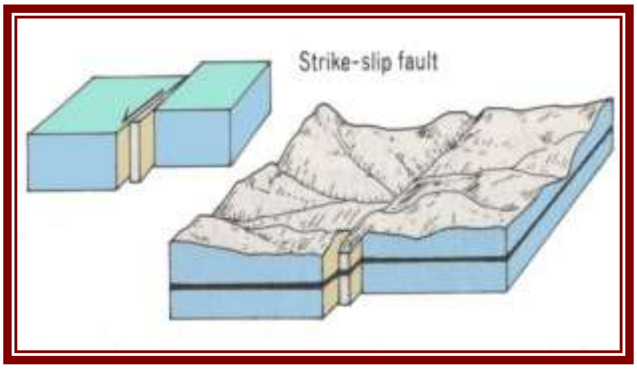
It is bordered by five folds four surface folds on the eastern side and one subsurface fold on the western side. Additionally, a fault extends along the same surface and continues westward.

The anticlines trend east–west, cutting across formations of aeolian deposits and Tertiary sediments, both of which constitute the structural units affected by these faults and folds.

Main Fault 4

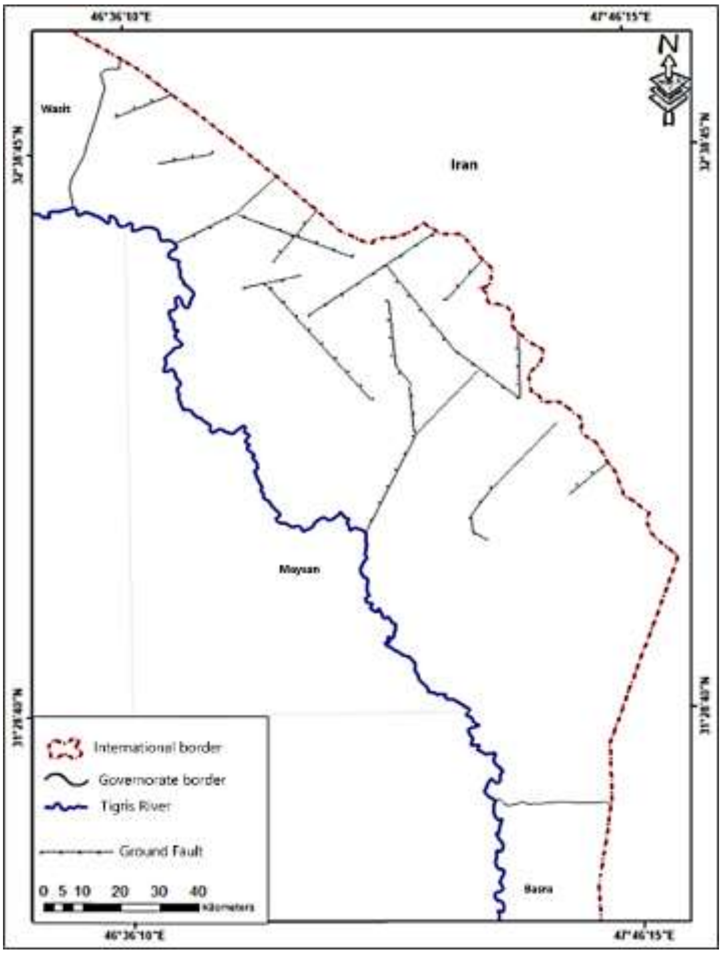
Located in the Abu Hadiriya area, more precisely in the Al-Sharifat region near the Iraqi Iranian border within the Amarah district, this fault has a length of 12.10 km. It runs parallel to some secondary tributaries of Wadi Dwayrij (take a look at Map (3) and Table (1).





Source: Based on Digital Elevation Model (DEM) data and outputs from ArcGIS v10.2, Iraq Structural Map

Map (3): Faults in the Study Area



Main Fault 5

This fault lies in the Amarah district within the Al-Sharifat area and runs parallel to a section of Wadi Dwayrij. It has a length of 14.72 km and trends from northeast to southwest. It is situated near the headwaters of Wadi Abu Ghraybat, influencing the direction of the valley's drainage and its hydrological characteristics, thereby affecting the intensity of water erosion in the area (you have a look at Map (3) and Table (1).

Main Fault 6

This fault is located within the Wadi Al-Shakkak and Wadi Dwayrij basins and significantly influences geomorphological processes, particularly rockfall activity, soil creep, and fluvial processes. It has a total length of 36 km and is situated administratively within the Amarah district.

The fault extends eastward from a fold in the sedimentary cover, with its path aligned with an unrecognised surface fault. It trends west to east across the study area. The dense alignment of linear structures along its course reinforces its presence and activity. You have a look at the Map and Table (1).

Main Fault 7

This fault has a length of approximately 10.65 km and is entirely located within the valleys of active water erosion near the Iraqi–Iranian border. It trends from east to west and intersects with two major surface faults within the eastern valleys of the study area that descend from the Iraqi–Iranian boundary, bordering the Amarah basin.

It intersects with a major graben-type surface fault known as the "Souq Al-Shuyoukh–Amarah Fault," which cuts across the study area from east to west near the Tigris River (you have a look at Map (3) and Table (1)).

This fault affects the drainage by displacing transverse tributaries that feed into Wadi Dwayrij, resulting in a linear stream pattern and the presence of small tributaries flowing into the same wadi (Figure (2)) (Al-Habiti, Safwan Taha, 2008, p. 89).

The regular linear pattern of a major stream aligned with this fault indicates that the fault has captured the main drainage channel.

Main Fault 8

This fault runs parallel to the Iraqi–Iranian border, trending from east to northwest, and is administratively located within the district of Ali Al-Gharbi. It has a length of 27.56 km and extends across the study area in the direction of the anticlinal structure from east to west. The fault cuts through the formations of eolian (wind-blown) deposits and Tertiary sediments—both of which are primary components of the folds and faults in the region.

It intersects the fold axis at an oblique angle, reaching the northeastern limb of the fold. The left-lateral displacement associated with the first fault has caused a shift in the geological formations, impacting the morphology of the anticlinal structure in the area. Consequently, this has influenced local geomorphological processes.

Main Fault 9

This fault extends for 42.86 km and runs parallel to the Iraqi–Iranian border. It transects four main wadis Al-Tayyib, Al-Shakkak, and Abu Ghribat, significantly altering their flow patterns. The fault's presence has obscured and transformed the landscape by intensifying geomorphological activity. Additionally, several folds are located near this fault.

The alteration in surface drainage patterns and stream orientations in the region reflects the influence of active faulting. These changes are further evidenced by conflicting dip directions of surface rock outcrops in various locations—an indication of fault-induced deformation (you have a look at Map (2–3) and Table (2–1)?.

Main Fault 10

This fault extends for 36.13 km, running parallel to the Tigris River within the administrative boundaries of the Amarah district. It is located in the low floodplain area. The dense presence of linear structures in this area suggests the possible existence of numerous secondary faults.

It is noted that the main folds in this area deviate, with the northwest plunge direction of the fold diverging from the main fold axis, which trends northeast. This inference is supported by the direction of erosion activity and the landforms resulting from these processes, which are widely distributed throughout the study area. The watercourses extending along the faults are generally active, and erosion activity is distinctly observable in the region.

Additionally, valleys exhibiting vertical incision are noted. This vertical incision is attributed to horizontal displacement caused by the lateral movement of the faults, which generated a zone of tension that widened the valleys and activated the vertical incision phenomenon.

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Folds

The current study area includes sectors of low and high folds characterised by convex, en-echelon, and alternating folds. These folds vary in axial length, amplitude, width, axis orientation, and dip direction. The folds consist of:

- Subsurface folds within the sedimentary cover and basement rocks,
- Subsurface folds within the sedimentary cover only,
- Surface folds within the sedimentary cover alone.

Most of these folds show axial plane deviations at one of their plunges, which serves as evidence for analysing the presence of faults. The deviation of some fold axes from their original orientation may reflect the effect of horizontal fault movement in the underlying basement rocks beneath these folds. Most folds are asymmetric, with dip directions varying from fold to fold; some dip north or northeast, while others dip southwest or south. Notably, the southwest dip direction predominates in the study area. The compressive stress resulting from tectonic forces led to the formation of these folds (you have a look at Table (2) and Map (4).

Table (2): Lengths and Percentage Distribution of Folds in the Study Area

Fold Name	Length (km)	Percentage of Total Length
Subsurface folds in the sedimentary cover	73.13	34.52%
Subsurface folds in the sedimentary cover + basement	75.18	35.49%
Surface folds in the sedimentary cover only	63.49	29.97%
Total	**211.8**	**100%**

Source: Based on Map (4).

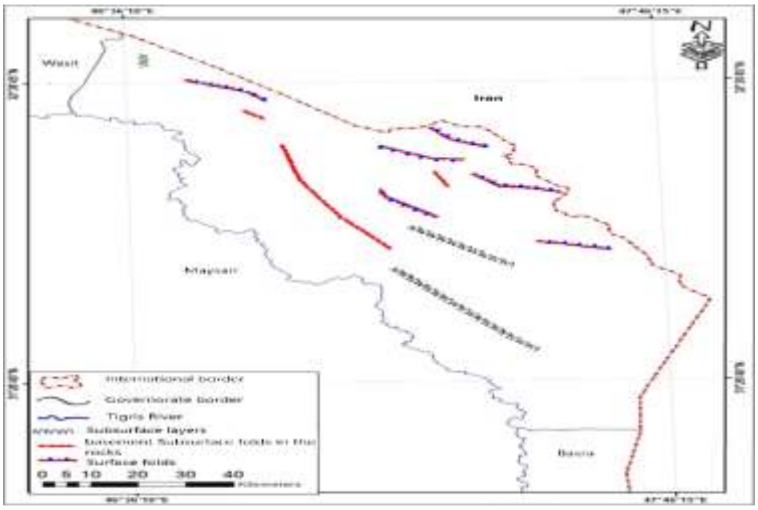
Subsurface Folds in the Sedimentary Cover

These folds are characterised by their shallow depth within the sedimentary cover, with a total length of 73.13 km, representing 34.52% of the total fold lengths in the study area (you have a look at Table (2). These folds are accompanied by several faults that affect the surface morphology by influencing geomorphological processes either directly or indirectly. Their axial directions trend through the central part of the study area near the alluvial fans and run roughly parallel to the Tigris River. These folds are concave in shape (you have a look at Table 2 and Map (4).

Surface Folds

A group of surface folds within the sedimentary cover is spread over the study area, particularly around Abu Hadriyah and Al-Sharifat Table (2) within the Amarah district along the Iraq-Iran border and extending across the Hamrin structure. The total length of these folds is 63.49 km, accounting for 29.97% of the total fold lengths in the area (you have a look at Table 2 and Map (4).

Map (4): Folds in the Study Are



Source: Based on the Digital Elevation Model (DEM), outputs from the software ArcGIS version 10.8, and the Iraq Structural Map at a scale of 1:1,000,000.

This type of fold is accompanied by the presence of deep faults extending into the basement rocks. These faults are characterized by being short and transverse relative to the fold axes in the study area. The folds are of a convex structure type, caused by intense tectonic movements that accompanied their formation.
The region exhibits a network of deep faults and fractures affected by these tectonic movements. The solid terrain is intersected by a fault system trending westward, with a maximum width not exceeding 750 meters, influenced by local geological properties.
The existence of drainage divides in the watershed networks was inferred, trending from the eastern part of the study area toward the west. This inference is further supported by the morphometric characteristics of the contour lines in the region.

Figure (2): Surface Folds and the Appearance of Cuestas

Source: Field study dated 2/4/2025, Coordinates N726528, N3592681

Subsurface Folds in the Sedimentary Cover and Basement Rocks

This group consists of deep folds extending within both the sedimentary cover and the basement rocks, with a total length of (75.18 km), accounting for (35.49%) of the total fold lengths in the study area (you have a look at Table 2). These folds are characterised by asymmetry and maximum width near the Tigris River within the Ali Al-Gharbi and Amarah districts. They extend westward, roughly parallel to the Tigris River. The morphological characteristics of these folds result from structural elements that have influenced the overall shape of the region.

5. Faults

1. **Main Subsurface Faults in the Sedimentary Cover**

Two types of subsurface faults are identified. The first type comprises main faults, where the Tikrit-Amarah fault extends for (296.34 km), representing (64.29%) of the total fault lengths in the study area, as shown in Map (5) and Table (3).

2. **Unknown Subsurface Faults in the Sedimentary Cover and Basement Rocks**

The second type includes faults of unknown nature located within the sedimentary cover and basement rocks, with a total length of (164.59 km), accounting for (35.70%) of the total fault lengths in the study area (refer to Table 3).

Fault Name	**Length (km)**	**Percentage of Total Length**
Tikrit-Amarah Fault	296.34	64.29%
Unknown Faults in Sedimentary Cover and Basement	164.59	35.70%
Total	**460.93**	**100%**

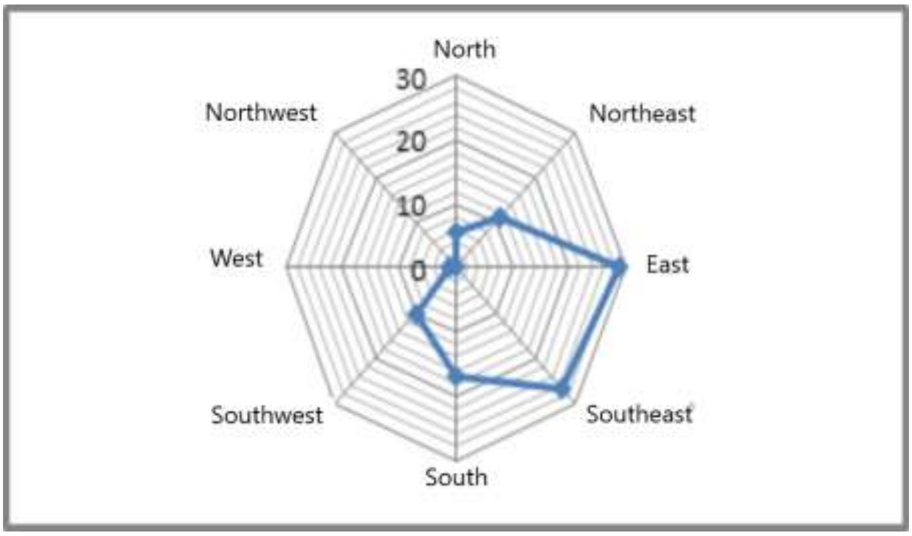
Table (3): Fault lengths and their percentages in the study area
Source: Author based on Map (5).

Linear Structures

Linear structures were automatically extracted using ArcGIS V.10.8 software based on satellite imagery. According to Map (6) and Table (4), the total number of lineaments in the study area is 426, with a cumulative length of 1033.41 km. The eastern trend lineaments were the most frequent, numbering 122 (28.63% of the total), with a total length of 243.1 km (30.84% of the total length). Conversely, the western trend recorded the fewest lineaments, with only 5 lineaments (1.17%) totalling 9.13 km in length (1.16% of the total).

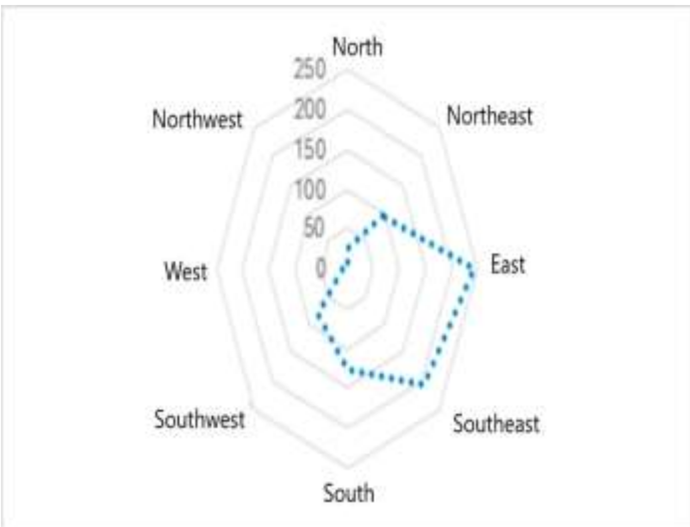
These structures can also be identified through surface landforms, as illustrated in Figures 3 and 4. Changes in drainage patterns along the edges of structural rock units provide clear evidence of the presence of these linear features.

Figure (3): Distribution of predominant lineament orientations in the study area



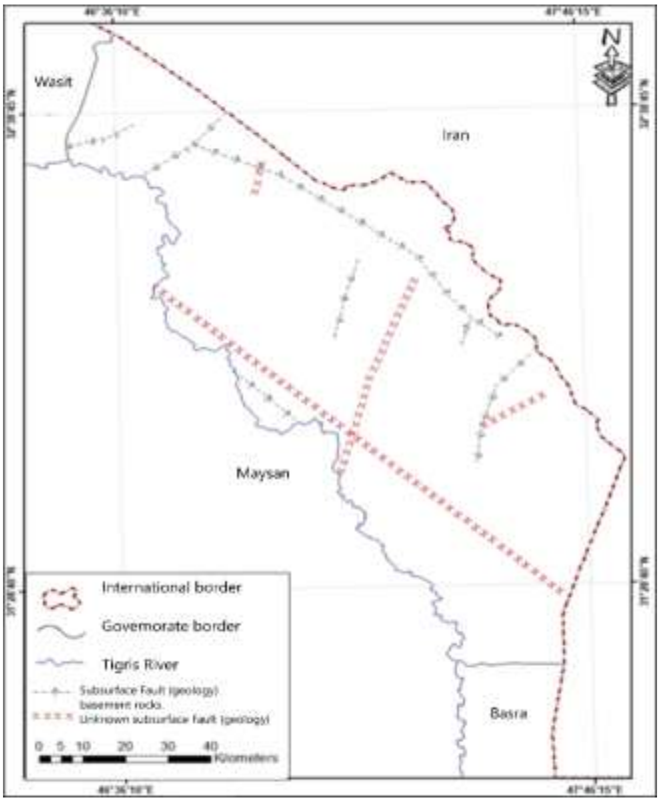
Source: Based on the data from Table (4)

Figure (4): Lengths of Predominant Orientations of Linear Structures in the Study Ar



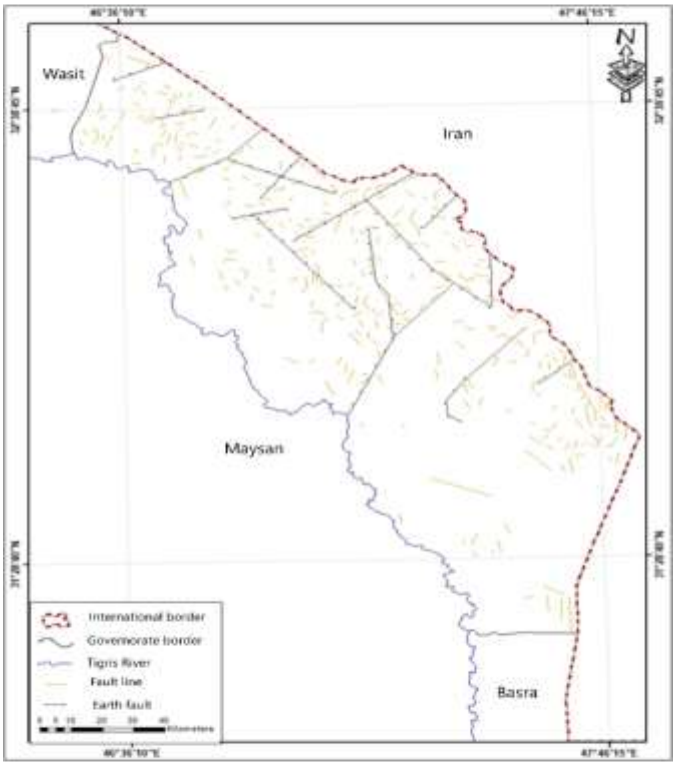
Source: Based on the data from Table (4)

Map (5): Faults in the Study Area



Source: Based on the Digital Elevation Model (DEM) and outputs from ArcGIS V.10.2 software, Structural Map of Iraq, at a scale of 1:1,000,000

Map (6): Linear Structures and Faults in the Study Area



Source: Based on the Digital Elevation Model (DEM) and outputs from ArcGIS V.10.2 software, Structural Map of Iraq, scale 1:1,000,000

Table (4): Directions, counts, lengths, and percentages of linear structures in the study area

Direction	Angle (°)	Count	Percentage (%)	Length (km)	Percentage (%)
North	337.5–67.4	24	5.63	25.58	3.24
Northeast	67.5–112.4	47	11.03	94.65	12.00
East	112.5–157.4	122	28.63	243.10	30.84
Southeast	157.5–202.4	113	26.52	207.63	26.34
South	202.5–247.4	72	16.90	127.89	16.22
Southwest	247.5–292.4	43	10.09	80.40	10.20
West	292.5–315.4	5	1.17	9.13	1.16
Northwest	315.5–337.4	–	–	–	–
Total		426	100	1033.41	100

Source: Based on Map (2) and ArcGIS V.10.8 software

Indicators for Identifying Linear Structures:
Topographic features may reflect structural causes such as the linear arrangement of depressions and alluvial fans (Kabisi, Manal Shaker Ali, 2000, p. 126). The study of linear structures (faults) relied on the interpretation of satellite data and digital elevation data, combined with field verification. A filtering process was applied to the digital elevation data for all secondary directions using a 7x7 window, followed by mapping the structures, revealing the presence of both vertical and transverse lineaments, with their orientations measured and identified.

6. CONCLUSIONS:

1. The structures of the region were studied in detail from geomorphological and structural perspectives.
2. Major valleys intersect the folds in the area and may have preceded the formation of the folds.
3. The faults significantly influence the region's geomorphology, extending through the faults or on Quaternary deposits, indicating recent activity.
4. Most folds in the region are simple in structure, with a general axial trend-oriented east-west.
5. The folds formed under the influence of a single stress regime, resulting from regional horizontal compression-oriented north-south, perpendicular to the fold axes.
6. Folds associated with fault propagation formed under early stresses related to a phase of compression, causing subsidence bounded by normal faults, followed by a later stage linked to a structural inversion process.
7. Folding and faulting likely resulted from regional horizontal stresses-oriented north-south during the Late Triassic, related to the collision of the Arabian and Iranian plates.
8. The folds flanking the faults and secondary structures associated with faulting and fold bending allowed for establishing the temporal relationship between fold development and faulting in the region.
9. Geological epochs and faults are contributing factors to the region's geomorphology.

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