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Large Geological Features Model Depending on Constructing Regional Seismic Transect Section Crossing Southern Central Iraq.

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ABSTRACT

A regional seismic section extending about 530 km is constructed using data from fourteen local seismic lines obtained from various surveys conducted between 1978 and 1990. This section traverses central Iraq from west to east. Generally, the seismic data quality is poor in the western part and improves in the central and eastern parts of the regional seismic section. Seven reflectors are identified along the regional seismic section, corresponding to geological ages ranging from the Lower Triassic to the Mid Miocene. These reflectors are represented by Mirga Mir (Lower Triassic), Geli Khana (Middle Triassic), Kurra Chine (Upper Triassic), Najmah (Upper Jurassic), Mauddad (Middle - Cretaceous), Shiranish (Upper Cretaceous), and Fatha (Lower Fars) (Mid-Miocene) formations. This study shows the existence of two sedimentary basins, one in western Iraq associated with the Paleocene formation and the other in the Miocene-Pliocene formations towards the east. These two basins are separated by an uplifted area in the central part of the regional seismic section, a finding that is supported by anomalies in gravity and magnetic data. Many faults are identified along the regional seismic section, most of them, extend predominantly from deeper to shallower formations.

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موديل الظواهر الجيولوجية الكبيرة بالاعتماد على بناء مقطع زلزالي اقليمي يقطع جنوبي وسط العراق.

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الملخص

تم إنشاء مقطع زلزالي إقليمي يمتد لمسافة 530 كيلومترًا باستخدام بيانات أربعة عشر خطًا زلزاليًا محليًا تم الحصول عليها من مسوحات مختلفة أجريت بين عامي 1978 و1990. تمتد خطوط الزلزالية وسط العراق من الغرب إلى الشرق. جودة البيانات الزلزالية قليلة نسبيا في الغرب وتتحسن تدريجيا كلما اتجهنا نحو وسط ثم شرقي المقطع الزلزالي الاقليمي. أمكن تمييز سبعة عواكس زلزالية تمتد اعمارها من عصر الترياسي الاسفل الى الميوسين الاوسط. وتشمل هذه التكوينات ميركا مير (العصر الترياسي السفلي)، وكلي خانا (العصر الترياسي الأوسط)، وكورا تشاين (العصر الترياسي الأعلى)، والنجمة (العصر الجوراسي العلوي)، مودود (العصر الطباشيري الأوسط)، والشيرانيش (العصر الطباشيري العلوي)، والفتحة (الميوسين الاوسط). اظهرت الدراسة وجود حوضين رسوبيين، أحدهما في غرب العراق مرتبط بتكوينات الباليوسين والآخر متوافق مع تكوينات الميوسين–البليوسين باتجاه الشرق. تفصل هذه الأحواض منطقة مرتفعة في الجزء الأوسط من المقطع الزلزالي الإقليمي، وهذا ما دعم بمعطيات الجاذبية والمغناطيسية. بالإضافة إلى ذلك، حددت العديد من الفوالق على طول المقطع الزلزالي الإقليمي، والتي تمتد في الغالب من التكوينات العميقة إلى التكوينات الضحلة.

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Introduction

The seismic method has been instrumental in a wide range of geological applications, including resource exploration, environmental studies, and hazard assessment (Sheriff and Geldart, 1995). Furthermore, the integration of regional seismic reflection data with well information has led to more precise depth conversions and improved geological interpretations (Yilmaz, 2001). The regional seismic section provides valuable information about the subsurface geology structures to help the geoscientist in visualizing and interpreting the distribution of rock layers, faults, and oil exploration (Telford *et al.*, 1990). The regional seismic section is important in geophysical and geological applications (Sheriff, 1991).

The tectonic setting of Iraq is characterized by the convergence of the Arabian and Eurasian plates causing the presence of many geological features, including fold-thrust belts, fault systems, and sedimentary basins. Furthermore, the presence of hydrocarbon reserves which are vital for Iraq's economic development necessitates a detailed comprehension of subsurface structures (Alsharhan and Nairn, 1977).

There are many researchers in Iraq who used various geophysical methods to investigate the deep geological features through regional studies such as (Al-Heety *et al.*, 2017; Al-Bahadily and Al-Rahim, 2023) using gravity and magnetic data, Ahmed, (2019), Al Karadaghi, 2022 used well data; while Abdulnaby *et al.*, (2013) and Gök *et al.*, (2008) used seismology data, Abdul-Jalil, (1998), Al-Sinawi and Al-Banna (1990), Muhammad, (2000), Mohammed, (2006), Al-Ameri and Al-Khafaji., (2013) Al-Bahadily, (2014), Khorshid *et al.*, (2017), Al-Banna et al (2020), Al-Banna and Al-Assady (2021) used potential and seismic data. One of the most aims of the geophysical studies is to detect the faults distribution along the considered seismic section. Many studies are achieved in Iraq attempting to detect the main tectonic boundaries of faults (Al-Banna and Al-Namar, 2019; Al-Banna and Dham, 2019). This study attempts to construct a regional seismic section southern the central part of Iraq depending on the available seismic lines and wells along the considered section.

Location and Geological Setting

Description of site

The study area is situated at southern central Iraq, within latitudes 31.4°- 33.8° N and longitudes 45.5° to 41.3° E. It is crossing Iraq transversely in NE-SW direction. It extends from western Iraq (the Saudi Arabia border), passing through the Mesopotamian zone towards the east, ending at the Iraq-Iran border, and crossing Iraq with about 530 km long (Fig. 1).

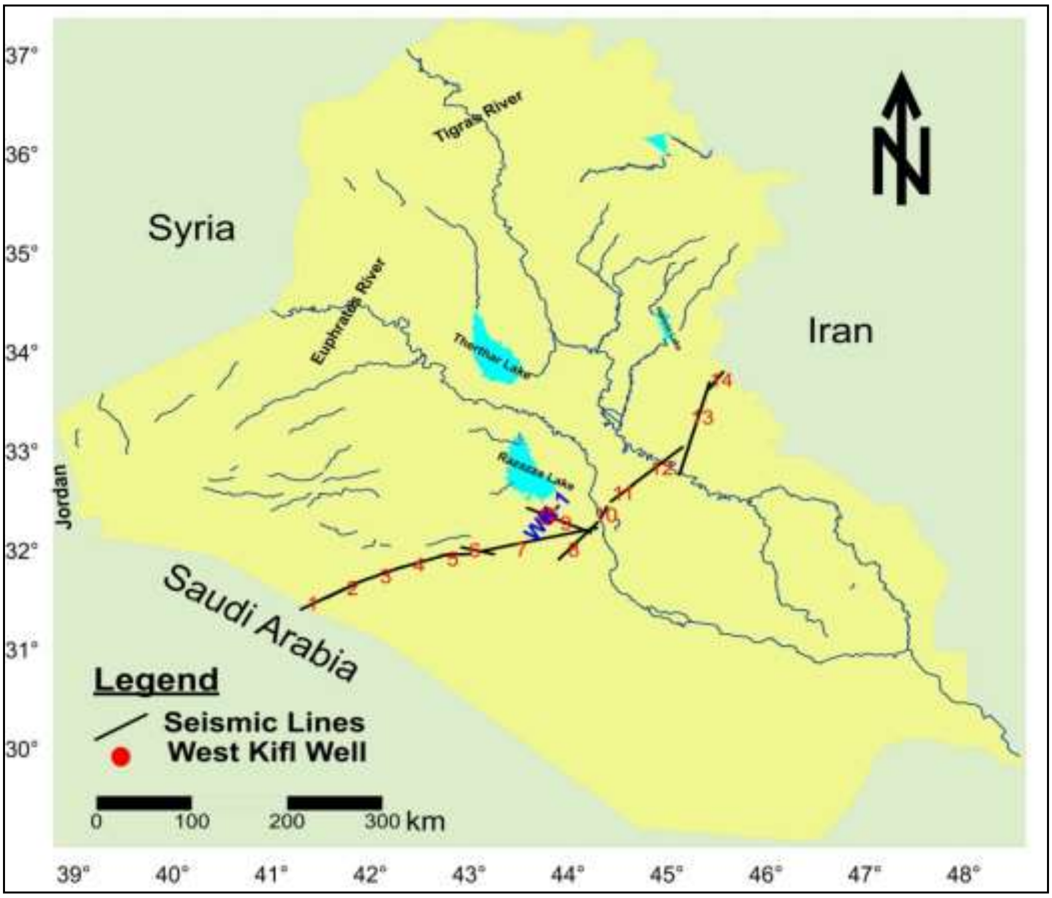

Fig. 1. Iraqi map showing main rivers, lakes of the regional seismic section used in this study.

Seismic survey

Many seismic survey projects have been conducted in Iraq including the study area. These surveys were initiated in 1974 and have continued to the present time utilizing both 2D and 3D-dimensional techniques to acquire precise sub-surface data (Oil Exploration Company, 2005). Fourteen seismic lines, namely TL-16, Kh-54, AZ-16, At-32c, At-32, At-34E, BW-1, BW-7, NK-28, ND-28, MD-23, MZ-23, DK-14 and DK-96, which achieved for the period 1978- 1990, are considered in this study. The parameters of these seismic lines are given in table (1).

Table 1: The Parameters of the seismic lines used in this study area.

NO	Line	Company	Datum	Date	Source	Configuration (meters)
1	TL-16	O.E.C 6	+500	1988	Vibroseis	3500-210-SP-210-3500
2	Kh-54	Bulgaria	+300m	1980	Vibroseis	2400-100-SP-100-2400
3	AZ-16	C.G.G-11	+400	1981	Vibroseis	2450-150-SP-150-2450
4	At-32c	Rompetrol	+200m	1980	Vibroseis	2400-100-VP-100-2400
5	At-32	Rompetrol	+200m	1980	Vibroseis	2400-100-VP-100-2400
6	At-34E	Rompetrol	+200m	1981	Vibroseis	2400-100-SP-100-2400
7	BW-1	INOC-3	Sea level	1982	Dynamite	SP-300-5,000
8	NK-28	INOC-3	Sea level	1982	Dynamite	SP-300-5,000
9	BW-7	INOC-3	Sea level	1982	Dynamite	SP-300-5,000
10	ND-26	O.E.C -11	Sea level	1990	Dynamite	3430-150-SP-150-3430
11	MD-23	C.G.G	Sea level	1978	Dynamite	2400-50-SP-50-2400
12	MZ-23	INOC-2	Sea level	1980	Dynamite	3,200-300-SP-300-3,200
13	DK-14	INOC-4	Sea level	1980	Dynamite	1,500-SP-3,200
14	DK-96	INOC-4	Sea level	1980	Dynamite	1,500-SP-3,200

Geology of the study area

The outcropped formations at the western part of the study area belong to the Tertiary age (Paleocene), while at the eastern part, the Quaternary formations (Pliocene) are exposed at the surface (Jassim and Goff, 2006) (Fig. 2). The geology description along the seismic lines is shown in table (2) and figure (2). The description of the subsurface formation, age and references are listed in table (3) and figure (3). The stratigraphic column of the subsurface formations in the study area is obtained from many wells penetrated in the study area (Fig. 3).

The regional section crosses one of the main tectonic boundaries in Iraq, Abu-Jir fault, which separates two tectonic zones. These zones are in the western part of Iraq called the stable shelf (inner platform), while the eastern part of the study section is within the unstable shelf (outer platform) (Buday and Jassim 1987; Fouad 2012; Al-Banna *et al.*, 2013; Al-Banna and Ali 2018). In figure (2), the seismic lines from BW-1 line to NK-28 lie in the inner platform part, while NK-28 seismic lines to DK-96 are within unstable shelf (outer platform part).

Table 2: The description of the major surface geological formations of the study area.

No	Lines Name	Age	Formations	References
1	LT-16, Kh-54, AZ-16, At-32 and At-34E	the Paleocene - Early Eocene sequence	The phosphatic facies of the Akashat Formation and Swab member of the Ratga Formation, the carbonate - evaporite facies of the Umm Er Radhumu and Rus Formations, the outer shelf facies of the Aaliji, the molasse of the Kolosh, the carbonate ramp facies of the Sinjar, and the inner shelf lagoonal carbonates of the Khurmala.	Jassim and Goff, 2006.
2	At-32c	Pleistocene-Holocene	Dibdibba Formation of the Miocene-Pleistocene formation covers the area. This formation is mainly composed of gravels and sand of igneous rocks.	Buday 1980.
4	BW-1	Tertiary era	Dhiban Formation,limestone, anhydrite and halite. Lower Fars (Fatha) Formation marked by conglomeratic limestones at the base. Early Miocene Sequence Clastic inner shelf (Ghar Formation).	Bellen, 1959; Jassim and Goff, 2006.
5	NK-28 and BW-7	Quaternary era	alluvial fan deposits, depressing filling, and flood plain	Hudson *et al.*, 1957; Yacoub and Hassan, 1996.
6	ND-26, MD-23, MZ-23 and DK-14	Quaternary era	alluvial fan deposits, flood plain, Bakhtiari and Muqdadiya	Owen and Naser, 1958; Al-Rawi et al, 1992.
7	DK-96	Miocene-Pliocene	Injana and Mukdadiya	Bellen *et al.*, 1959.

Table 3: The description of the major subsurface geological formations of the study area.

No	Formations	Age	Lithology description	References
1	Mirga Mir	AP2-Megasequance the Lower Triassic	thin bedded grey and yellow argillaceous limestone and shale	Balaky *et al.*, 2020.
2	Geli Khana	AP2- Megasequance	comprising dolomite, dolomitic, and marly	Sissakian and Al-Jiburi, 2014

		Middle Triassic	limestones; calcareous shaly and marly limestones; limestone with dolomitic and marly limestones; black shales; and evaporites	
3	Kurra Chine	AP6- Megasequance Upper Triassic	limestones, dolomite, anhydrite and ribbons of shale	Al-Hamdani *et al.*, 2021; Aswad *et al.*, 2023
4	Najmah	AP7- Megasequance Upper Jurassic	limestone and dolomite, as well as shale and marl layers	Sadooni,1997; Bibani and Al-Haleem, 2023
5	Mauddad	AP8- Megasequance mid-Cretaceous	organic limestone separated by shale layers that are "green or bluish	Sadooni and Alsharhan, 2003; Alhadithi, 2017
6	Shiranish	AP9- Megasequance (Upper Cretaceous)	dark-blue, friable marl, marly limestones, arenaceous limestones, marls and breccias	Jassim and Goff, 2006
7	Fatha (Lower Fars)	AP11- Megasequance Mid Miocene	marl, limestone and gypsum	Al-Juboury and McCann, 2008

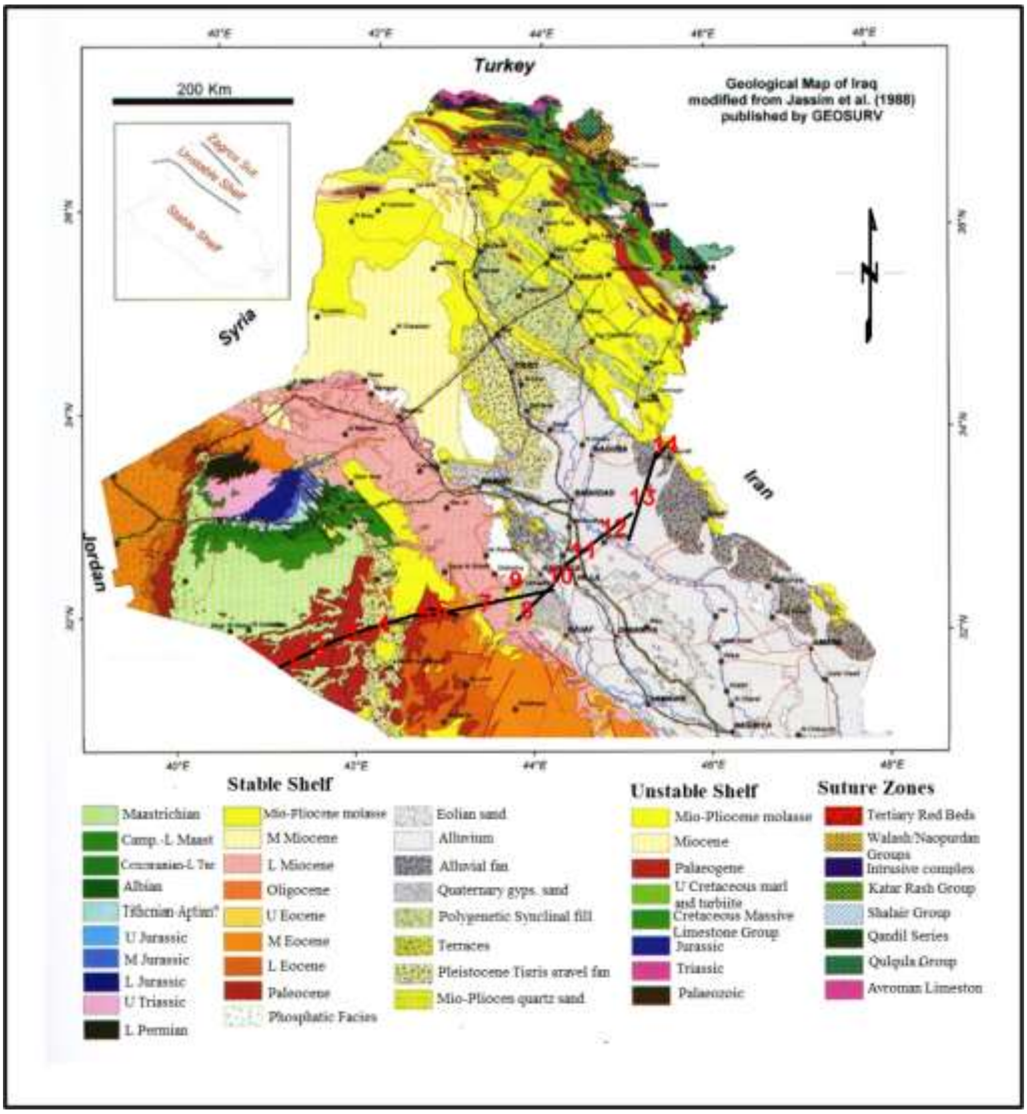

Fig. 2. The regional seismic section location on the geological map of Iraq (modified after Jassim and Goff, 2006).

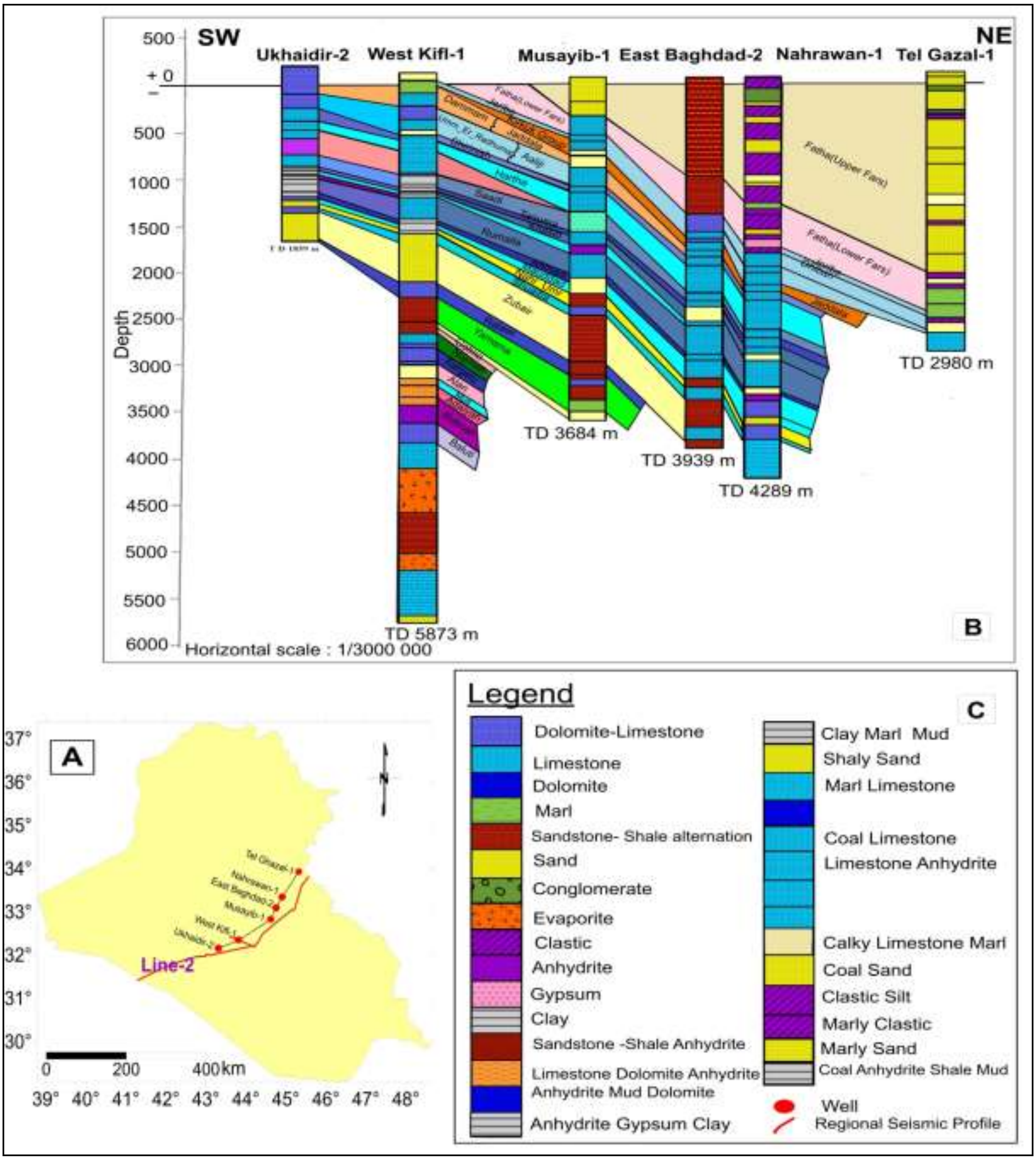

Figure 3. (A) Location of the considered wells, (B) The correlations between the formations along the study area, (C) Legend showing the lithology of subsurface formations (modified After O.E.C., 1989).

Fault Systems

The separation of the Arab plate from the African plate in earlier geological epochs, along with its ongoing collision with the Iranian plate, has resulted in significant deformation within the study area, which is predominantly overlain by Quaternary sediments. Many researchers have used the geological, geophysical, well logs, and satellite images information to detect the major and minor structural and tectonic features in Iraq. Some of these studies are Buday and Jassim, 1987; Al-Banna, 1992; Mohammed, 2006; Fadhel and Al-Rahim, 2019; Al-Banna and Al-Namar, 2019; Al-Banna and Dham, 2019; Al-Hadithi and Al-Banna, 2022.

Jassim and Buday, in Jassim and Goff, 2006, derived fault information from a variety of sources, including satellite imagery, gravity and magnetic gradients, and to a lesser extent, the seismic data. Among these, the total horizontal derivative of gravity emerged as the most effective parameter for delineating fault trends. Jassim and Buday in Jassim and Goff, 2006 identified several fault systems that include longitudinal and traverse faults in the study area.

These include the N-S oriented Nabitah (Idsas) system, along with the NW-SE trending Najd system, which encompasses the fault zones of (Tar Al Jil, the Euphrates boundary, Ramadi-Musaiyib, Tikrit-Amara, and Makhul-Hemrin). Additionally, there is the NE-SW or E-W oriented transversal system, represented by the Kut-Dezful (Fig. 4). These fault systems originated during the Late Precambrian Nabitah orogeny, and they have experienced multiple episodes of reactivation throughout the Phanerozoic (Jassim and Goff, 2006).

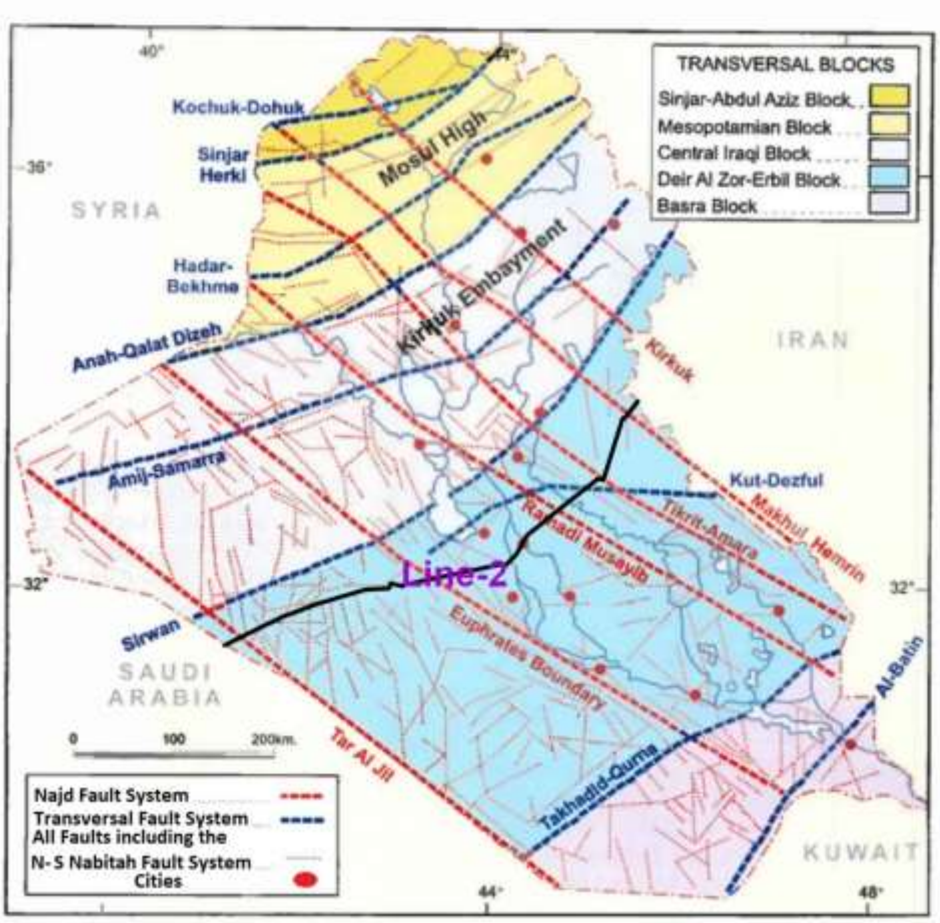

Fig. 4. The regional seismic section crossing many regional NW-SE faults traced on the tectonic map of Iraq prepared by Jassim and Goff, (2006).

Materials and methods

Geophysical information

The well Information, which include density, velocity, sonic log, check shot, top formation as well as the synthetic seismograms are obtained from West-Kifl- 1 and Marjan- 1 wells. The seismic reflectors in the study area are defined from the West-Kifl-1 well, which reaches 5873m in depth. The Bouguer gravity map and aeromagnetic information which used in the study area were taken from maps prepared by Getech, (2010). The basement depth which used in the final model of this study depends, generally on the information presented in the interpretation report of CGG, (1974).

Echos™ software processing system

The processors employed within the Echos system, owned by Paradigm Geophysical Ltd Company, constitute a suite of tools designed for the integrated processing of seismic data

(Paradigm, 2011). The Echos™ seismic processing system is capable of generating both 2D and 3D dimensional seismic images and is compatible with Linux® 64-bit operating systems (Echos, 2019).

To construct the regional seismic section, numerous post-stack processes are applied to the seismic data. These encompass tasks such as geometry definition, static correlation, time sample determination, band-pass filtering, F-KPOWER analysis, Digistics application, gain control, muting, amplitude standardization, enhancement of signal-to-noise ratio, and velocity analysis. These processes are executed utilizing the Echos™ 1.0 system (Fig. 5).

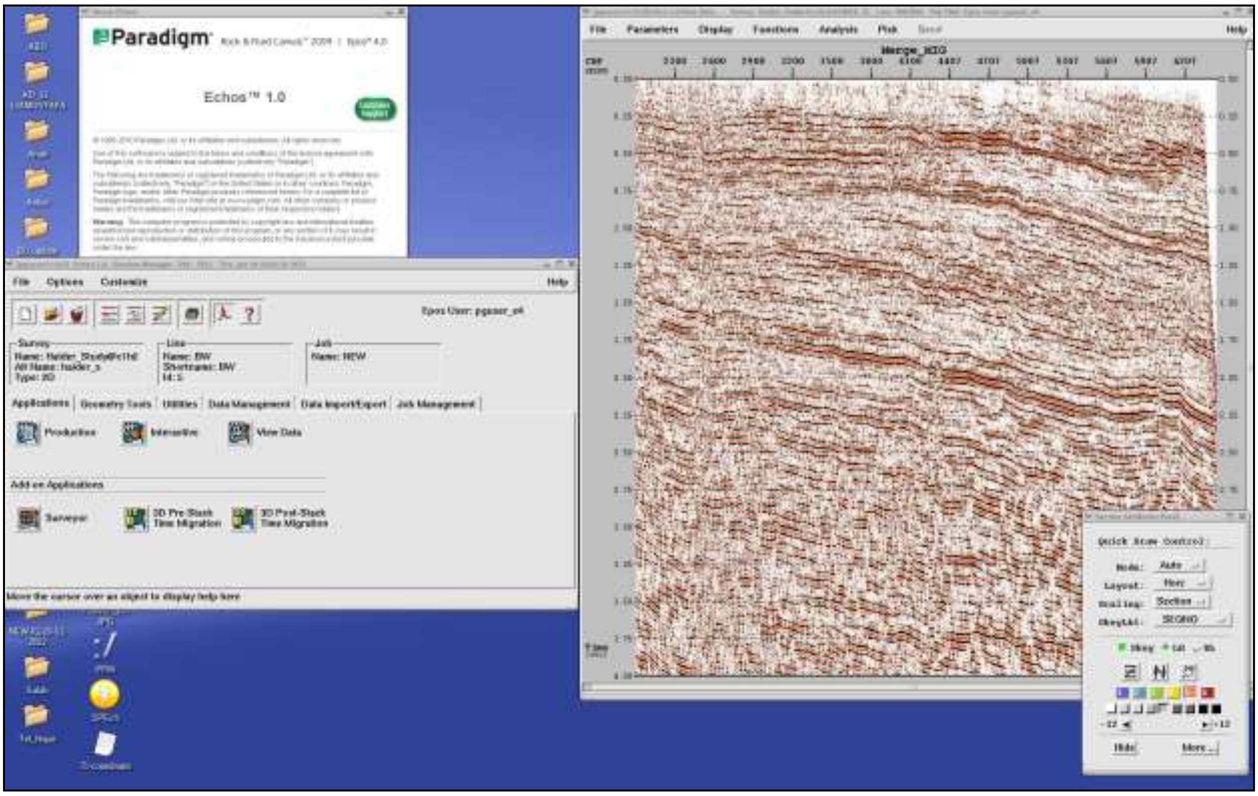

Fig.5. The main page of the Echos™ 1.0 system program.

Instantaneous Phase

Instantaneous phase serves a crucial role, offering similar benefits as standard instantaneous phase while presenting an added advantage of continuous smoothness. This eliminates the ±180-degree discontinuity often encountered in instantaneous phase analysis. Reflectivity strength proves to be a valuable tool for detecting variations in brightness and intensity. Additionally, phase data plays a vital role in delineating noteworthy features like faults, onlaps, and prograding reflections. The utilization of instantaneous frequency data aids in the identification of condensate and gas reservoirs, (Taner and Sheriff., 1977). Instantaneous Phase also finds utility in several key aspects:

- It serves as a prime indicator of lateral continuity.
- It pertains directly to the phase component of wave propagation.
- It enables computation of phase velocity.
- Due to its exclusive focus on phase, it captures all events without distortion by amplitude.

While it reveals discontinuities, it is particularly adept at highlighting continuities, which can be crucial in various geological contexts. It aids in identifying sequence boundaries and provides detailed insights into bedding configurations. Moreover, it plays a basic role in computing instantaneous frequency and acceleration (Taner *et al.*, 1979).

Results

The processing steps to build the regional section

The local seismic lines undergo a sequence of processes culminating in the creation of consistent seismic profiles. Key specifications of the local seismic lines utilized in constructing the regional profile are shown in detail in table (1) above. The seismic processing involves multiple post-stacking steps aimed at standardizing seismic parameters. This begins with individual downloads of the local seismic line from the data bank onto a computer disk (Explorations Company, Processing Department), followed by the integration of trace headers. This latter step is crucial for establishing a unified datum plane. Additional processing tasks encompass the establishment of geometry lines to define a standardized metric unit, a designated data type (FINAL STACK), interlinking lines, traces, sample rate, time sample, primary header (CMP), and secondary header geometry lines.

Given that the local seismic lines exhibit varying reference levels, it becomes imperative to rectify these levels to establish a unified reference point. For this project, sea level is adopted as the datum plane, as outlined in table (4). The time sample for all local seismic lines is set at four milliseconds. A box filter, termed "cap", is employed as a band-pass filter. This entails selecting two gates, one at the beginning and the other at the end, for each time and frequency interval. The objective is to ascertain the time samples, as elucidated in table (5).

The approach employed to ensure a robust representation of seismic reflectors involves the conversion of the seismic signal from the time-distance domain (time domain or space domain) to the frequency-number wave domain (frequency domain) using Fourier transform while preserving the original phase. This process is crucial for isolating the original signal from noise; thereby, amplifying the signal-to-noise ratio and enhancing reflector clarity are gained. The F-K power values (1.25) are chosen following extensive testing and applied against the stacked data to retain the authentic features of the seismic section. Signals are further refined by augmenting constructive interference and minimizing destructive interference, resulting in an amplified signal-to-noise ratio. A factor value of 0.3 is then multiplied with the preceding step to intensify the signal strength. Extensive testing is conducted to ascertain the appropriate factor value that amplifies the signal while preserving the original seismic characteristics. Automatic gain control is implemented to fortify weak reflections and attenuate strong reflections in a balanced manner, and automated process also supplements data in low-fold areas. A process is employed to eliminate noise data generated from preceding operations. Each local line contributing to the regional line undergoes a preliminary screening process, addressing any unavoidable gaps by populating them with an appropriate number of dummy seismic traces. These gaps are categorized into transverse creep gaps (overlapping) and discontinuity gaps as specified in table (6). The final regional seismic section, spanning approximately 530 kilometers, is a composite product obtained by linking a series of the finest local seismic lines, referred to as composite lines.

Table 4: The time shift of the considered seismic lines.

NO.	Line	Datum	Time Shift (msec)
1	TL-16	+500	-495
2	Kh-54	+300m	-296
3	AZ-16	+400	-389
4	At-32c	+200m	-204
5	At-32	+200m	-197
6	At-34E	+200m	-197
7	BW-1	Sea Level	0
8	NK-28	Sea Level	0
9	BW-7	Sea Level	0
10	ND-26	Sea Level	0
11	MD-23	Sea Level	0
12	MZ-23	Sea Level	0
13	DK-14	Sea Level	0
14	DK-96	Sea Level	0

Table 5: Box Band filter showing the end for each time and frequency.

Ts2	F1min	F2min	F3max	F4mx	Ts2
0	1800	10	14	35	45
2000	4000	8	12	30	40

Table 6: The position and type gap between the seismic lines.

No.	Between line	Length (km)	Gap type
1	TL-16 and KH-54	0.35	Overlap
2	AT-32 and AT34E	5.4	Discontinuity
3	AT34E and BW-1	1.3	Discontinuity
4	NK-28 and ND-26	5.3	Discontinuity
5	ND-26and MD-23	7.2	Discontinuity
6	MD-23and MZ-23	4.3	Overlap
7	MZ-23and DK-14	5.4	Discontinuity
8	DK-14 and DK-96	1.5	Discontinuity

Constructing regional line and definition of reflectors

A series of processing steps are employed on the fourteen local seismic profiles to augment the signal-to-noise ratio. This process led to the creation of synthetic seismogram logs for the well West Kifl-1 (Fig. 6). This particular well is considered one of the deepest wells in the center of the study area, reaching a depth of (5873m). Their data are augmented by incorporating top formation data from seven additional wells close to the regional profile. These wells are identified as KH4-3, KH4-5, KH7-1, EK-1, Kf-1, Me-1, Mu-1, Eb-30, EB-1, Nw-1 and TG-1.

The determination of horizon surfaces is established on the basis of reflection quality and continuity across reflectors, encompassing the time span from the Ordovician to the Miocene epochs. Seven distinct horizons from the previously mentioned wells are utilized for the purpose of selection. These horizons are labeled as Mirga-Mir, Geli-Khana, Kurra Chine, Najmah, Mauddud, Shiranish, and Fatha (Lower Fars).

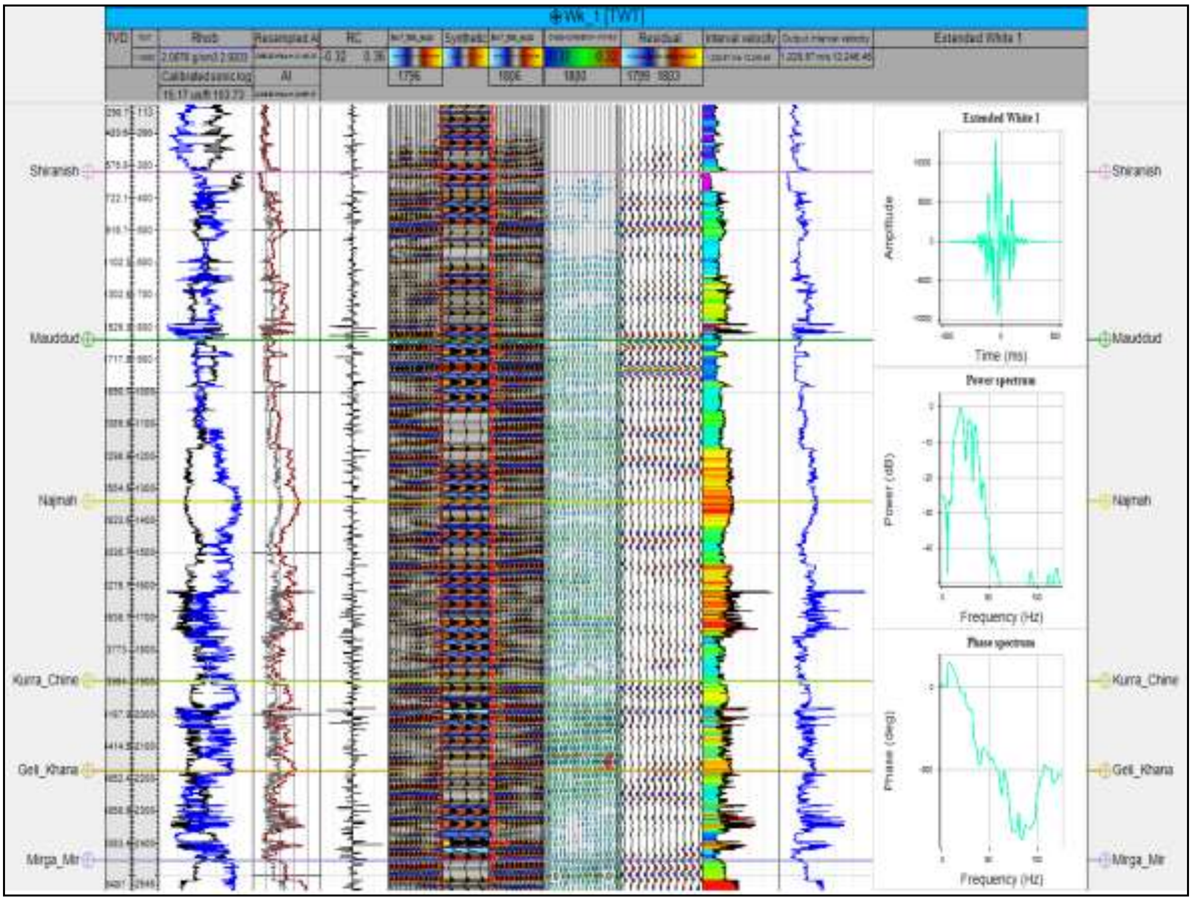

Fig. 6. The synthetic seismogram logs for the well West Kifl-1.

Structural and depth description

The regional seismic section systematically delineates the stratigraphic architecture from the western to the eastern expanse of Iraq facilitating the generation of highly detailed geological depictions along the examined profile. The chosen reflectors during the selection process exhibit a uniform dip of all stratigraphic units towards the eastern direction. It is noteworthy that the Salman tectonic zone indicates an elevated region partitioning the profile into two discernible domains or primary basins (Fig. 7).

The research has delineated a substantial number of faults, surpassing a cumulative tally of 121 and constituting the principal fault network exerting influence on the structures within the investigated region. Subsets of these faults are given in Figure (8). The instantaneous phase attribute is employed to enhance the figure of reflectors continuity within the seismic section. This is achieved through the utilization of the Hilbert transform and calculations of instantaneous phase (Fig. 9).

The assessment of depths to the upper boundaries of the Fatha, Shiranish, Mauddud, Najmah, Kurra-Chine, Gile-Khana, and Mirga-Mir formations entailed the multiplication of One-Way Time (OWT) by the corresponding average velocity values obtained from sonic log data and check shot information (Fig. 10).

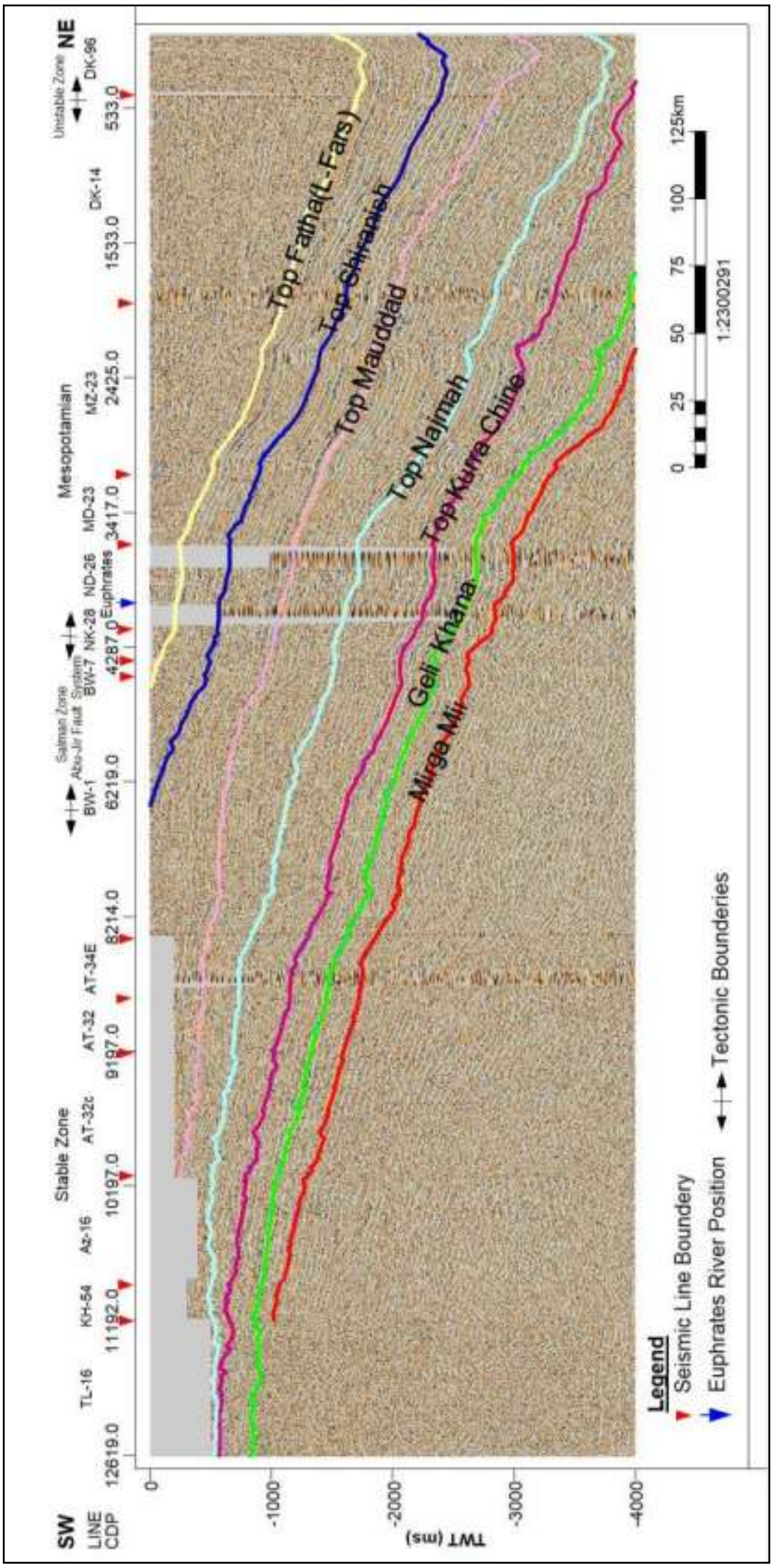

Fig. 7. The regional seismic section in the study area.

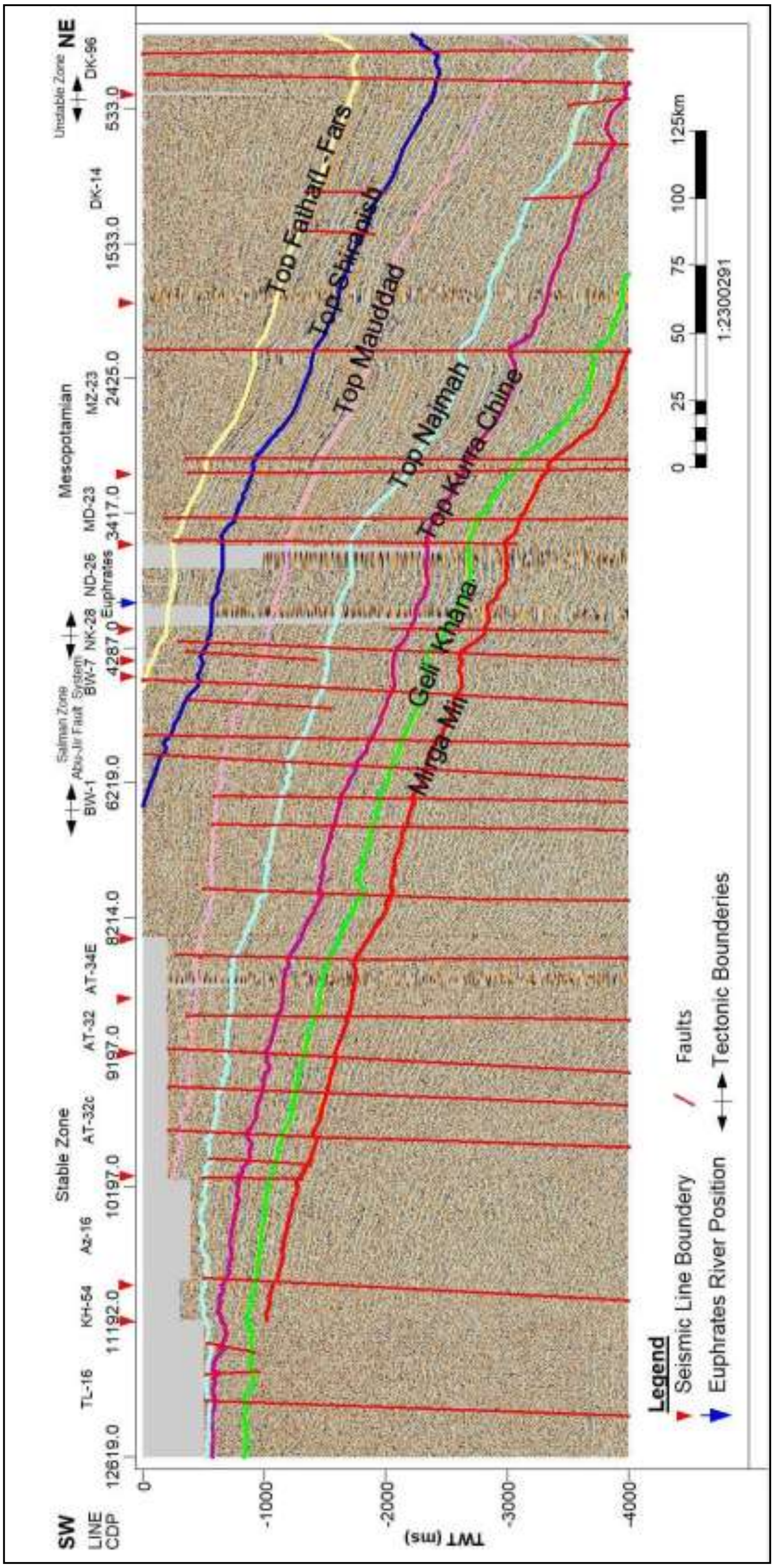

Fig. 8. The faults detected on the constructed regional seismic section.

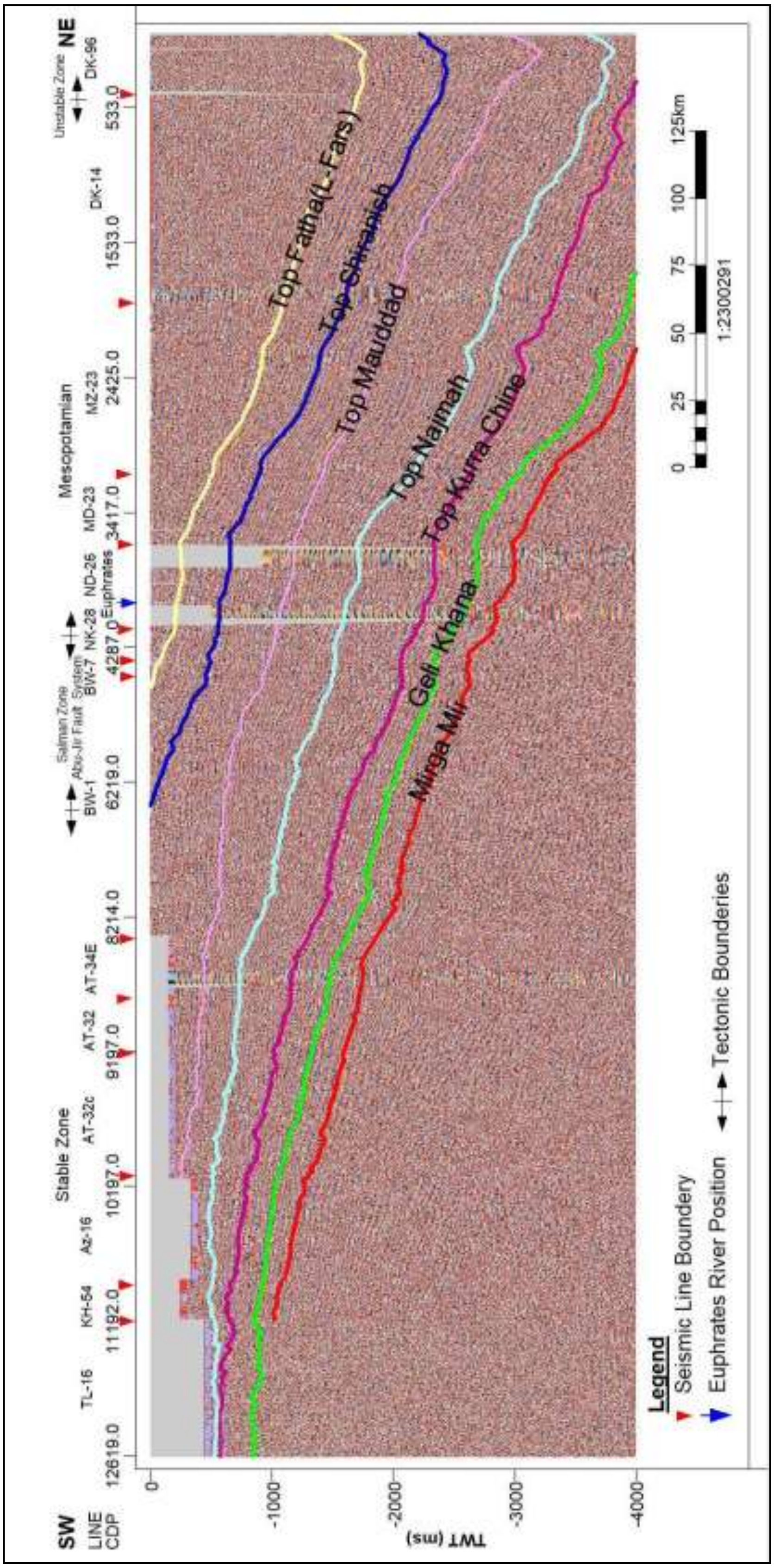

Fig.9. The Instantaneous phase of the regional seismic section.

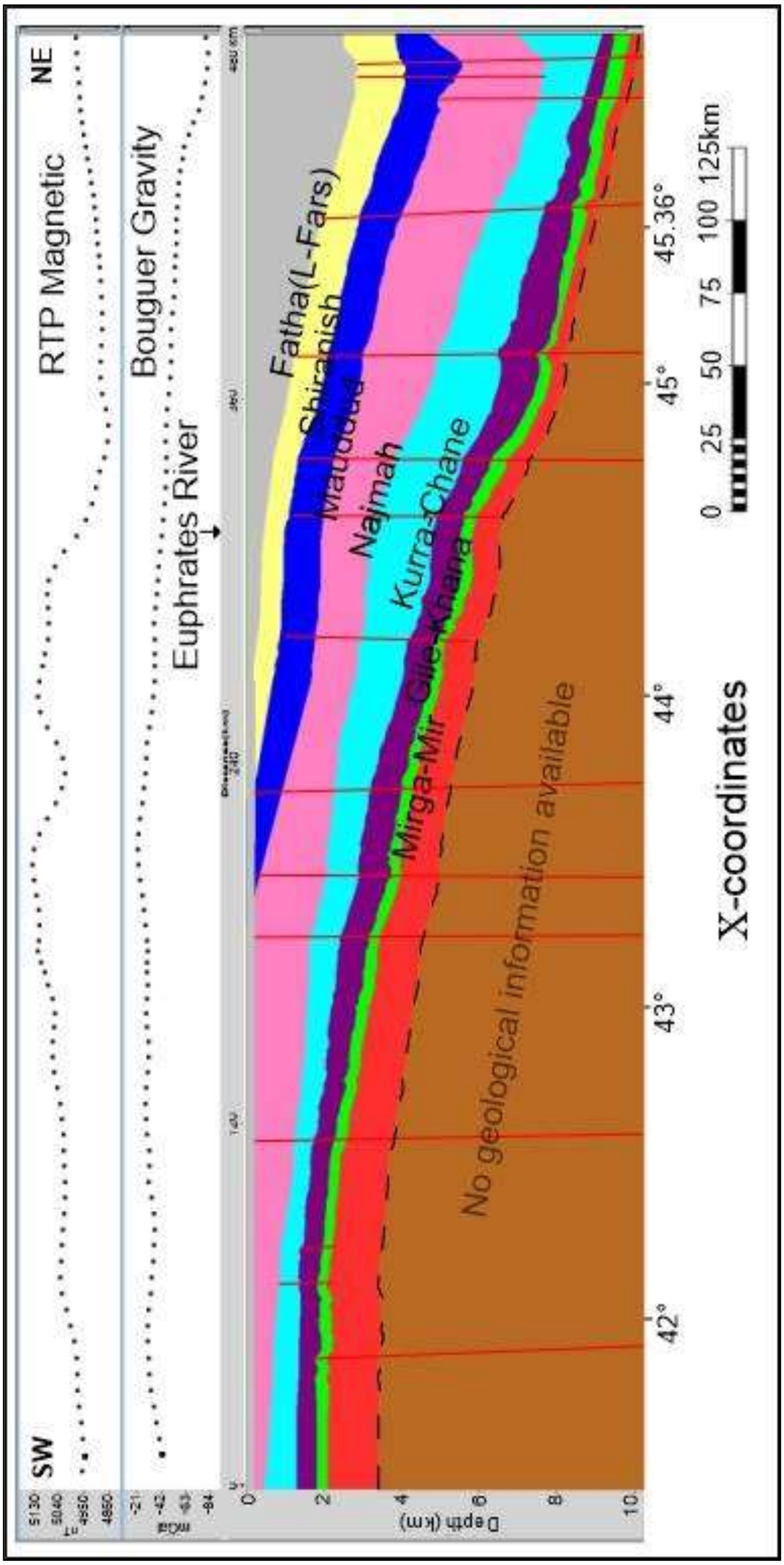

Fig. 10. The final geological model along the considered regional seismic section, depending on the seismic, gravity and magnetic modeling

Discussion

The constructed regional geophysical section is determined to delineate the two-way time and depth top of Fatha, Shiranish, Mauddad, Najmah, Kurra Chine Geli Khana, and Mirga Mir sections.

The gravity and magnetic profiles along the section exhibit congruence with the regional seismic profile.

The final geophysical profile delineates the presence of two sedimentary basins, the first basin lies within the Paleocene and older formations rocks on the western part of Iraq. The second basin represents mainly the Mesozoic and Cenozoic sedimentary formations eastern the considered section. The eastern basin is characterized by high sedimentary thickness deep basement rocks. These basins exhibit dissimilar geological ages, having been delineated along the regional seismic transect by a substantial uplifting structure known as the Hail-Khalisiya-Maridin axis.

The uplifted area in the middle of the study area between lines corresponds relatively with high gravity, and magnetic values are in the middle of the study area between longitudinal 43º -44º. The western part characterizes relatively low gentle gravity and magnetic values that reflects the effect of low variation within density and susceptibility relative to adjacent high potential anomaly values area. The high gravity values correspond with related low magnetic values along the profile at location between longitudes 45°- 46° may be due to a variation in the lithological basement rocks along the study transect compatible with deep basement depth.

Conclusions

1- The top depth of seven formations from the Ordovician to Miocene age is defined along the considered regional seismic section crossing central Iraq for first time. These formations are Mirga Mir (Lower Triassic), Geli Khana (Middle Triassic), Kurra Chine (Upper Triassic), Najmah (Upper Jurassic), Muddud (Mid-Cretaceous), Shiranish (Upper Cretaceous) and Fatha (Lower Fars, Mid Miocene).

2-It is found that the western part of the study area is characterized by thick Jurassic, Triassic and Paleozoic sedimentary columns, while the eastern part is characterized by thick Cretaceous and Mesozoic sedimentary columns.

3- An uplifted area in the middle of the study section is observed. This uplift seems to separate into two uplifts by a saddle shape. The western uplift located between longitudes 43º-44º and coincide with high gravity anomaly, while the second uplift located at the mid distance between longitudes 44°- 45°, coincides with high magnetic gradient.

4- The high gravity anomaly value at the location within the longitude 45°- 46° correspond with low magnetic value in eastern Iraq may be due to variation in the lithology of basement.

5 - About 121 minor and major faults were identified along the regional seismic section; extended from deep to shallow formation. A relatively broad zone delineated the boundary between Iraq's inner and outer Arabian platforms, including group of a lot of faults.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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