The Geology of Iraqi Territorial Waters, Northwest of the Arabian Gulf

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Abstract The Shatt al-Arab Delta is an important feature within the Iraqi territorial waters, it is primarily responsible for the nature, quality, and quantity of sediments transported to the area. The texture of the bottom sediment types in the Iraqi territory water is muddy with some places covered by sand. All of these sediments are reworked from the tidal flats, the river discharges, and the surrounding areas, and the aeolian deposits which are present in the area in notable quantity. The thickness of the sediments in the lands adjacent to the Iraqi territorial waters exceeds 250 meters, and the upper part of it dates back to the Holocene period, which is dominated by silt from the Shatt al-Arab delta, as well as a significant amount of dust storms. The area of the southern part of Mesopotamia is about 115,000 km2, due to the morphological location of the region, the Mesopotamian Basin was subjected to repeated processes of erosion and sedimentation phases, coinciding with the fluctuations that occurred in sea level during the Pleistocene era. The presence of some archaeological evidence supports the region's exposure to cycles of floods. The Arabian Gulf was formed during the past three or four million years, and there are also some islands and shoals that are attributed to the tectonic processes arising from the piercement of salt domes. The current coastline of the northwestern part of the Arabian Gulf arrived a little before 6,000 years ago. The sea-level rose about 1 to 2m above the present level, which induced an inundation to the lower area of southern Mesopotamia. The main marine morphological features in the northwestern part of the Arabian Gulf are the emergence of shoals, tidal flats, subaqueous channels, spits, and navigation channels. Due to the discharge of suspended loads of the Shatt al-Arab River and the stopping of the dredging in the mouth of the river, the main navigation channel of the Shatt al-Arab River continuously moving toward the west and forming three lobes which are successively active with time.

Keywords Geology · Physiography · Sedimentology · Mineralogy · Arabian Gulf · Iraqi Coast

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L. A. Jawad (ed.), *The Arabian Seas: Biodiversity, Environmental Challenges and Conservation Measures*, https://doi.org/10.1007/978-3-030-51506-5_9

1 Introduction

The study area is situated in the northwestern part of the Arabian Gulf. In order to read the geology of that area, it is obligated to read the geology of the southern part of the Mesopotamia. The Arabian Gulf is considered as an epicontinental sea that tends from northwest to southeast from the Iraqi territory to the Gulf of Oman (Fig. 1). Its length is about 1000 km and width ranges from 60 to 340 km (Evans 1966). The axis of the gulf is nearest to the Iranian side, with maximum depth ranges from 80 to100 m. The Arabian Gulf was divided, along its longitudinal meridians, to a number of basins or sectors (Seibold and Vollbrecht 1969); these are the central basin, the eastern basin, and the central swell which divides the Iranian side into two secondary basins, which are the western basin and the central basin (Fig. 2). The western basin is terminated by the platform that called the Mesopotamian Shallow Shelf. The Arabian Gulf includes many islands, these are the islands near the Iranian side which are formed by subsurface anticlines, and the islands in the central basin are formed by subsurface salt domes. Generally, the eastern side of the gulf is dominated by clastic sediments transported from the Zagros Mountain of the Iranian territory, whereas the western side is dominated by carbonate and evaporite sediments (Karim and Salman 1988).

The northwest part of the gulf, which represents the area of this study, is influenced by clastic sediments originated from the Shatt Al-Arab River and the

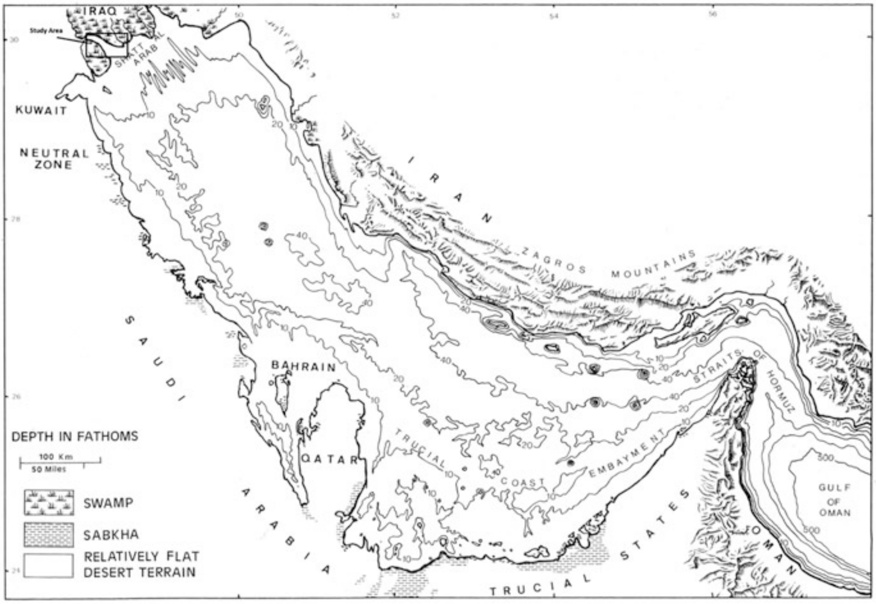

Fig. 1 Location of the study area (after Purser and Seibold 1973)

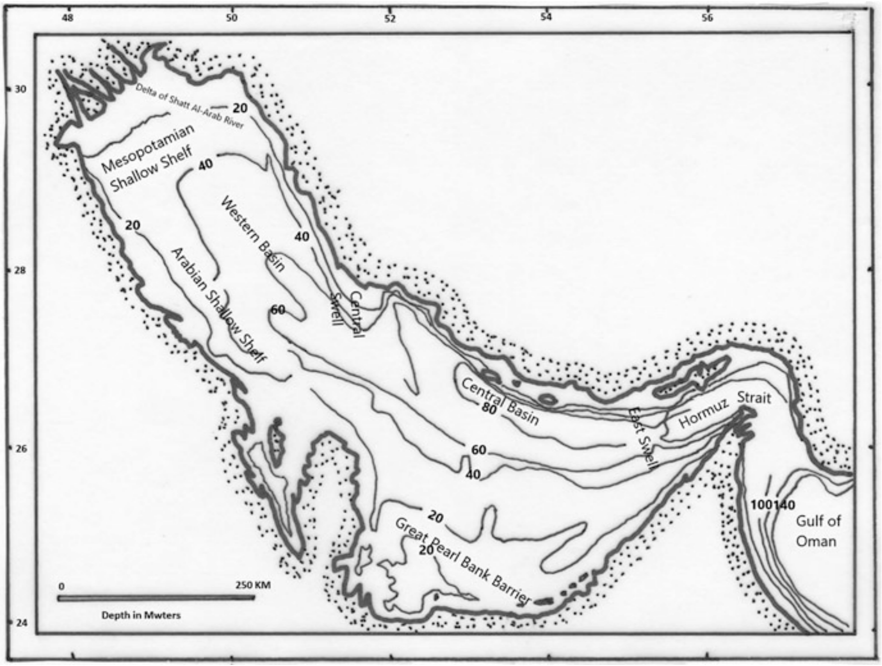

Fig. 2 Basins of the Arabian Gulf (after Seibold and Vollbrecht 1969)

Khor Al-Zubair (Albadran 2004). Many physiographic features present in the northwestern part of the gulf that could be related to the tectonic activities in the area.

2 Lower Mesopotamia

The southern part of the Mesopotamia is one of the most important regions in both ancient and modern Iraq. It is near the center of the so-called Fertile Crescent that is characterized by a low topography. It contains widespread Quaternary deposits of the Tigris and Euphrates Rivers (Jassim and Goff 2006). The thickness of these deposits in the southern part of the Mesopotamia exceeds 250 m, and the upper part belongs to the Holocene age and comprises silts of fluviatile flood and aeolian (Kukal and Saadalla 1973). Generally, the cultivated area covered by a huge forest of date palms. Southern Iraq bears a very economic importance since it is the home to perhaps 5% of the world's total oil reserves. The largest oilfields in southern Iraq include Rumaila, North Rumaila, West Qurna, and Majnoon.

The Mesopotamia during the Plio-Pleistocene to the present was a vast basin in which relative thick Quaternary sediments accumulated. According to Fox and Ahlbrandt (2002), the surface of the Mesopotamia is flat and covered by Quaternary fluvial-aeolian plain deposits of the Tigris and Euphrates Rivers and mash/lacustrine sediments of southern Mesopotamia. The lower Mesopotamia covers about 115,000 km^2 that is located within the Iraqi Territories. Based on Al-Sayyab et al. (1982), the area extends for about 600 km in length and 250 km in width. The average elevation of this plain is 65 m above sea level near the northern part and gradually decreases in the southeast direction toward the Arabian Gulf. The slope of the Tigris and Euphrates Rivers within this plain is 9.6 and 10.5 cm/km, respectively. The lower Mesopotamia is mostly covered by muddy sediments that are consisted mainly of fluviatile flood silt with strong aeolian admixture (Kukal and Saadallah 1973). The presence of marine sediments has been proved in this area too; therefore, the existence of some brackish-estuarine deposits might be supposed as well (Buday 1980; Al-Hamad et al. 2017; Abdalrazak et al. 2017). Because of the advantage of geographic position and morphological situation, the basin of the Mesopotamia was most probably subjected to periodically repeating phases of accumulation and erosion (washing out) in accordance with the periodical fluctuations of the sea level caused by cyclic changes during the Pleistocene (Aqrawi 1993).

3 Physiography of the Study Area

The area of Iraqi territory waters includes many physiographic features, which could relate to the tectonic and/or sedimentological activities (Al-Asfour 1982; Al-Mosawi 2015). The main feature of the area is the delta of the Shatt Al-Arab River in the middle of the area (Fig. 3). At the end of this delta, there are three subaqueous distributary channels. These subaqueous channels are called (from the west to the east) Khor Al-Kafka, Khor Al-Umaya, and Khor Al-Roka (Fig. 3). The depth of these Khores is between 20 and 24 m (Admiralty chart No. 1350). The depth is related to the lowest low water in the area. According to Kassler (1973), these khores were the subaerial distributary channels of the delta of Shatt Al-Arab River during the glaciation periods, where the sea level drown down about 60 m, followed by transgression and flooding periods during the deglaciation. There are many archeological evidences that proved that the Mesopotamian plain subjected to many cycles of flooding. For instance, the occurrence of the 2.5 m bed of clay confirms the major flooding mentioned in the story of Noah (Pournelle 2003).

To the east of the delta, there is the Khor Mossa of the Iranian territory, and to the west of the delta, there is the large channel, called Khor Abdullah. Khor Abdullah is situated between the Iraqi and Kuwaiti territories. It tends NW-SW direction and is ended to the northwest by the Khor Al-Zubair. The depth of the Khor Abdullah and Khor Al-Zubair is between 10 and 14 m. Two Kuwaiti islands southwest of Khor Abdullah are present: the Warbah Island at the northern end of Khor Abdullah and the Bubiyan Island at the southern end of Khor Abdullah (Fig. 3). The axis of Khor Abdullah is near the coasts of these islands.

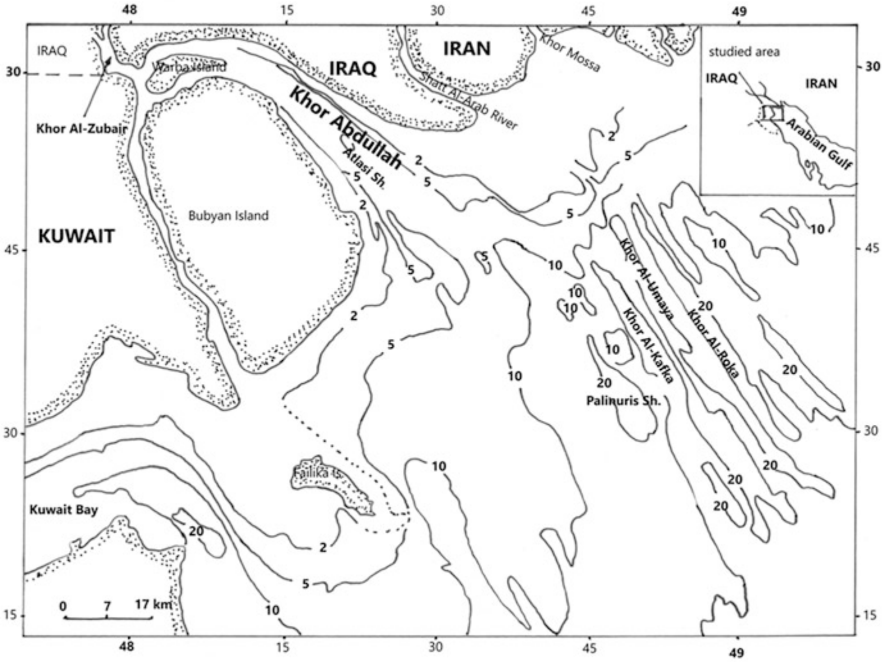

Fig. 3 Physiography of the study area (depth in meter)

In the area, many shoals are present as Palinuris and Atlassi shoals. The first one is to the southeast end of Khor Abdullah, and the second is in the middle of Khor Abdullah.

4 Tectonic Setting

The northern part of the Arabian Gulf is the remnant of the old Tethys Sea, which closed at the late Eocene (Buday and Jassim 1987). The basement rocks under the Gulf are inclined toward the northeast, covered by the sedimentary column which belongs to shallow environments (Al-Ghadhban 2002).

Iraq is situated on the border of the Arabian Plate; this plate converges with the Eurasian Plate. The convergence was started at the Miocene during the closing of Neo-Tethys Ocean and continues to the present day (Dewey et al. 1973; Numan 1997; Abdulnaby et al. 2016a). Due to this situation of Iraq, it induced two fault systems: longitudinal one NW-SE and transverse NE-SW and/or EW. For Abdulnaby et al. (2016b), the longitudinal faults are more active in the area.

The nearest fault to the study area is the Euphrates Fault, composed of many step faults (Jassim and Goff 2006) formed by the Najd Orogeny (Pre-Cambrian). The N-S trend of faults Nabitah fault system is prominent in the south and west of Iraq (Jassim

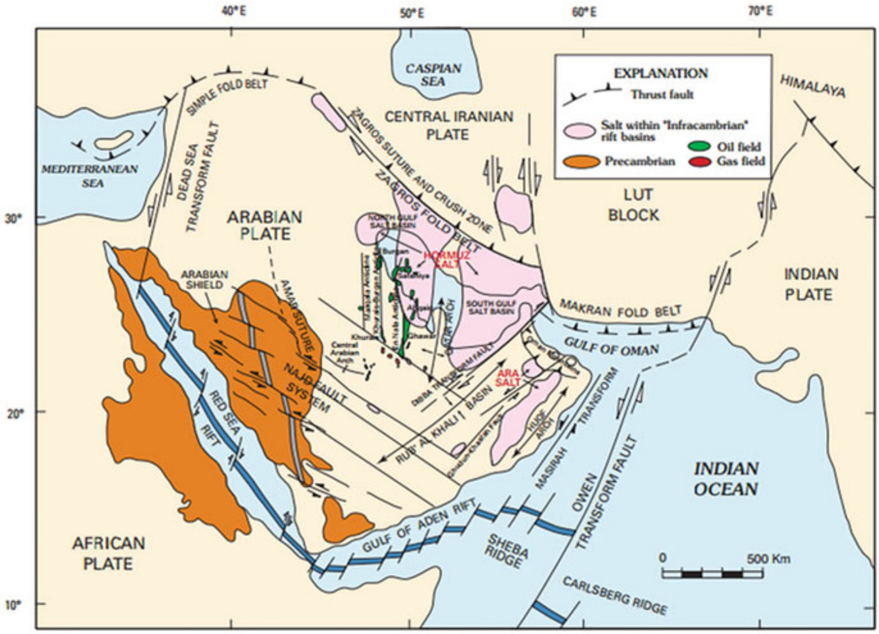

Fig. 4 Tectonic map of the area (www.usgs.gov)

and Goff 2006). The lower Mesopotamian depression includes the southern part of Iraq, the northern Arabian Gulf region, and the northeastern corner of Saudi Arabia. It is bounded on the east by the Zagros Mountains, on the west by the great Nefud Deserts and the Syrian Plateau, and on the south and southeast by the Arabian Gulf (Fig. 4). The southern part of Iraq can be divided into two main physiographic provinces, namely, the lower Mesopotamian plain and the Southern Desert (Buringh 1960).

The lower Mesopotamian plain includes Pleistocene fluviatile terraces, Holocene floodplains, and the delta plain of the Tigris, Euphrates, and Karun Rivers. These plains mostly border the western limit of the lower Mesopotamian plain and include the southern parts of the stony Al-Hajar plain and the gravel and sand regions of Al-Dibdibba (Al-Naqib 1967). It is characterized by extensive belts of sand dunes.

The southern part of Mesopotamia is situated in the Zubair subzone of Buday and Jassim (1987), which is controlled by the underlying basement rocks. This subzone also is covered by the Quaternary sediments derived from the marsh, lacustrine, and fluvial/aeolian origins of the Tigris and Euphrates Rivers (Fox and Ahlbrandt 2002). Karim (1989) mentioned that this subzone contains many subsurfaces gently plunging structures of different size. These subsurface structures are the main traps of the oil field in the area. The tectonic activities in the area could relate to the Alpine Orogeny, which produces a movement of blocks on the fault planes in the basement rocks. This movement is still effective to the present days and enhanced by the existence of the thick salt beds of Hormuz and Gotnia Formations (Al-Sakini 1995). For Lees and Falcon (1952), the area is tectonically active and continuously subsided as in the marshes. Abdulnaby et al. (2016a, b) considered that the area is tectonically active and continuously uplifted. Fouad and Sissakian (2011) classified the Mesopotamia fore-deep into two plains, Mesopotamia plain and Al-Jazira plain, and both of them are unstable plains.

The marshlands originated during the Holocene period following the end of the last glacial maxima (Al-Sudani 2015). The area was subjected to an extensive marine transgression in the Middle and Late Holocene in response to rapid sea-level rise (Larsen and Evans 1978; Evans 1979; Rzoska 1980; Yacoub et al. 1981; Al-Azawi 1986; Baltzer and Purser 1990; Lambeck 1996; Aqrawi 2001). This led to the shoreline to be far north of its present position, followed by a delta progradation due to eustatic sea-level changes. The result of this transgression during the Holocene was the deposition of the Hammar Formation underneath the fluvial deposits (Hudson et al. 1957). The sea level has fluctuated above and below the present level during the last 7000 years (Al-Asfour 1982). The geomorphological and satellite images could indicate that the Tigris and Euphrates Rivers were flowing separately into the Arabian Gulf (Al-Sakini 1993). Some geomorphological features near the northwestern part of the Arabian Gulf were related to the tectonism as the detachment of Bubiyan and Warbah Islands by local faults of NE-SW trends (Al-Asfour 1982).

The Shatt Al-Arab River is located in the southeastern part of the Mesopotamian plain, within the unstable pavement of the Arabian Plate. This area is characterized by a column of thick sediments, and the sedimentary cover of the unstable pavement and with subsurface geological structures in the areas passing through the Shatt Al-Arab River (Buday and Jassim 1987) induced a shifting in the channel of the river in many areas. The study of Karim et al. (2010) reported that the subsurface structures refer to the negative residual anomaly, including the structures of the Nahr Umar, Zubair, North and South Rumaila, and the Basrah Depression. This indicates the presence of light plugs due to the salt layers, and positive anomaly such as the subsurface Siba anticline and the Jabel Senam, which represents a saline dome. For Konyuhov and Maleki (2006), the region has landscape climatic conditions, which are favored by carbonate rocks and evaporites.

Khaleefa (2014) gives evidence about the tectonism of the area by the formation of islands in the Shatt Al-Arab River channel due to the uplift indicated by the emergence of islands of the Shatt Al-Arab River. Kassler (1973) mentioned that the Gulf was formed during the last 3 or 4 million years, and there are many islands and shoals which belong to the tectonic activity produced by the piercement of salt domes in the area. Al-Mosawi (2015) also correlates all the bottom features of the Gulf to the tectonic vertical uplift induced by the deep salt domes.

5 Stratigraphy

The crystalline basement of Iraq belongs to the Arabian part of the African (Nubio-Arabian) Precambrian Platform. The folded metamorphosed and intruded complexes forming the basement are generally considered Precambrian. Cambrian rocks are generally attributed to the cover of the platform (Buday 1980). The basement rocks in Iraq are composed of metamorphosed and partly metamorphosed Late Precambrian and granite-intruded lower Infracambrian rocks, which are correlative with the Telbismi and Rizu Formation and belong to the Najid orogenic cycle (Buday 1980).

The source of stratigraphic information dealings with the Paleozoic and a large part of Mesozoic Era are gathered from neighboring countries. Because of no surface exposures older than Tertiary were available in Basrah area and the absence of any deep oil well that reaches the rocks of Paleozoic Era, the best known stratigraphic column in the southern part starts from Jurassic to Recent (Fig. 5). Paleozoic formations are cropping out on restricted areas in northern Iraq and in the top of part of Rutba Uplift (Ga'ara area); furthermore, they were struck by some borehole between Khleisia and surroundings Mosul. The Paleozoic sedimentary sequence fall into three characteristic major sedimentary cycles, which separated by relatively major breaks, that indicate mainly the effect of Caledonian and Hercynian Orogenies. These cycles from older to younger: Cambrian-Ordovician, the Devonian (Late Devonian)-Lower Carboniferous cycle, and Upper Carboniferous-Upper Permian cycle (Buday 1980).

The Neo-Tethys Ocean opened in the Late Permian time when one or more narrow blocks of continental crust drifted away from the northeast margin of Gondwana. The Late Permian-Triassic mega sequence was deposited in the north and east facing passive margin of the Arabian Plate. The unconformity at the base of the mega sequence is a breakup unconformity. Sharland et al. (2001) define two tectonic mega-sequences on the Arabian Plate encompassing Late Cretaceous and Early Tertiary time—AP9 and AP10. Renewed rifting occurred within the passive margin in Mid-Late Triassic time creating a highly restricted intraplate basin in Mesopotamia separated from the open ocean by a narrow rift with alkali basalts and outer ridge of the thinned crust on which an open marine carbonate platform developed. This phase is Norian-Liassic (Jassim and Goff 2006). During the Cenozoic Era, many formations were deposited in the southern part of Mesopotamia that started from Umm Er Radhuma to Rus, Dammam, Dibdibba, Lower and Upper Bakhtiari, and Upper Fars. During the Plio-Pleistocene, Mahmudiya Formation was deposited followed by deposits of river terraces and fluvial and alluvial fans in the Pleistocene and terminated by Hammar Formation in the Recent.

The source of subsurface stratigraphic information is from deep oil well named Diwan-1. This well was drilled by Iraq National Oil Company (INOC) and spudded in April 1988. The well reached the bottom of Paleozoic Permian Chia Zairi Formation. The Hurmuz series crop out at Jabal Sanam which is situated in Basrah, south of Iraq. However, Buday and Jassim (1987) determined that Late Infra-Cambrian to Cambrian about 580 M.Y.

The Chia Zairi Formation was deposited in a transgressive neritic sea on board carbonate platform with a locally developed lagoonal condition and Sabkha. The Chia Zairi Formation is rich in fossils, the corral and algal fauna indicate a Mid-Late Permian age, and the uppermost beds of the formation are some Early Triassic fauna.

The Mirga Mir Formation was first described by Wetzel (1950 cited in Van Bellen et al. 1959) in the region of the Northern Thrust Zone. According to the

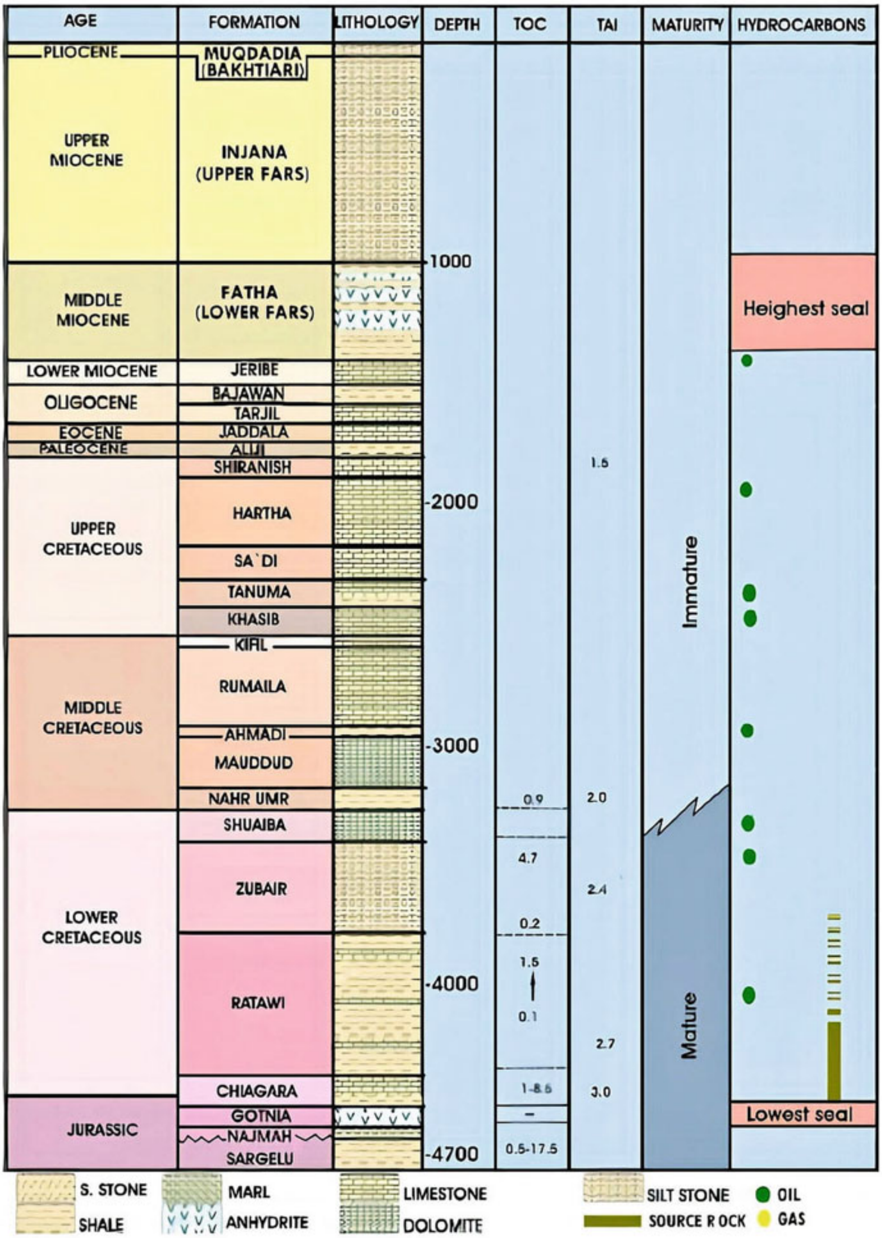

Fig. 5 Stratigraphic succession of the southern Mesopotamia (after Darweesh et al. 2017b)

fossils, a Lower Triassic (Lower Werfenian) age was attributed to the Mirga Mir Formation. In its type section, the formation is composed of 200 m thin-bedded gray, and very typical, yellow clayey limestone and shales, with some recrystallized breccia, some oolitic limestone, and rare sandy admixture had been ascertained near the base of the formation (Van Bellen et al. 1959). In well Atshan-1 of the Foothill Zone, the formation contains a higher proportion of clastics probably derived from Rutba uplift to the southwest.

The thickness of Mirga Mir Formation is 165, 134, and 99 m in Jabal Kand-1 in north Iraq, west Kifl-1 in south-central Iraq, and in Diwan-1 in southern Iraq, respectively. Mirga Mir Formation in conformably underlain by the Chia Zairi Formation. In type area the upper boundary could not be ascertained due to the alternation of the purplish and yellowish-grayish colored beds (Hamza and Issac 1971). The formation is also present in the High Folded Zone in the Sirwan Gorge in northeast Iraq (Van Bellen et al. 1959). In the stable shelf, its most western occurrence is probably along the western boundary of the Salman Zone. Anhydrites in well Atshan-1 and the presence of a solution of breccia in outcrops also indicate lagoonal conditions (Jassim and Goff 2006).

6 Basement Sedimentary Cover

It is believed that the Mesopotamia plain represents a huge depositional basin. The estimation of the total thickness of the Mesopotamian sedimentary column based on the geophysical researchers still forms a point of controversy between authors. Based on the geophysical survey carried by C.G.G. (1974), the depth of basement ranges between 10 and 13 km. In general, the characteristics of sedimentary cover in the Mesopotamia, particularly in the Basrah region, could be summarized in the following points:

1. The great thickness
2. The absence of mega sedimentary break
3. The shallowness of sedimentary environments

The basement rocks are faulted and affected by compression and tension stress with geological time (Darweesh et al. 2017a). Recently, the basement rocks are affected by uplift movements induced by the piercement of salt domes in the area. These uplift stresses, due to faulting and piercement of salt domes, could be responsible for the origination of the giant anticlines in the area.

7 Geomorphology and Sedimentology

7.1 Geomorphology

The existing geomorphologic features of Iraq started forming in Late Miocene-Early Pliocene era, associated with the more recent history of the territory's geological evolution. The present shoreline of the northwestern part of the Arabian Gulf was reached shortly before 6000 years ago (Lambeck 1996). The sea level rose about 1 to

2 m above the present level, which induced an inundation to the lower area of the southern Mesopotamia. Where recent intensive uplifts are present, the area has mountainous erosion denudation topography. A variety of morphologic relief features are present here, because Iraq is underlain by rocks of different lithology and different susceptibility to exogenous geomorphologic processes. The following relief types may be distinguished: denudation, erosion-denudation, and aggradation. Many topographic features could be found in the southern part of the Mesopotamia (Fig. 6) such as (1) the lakes as Al-Hammar, (2) rivers, as the Tigris, Euphrates,

Fig. 6 Topographic features and sedimentary environments of southern Mesopotamia (after Sissakian et al. 2014)

Karun, Shatt Al-Arab, and the irrigation canal that connected by Khor Al-Zubair, (3) mountain belt to the east that is called Zagros Mountain, (4) tidal flats near the mouth of Shatt Al-Arab River, (5) marine and on land sabkha, (6) alluvial fan of Al-Batin, and (7) desert to the southeast of the Mesopotamia.

Owing to Buringh (1960), the southern part of Iraq can be divided into three main physiographic provinces; these are the Dibdibba plain, Lower Mesopotamian plain, and Western Desert and covered by a thick column of quaternary deposits (Aqrawi et al. 2006) (Fig. 7).

The regional slope of the southern part of the lower Mesopotamia plain is about 26.7 cm/km with a general southeast trend toward the Arabian Gulf, while the general slopes of Dibdibba plain is toward the northeast. The maximum elevation of northern part of Basrah Governorate is 4 m above sea level (Qurna city) and the sea level at the distal part of the governorate (coastal area and tidal flats) (Al-Khaiat 2002).

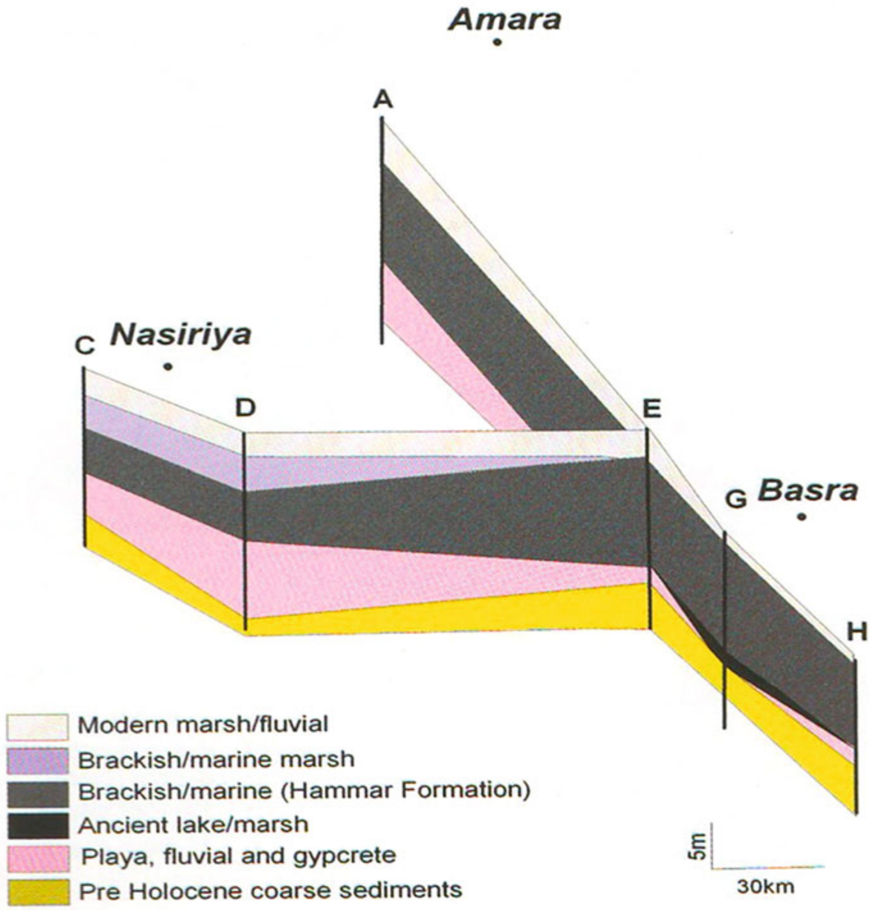

Fig. 7 Quaternary sediments of the southern Mesopotamia (after Aqrawi et al. 2006)

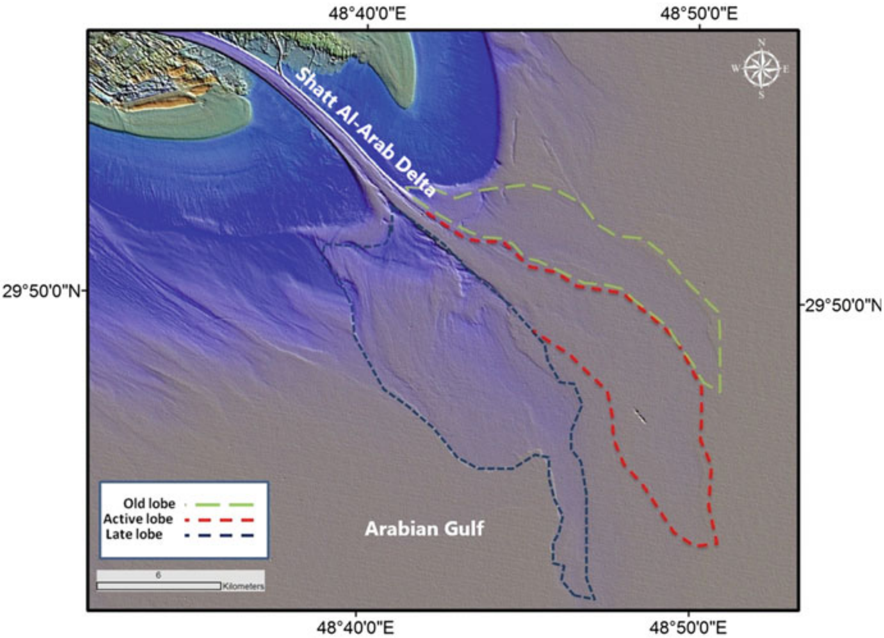

Fig. 8 The lobes of the Shatt Al-Arab River (after Albadran et al. 2016)

The main marine morphologic features of the northwestern part of the Gulf are demonstrated by shoals, tidal flats, subaqueous gullies locally called Khor (In Arabic), spits, navigational channel, flat plateau of the Shatt Al-Arab delta, and khores. The subaqueous khores formed during the last regression (Kassler 1973) and during this regression acted as a funnel to withdraw the sediments derived from the Shatt Al-Arab River (Albadran 2004).

Due to the discharge of suspended loads of the Shatt Al-Arab River and the stopping of the dredging in the mouth of the river, the main navigation channel of the Shatt Al-Arab River continuously moves toward the west forming three lobes which are successively active with time (Albadran et al. 2016) (Fig. 8).

7.2 *Sedimentology*

The surface sediments are mainly composed of friable and loose sediments derived by the Tigris, Euphrates, and Karun Rivers (Khan et al. 1992) (Fig. 9). The textures of the northwest part of the Gulf area are classified into (1) sand covering the surrounded area of Kuwait and the western part of Iraq and (2) the silt and clay, dominantly fine clay, covering the southern part of Iraq represented by a wide tidal flat near the mouth of Shatt Al-Arab River to a narrow strip near the northern end of Khor Abdullah.

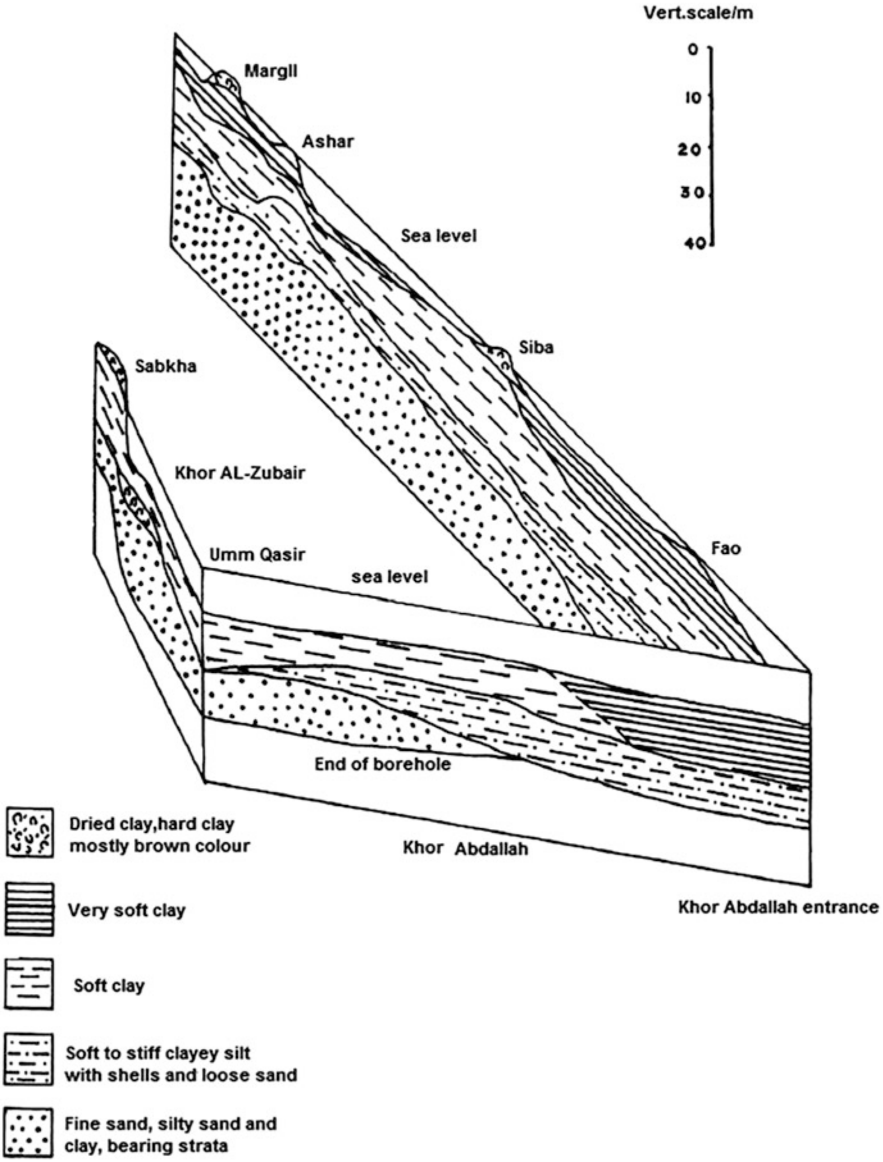

Fig. 9 Quaternary deposits of the Iraqi territorial waters (after Khan et al. 1992)

The Kuwaiti Islands (Bubiyan and Warbah) are also covered by silt and clay sediments, except narrow spits of sand attached to the southeast of Bubiyan Island. According to the bottom sediment types, the aerial distribution of the sediments in the Iraqi territory water is muddy with some places covered by sand (Albadran 1992) (Fig. 10). All of these sediments are reworked from the tidal flats, the river discharges, and the surrounding areas, and the aeolian deposits which are present in the

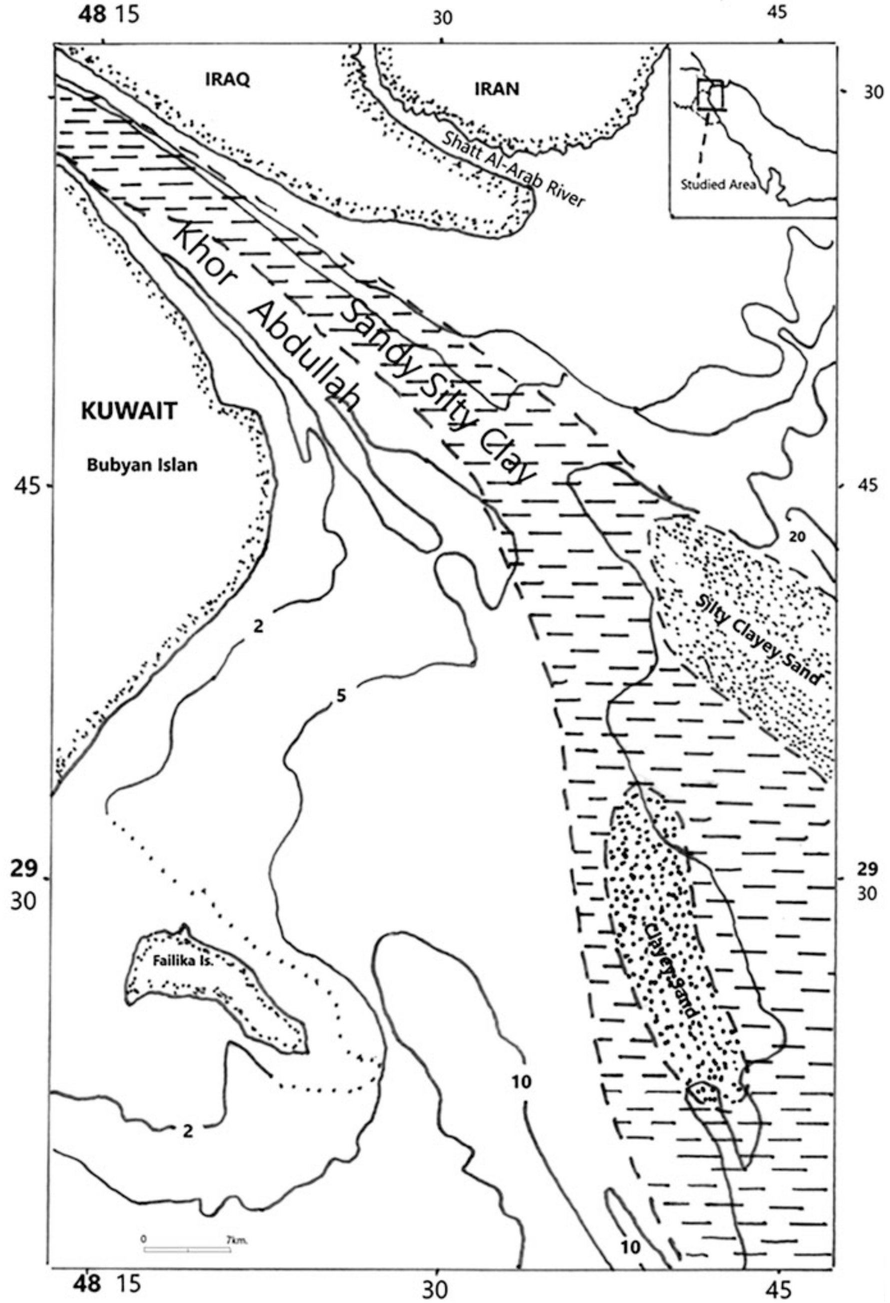

Fig. 10 Texture of the gulf bed (modified from Albadran 1992)

area in notable quantity (Khalaf et al. 1984). The deltaic sediments in the marsh area dominated by silt fraction (Salman 1980) as lacustrine deltas of Tigris and Euphrates Rivers have been constructed during sea-level fluctuations and climatic changes (Aqrawi 1993).

Mineral composition of the area in descending order of percentage is quartz, calcite, feldspar, dolomite, gypsum, and halite as the main light minerals, and the heavy minerals are opaque, unstable, and metastable groups (Albadran et al. 1996; Al-Jaberi 2015). The clay minerals are kaolinite, palygorskite, illite, montmorillonite, and illite-montmorillonite mixed layers (Albadran et al. 1996; Albadran and Hassen 2003; Al-Jaberi 2015). Albadran and Issa (2011) suggested according to the foraminifera assemblage that the shoals in the area could represent ancient beach rocks during the regression in the area.

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