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Geology of the Tigris River with Emphasize on the Iraqi Part

Varoujan K. Sissakian[1], Nadhir Al-Ansari[1], Nasrat Adamo[2], Sven Knutsson[2] and Jan Laue[2]

Abstract

The Tigris River is the longest river in Iraq with 5 main tributaries inside Iraq. The river flows from the Eastern highlands of Turkey then crosses the Iraqi territory from extreme north-western part to the central part then meets with the Euphrates River in the southern part. The geology of the Tigris River's basin is presented with emphasize on the Iraqi part. Besides, the stratigraphy of the basin, the tectonic style, main geomorphological features and minerals' resources are presented within the basin too. Wide range of rocks; age wise, are exposed in the basin, with different economic potentials at different parts of the basin.
This study is a unique one, which deals with the geology of the Tigris River's basin. It is conducted using the most relevant updated geological data.

Keywords: Tigris River, Tributaries, Geology, Mineral potential

1 Introduction

Geological studies dealing with different parts of any river are a very common; however, dealing with the whole course within the catchment basin of a certain river with its tributaries are extremely rare, especially in Iraq. The geology of different parts of the Tigris River within the Iraqi territory is given in details in the geological quadrangles through which the river flows at a scale of 1: 250000. These are from northwest, where the river enters Iraq until it meets the Euphrates River in the southern part of Iraq (Fig.1): Zakho (Al-Musawi et al., 2005), Mosul (Sissakian et al., 2013), Qayara (Zuwaid, 1993), Kirkuk (Sissakian and Fouad,

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[1]University of Kurdistan, Howler, KRG, Iraq and Private Consultant Geologist, Erbil, Iraq
[2]Lulea University of Technology, Lulea, Sweden

2014), Baghdad (Deikran, 1995), Hilla (Barwary and Slewa, 1993), Kut (Barwary and Slewa, 1992), Ali Al-Gharbi (Barwary and Slewa, 1995), Amara (Yacoub, 1996), and Al-Basra (Yacoub, 1992).

The geology and topography along the courses of the Tigris River and its tributaries are given with many satellite images and different maps for clarification purposes. However, the given details in Turkey, Syria and Iran are presented more briefly, as compared to those given in Iraq.

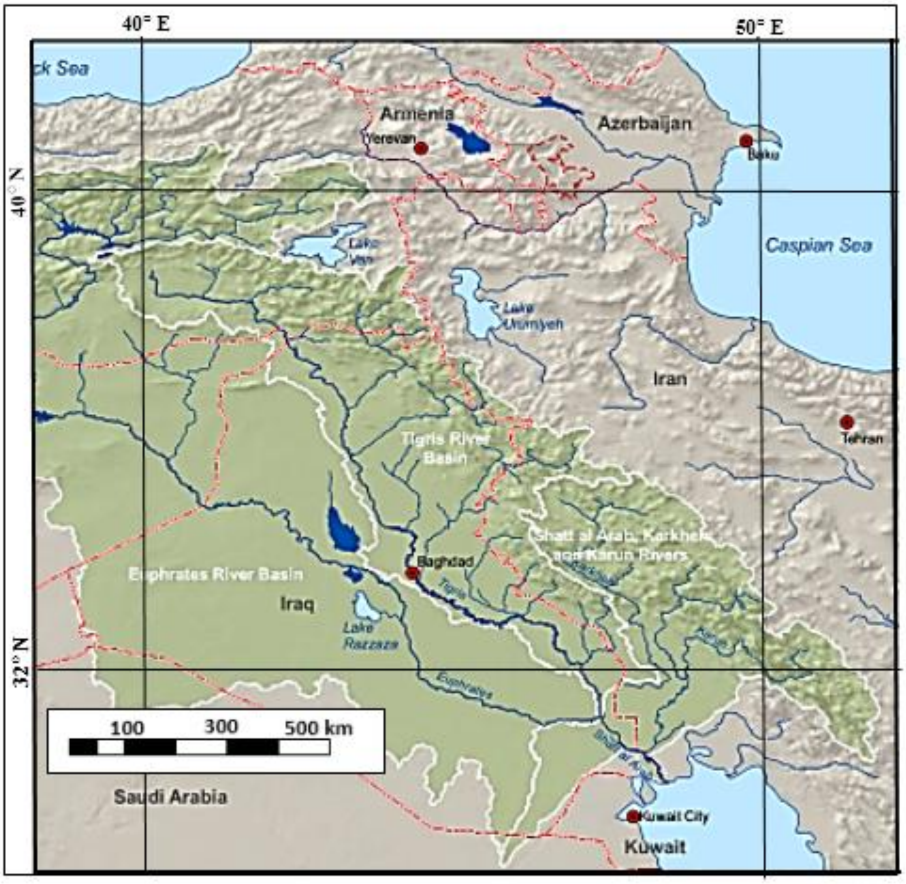

Figure 1: The Tigris River's basin map (Modified from ESCWA, 2013)

The aim of this study is to present the geology of the Tigris River's basin, which extends from Turkey to Iraq and Iran. The stratigraphy, tectonics and structural geology and the main geomorphological features and units are briefly mentioned with the main economic potentials; as far as the geology is concerned; such as oil, gas, metallic and non-metallic minerals and industrial rocks.

To fulfil the aim of this study, the following materials were used:

- Geological maps of different scales
- Satellite images
- Relevant published articles and different geological reports

Geological maps of different scales of different parts of the Tigris River's basin were used with the help of the satellite images with different resolutions to indicate the stratigraphy, tectonics, structural geology and geomorphology of the basin. In Iraqi territory, the Series of Geological Maps of Iraq at scale of 1:250000 (Fig. 2) were used to present all the important geological aspects. To indicate the economic potential as far as geological materials are concerned: many relevant geological reports and published articles of different parts of the basin were reviewed.

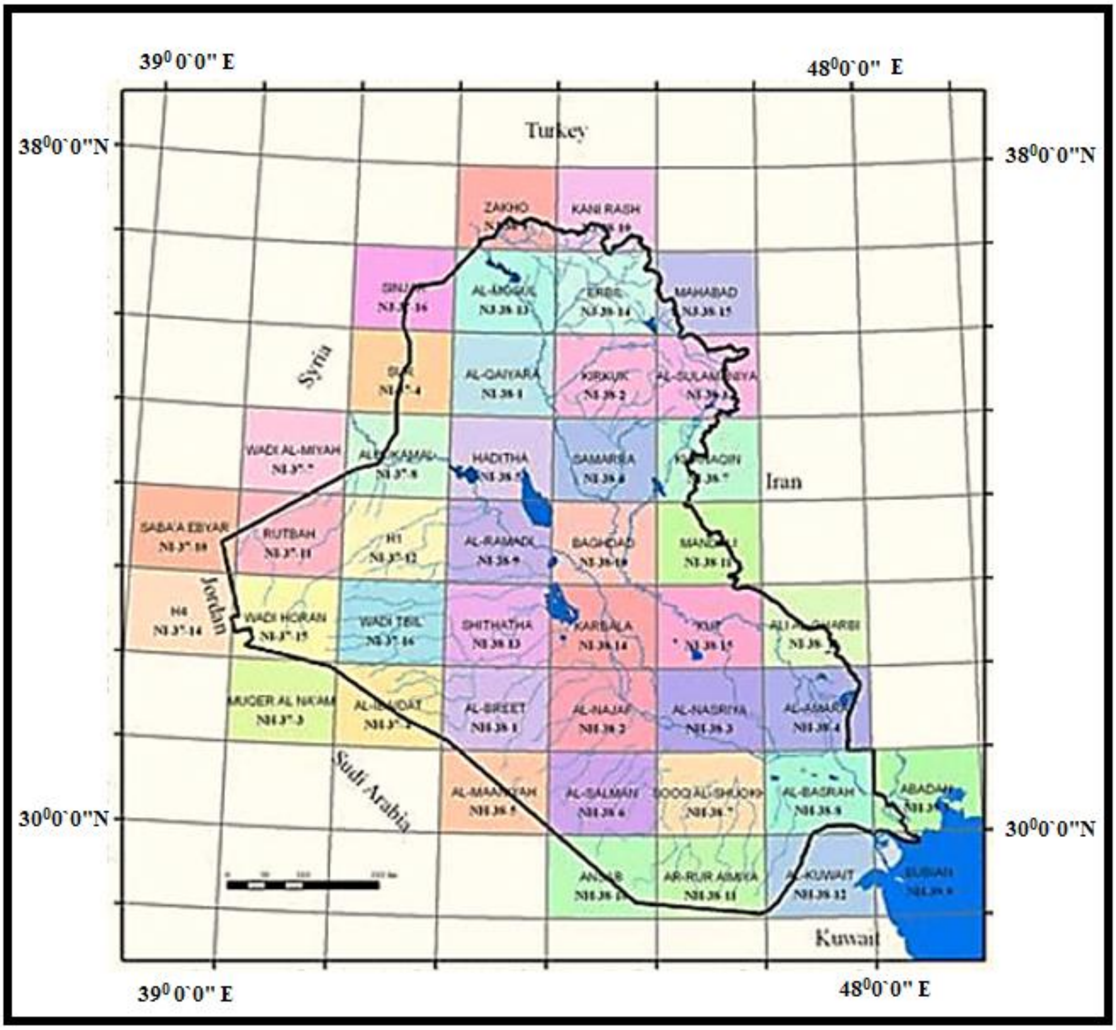

Figure 2: Index of geological maps of Iraq at scale of 1:250000

2 The Course of the Tigris River

Inside Turkey, Tigris River flows mainly in mountainous areas, where it crosses many ridges along Taurus Mountain; however, in small areas it flows within flat and plains. In Turkey, it starts with Batman Su then followed by three other tributaries called Karzan, Hazu and Butan Su. Inside the Iraqi territory, the river flows from the extreme north-western part of Iraq (Figs. 1 and 2) at Fish Khabour town in NW – SE trend. The landscape is gently rolling to flat plains with a wide flood plain of the river. The first tributary of the Tigris River merging with, it is called the Khabour River. The river continues flowing in the same landscape; until it enters Mosul Dam Reservoir. The reservoir is surrounded by hilly terrain from the west and undulated plain to the east.

After passing through Mosul Dam, the river flows in an undulatory plains maintaining its general trend and crossing some hilly terrain. After crossing Mosul city, the river returns to its main NW – SE trend until north of Al-Qayara town where the second tributary; called the Great Zab River merges in (Fig. 1). There, the river changes its main trend to N – S, flowing in an undulatory landscape on the western side and almost flat plains to the east; until the third tributary; called the Lesser Zab River merges with it. There, the river flows following two main mountains called Khanooqah and Makhoul mountains until it enters in a gorge called Al-Fatha with an NE – SW trend, which is abnormal to its main trend. This is attributed to tectonic effect.

After crossing Al-Fatha gorge, the Tigris River flows in a gently rolling plain forming the Mesopotamia Plain (Yacoub, 2011) and particularly the giant alluvial fan called Al-Fatha Alluvial Fan, which was deposited by the Tigris River, its length is about 132 km and the width is about 80 km (Jassim, 1981). The main trend of the river in this area is NW – SE until the river reaches Samarra town.

At Samarra, the river changes its main trend to NNW – SSE, and near Al-Dhilooiyah town, the fourth tributary; called Al-Adhaim River merges in. After Al-Dhilooiyah town by about 20 km, the river changes its trend to almost N – S until it reaches the capital Baghdad.

In Baghdad city, the Tigris River flows in many acute meanders, indicating that the river started its mature stage. The river leaves Baghdad, and the fifth and last tributary called the Diyala River merges in near the small town called Selman Pack, and the Tigris River continues its trend NW – SE until reaching Kut city. The river course between Baghdad and Kut city is characterized by many acute meanders. Some of the meanders are already abandoned forming ox bow lakes; others are still visible on satellite images and aerial photographs (Fig. 3).

From Kut city, the Tigris River starts branching, the first branch is Al-Gharraf River, which flows directly southwards and reaches almost the Euphrates River north of Nasiriyah city. The second is the Dujalia canal. The Tigris River continues flowing to the southeast until it reaches Amarah city. There, the river has another two branches, which are called Al-Khala’a and Al-Musharrah. Three more branches take off water from the left and right banks of the south of Amarah

are called Al-Majar Al-Kaber, Al-Majar Al-Saghir and Al-Mejariah canal.
After about 50 km south of Amarah city, the Tigris River starts merging in a marsh system and continues until Al-Qurna town where both Tigris and Euphrates rivers merge together forming Shat Al-Arab (Fig. 1). Shat Al-Arab is about 190 km long and flows in NW – SE trend and empties into the Arabian Gulf.

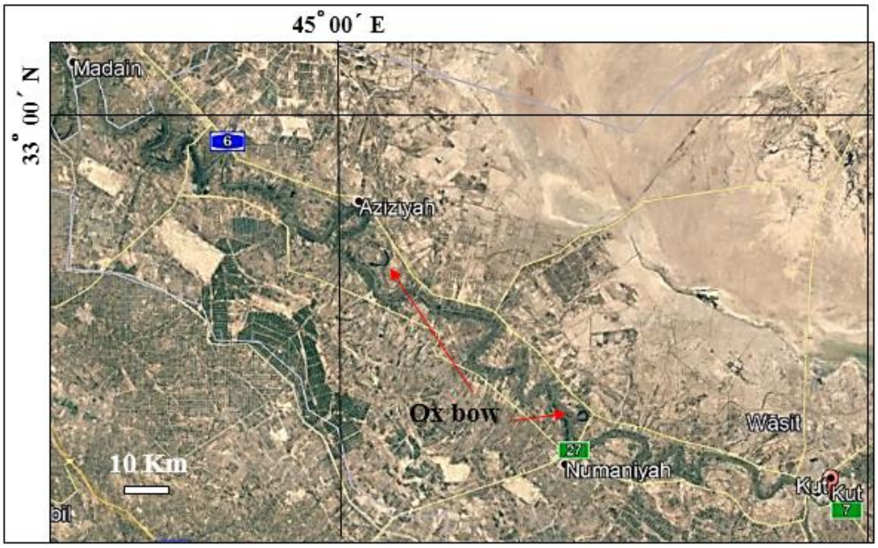

Figure 3: Google Earth image showing the acute loops along the course of the Tigris River, between Baghdad and Kut cities.

3 Geological Setting

The geological setting of the Tigris River's basin is briefly reviewed using the best available data; compiled by Iraq Geological Survey (GEOSURV) staff. However, in Turkey, Syria and Iran, the geological data are more briefly presented. The geological setting includes: 1) Geomorphological aspects, 2) Tectonic and structural Geology, and 3) Stratigraphy. Each subject is dealt with separately.

3.1 Geomorphology

The used data for describing the Geomorphological aspects inside Iraq are mainly acquired from the Geomorphological Map of Iraq (Hamza, 1997) and the Geological Map of Iraq (Sissakian and Fouad, 2012). The main geomorphological units along the course of the Tigris River and its tributaries are the terraces, anticlinal ridges, fault ridges, flat irons and erosional pediments. These units and forms along the course of the Tigris River and its basin are briefly described; hereinafter.

The main Geomorphological fluvial units of the river are the terraces and flood plain. Tauifq and Domas (1977) mentioned that ten levels of terraces occur in the upper reaches of the Tigris River. Sissakian and Al-Jiburi (2014); however, believe that maximum four levels of terraces occur along the course of the Tigris River.

Among the other geomorphological units, which exist along the course of the Tigris River inside Iraqi territory are the anticlinal ridges, as in Mashura, Ani Zala, Butma, Alan, Khanooqa and Makhoul anticlines.

After Al-Fatha gorge, the Tigris River flows in the Mesopotamian Plain. Two levels of terraces are developed along the course of the river; until Al-Niba'ai town about 60 km north of Baghdad; southwards, no more terraces are developed. The river course runs in a wide flood plain, and then in the wide Mesopotamian Plain, which is characterized by depressions of different sizes, crevasse splays, sheet run off, marshes, and estuarine sabkhas (salty) sediments. In the extreme southern part of the Shat Al-Arab course, tidal flat and inland sabkha sediments occur (Yacoub, 2011).

3.2 Tectonics and Structural Geology

The main tectonic zones through which the Tigris River flows are described, besides the main structural features, such as anticlines, faults, subsurface anticlines (Fig. 4). However, the tectonic units inside Turkey, Syria and Iran alongside the Tigris River with their tributaries are briefly mentioned. Moreover, the neotectonic activities inside Iraq are also briefly described for the Tigris River; emphasizing on the Mesopotamia Plain, which is a very mobile subsiding trough.

The Tigris River inside Turkey flows mainly in the Anatolide – Turoside Block, and crosses Bitlis – Zagros Suture Zone. In its upper and western reaches, the river crosses the North and Eastern Anatolian faults, respectively. It also crosses many anticlines and other minor faults.

The Tigris River inside Iraq flows within the Low Folded Zone, Outer Platform of the Arabian Plate. The zone is a part of Zagros Thrust – Fold Belt (Fouad, 2012). The river runs parallel to many anticlines and never crosses one; it passes through the plunge areas of the anticlines, such as Mashiura, Butmah East, Alan, Khanouqa and Makhoul. This is a good indication that the incision rate of the river was less than the growth rate of the anticlines (Killer and Pinter, 2002). All those anticlines are on the right side (west) of the Tigris River. However, south of Mosul city, the river crosses Mishraq anticline in its eastern part; not from the plunge area. However, the majority of the tributaries cross all those anticlines that are located along their courses.

After Al-Fatha gorge, the Tigris River flows in the Mesopotamia Zone, Outer Platform of the Arabian Plate (Fouad, 2012). Although there is not any surface anticline along the course of the river, but there are many subsurface anticlines. All those subsurface anticlines, which are along the course of the Tigris River, are dislocated from their original locations due to neotectonic activities (Fouad and Sissakian, 2011).

After Amarah city and southwards (between latitude 31^0 N and 32^0 N) the Tigris River changes its trend to almost N – S; influenced by the regional trend of the subsurface anticlines (Fig. 4).

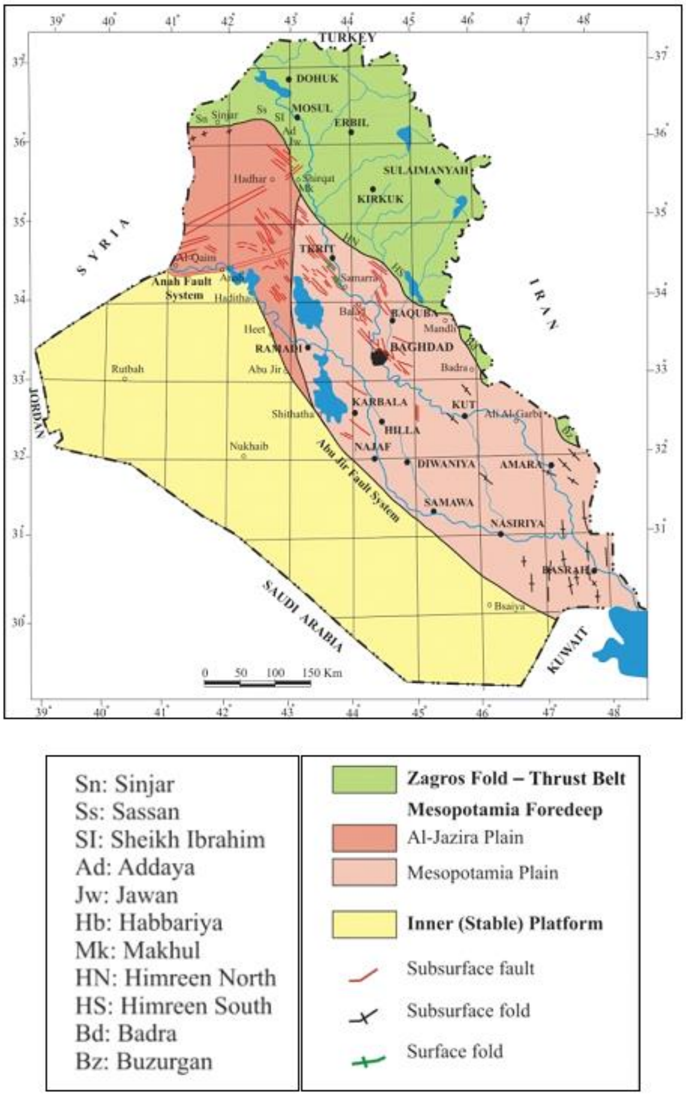

Figure 4: Structural Map of Iraq, showing the Mesopotamia Foredeep
(After Fouad and Sissakian, 2011)

3.3 Neotectonic

The concept of Obruchev (1948); Pavlides (1989) and Koster (2005) is considered in defining the neotectonic movements, in this study. The constructed Neotectonic Map of Iraq (Sissakian and Deikran, 1998) shows that the Mesopotamia Plain is a subsiding basin with an NW – SE trend and of oval shape. The maximum subsidence, as expressed by means of contour lines, is 2500 m and it forms an elongated oval shape, with NW – SE trend and extends from about 30 km east of Al-Khalis, to about 20 km west of Badra, (Fig. 5). However, the subsidence decreases westwards until it reaches to zero level near the Euphrates River and northwards crossing Tharthar Lake.

The basin is asymmetrical, indicating a very steep eastern rim as compared to the western one. This asymmetry is typical of foreland basins, formed because of plate collision, manifesting the shape of the subsiding foreland basin, in front of the rising Zagros Mountain. Such asymmetry also indicates tectonic tilting of the basin (Philip and Virdi, 2007). The length of the basin, in Iraq is about 540 km, whereas the width is variable; it is 80 km, in the extreme northern part, 200 km between Hilla and Badra, and 230 km between Samawa and Ali Al-Gharbi, and 40 km near Basrah (only the included part in Iraq) (Fig. 5).

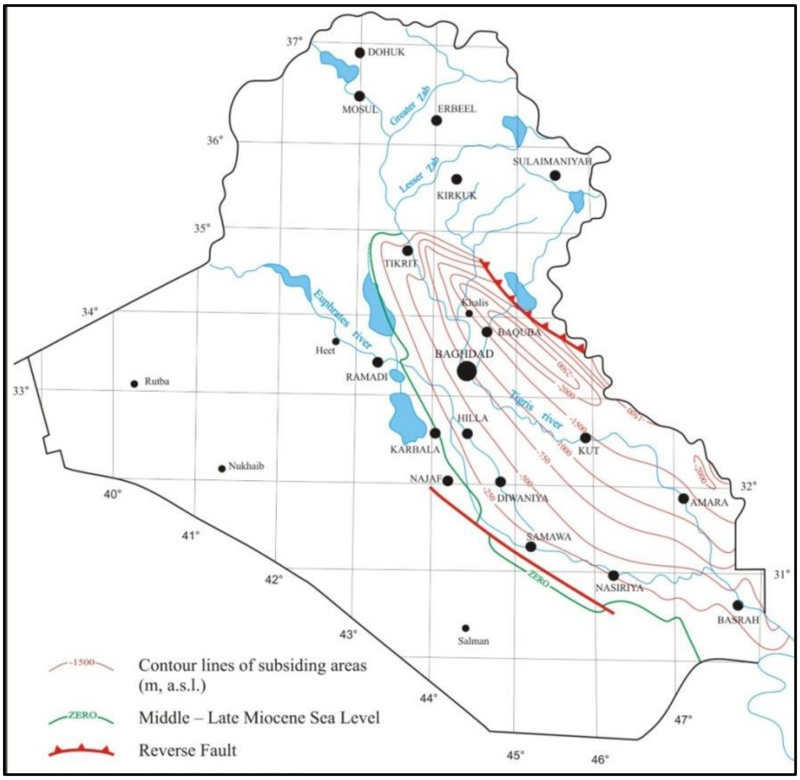

Figure 5: Neotectonic map of the Mesopotamia Plain
(After Sissakian and Deikran, 1998).

Within this huge continuously subsiding Mesopotamia Basin, there are many uplifted areas, which are still active, indicating neotectonic movements. Those areas are evidenced by many Quaternary landforms, like: topographic indications, abandoned river channels, shifting of river courses, active and inactive alluvial fans, and such features are evidence for neotectonic activities (Al-Sakaini, 1993; Markovic et al., 1996; Mello et al., 1999; Kumanan, 2001; Bhattacharya et al., 2005; Jones and Arzani, 2005; Philip and Vidri, 2007, and Woldai and Dorjsuren, 2008. In: Fouad and Sissakian, 2011).

It is worth mentioning that the majority of the uplifted areas, within the Mesopotamia Plain represent nowadays oil fields. Their trends differ in the plain; in the southern part, they have N – S trend, whereas in the central and northern parts of the basin, the trend changes to NW – SE. It is also noticed that the distal parts of the majority of the alluvial fans, both active and inactive, which are developed in the plain, are parallel to those uplifted areas (oil fields).

3.4 Stratigraphy

The type, age and geological formations along which the courses of the Tigris River flow inside Iraq are described here depending on Sissakian and Fouad (2012) and Sissakian and Al-Jiburi (2011 and 2014). The geological map of the river course is shown in Fig. (6). However, the exposed rocks alongside the course of the river and its tributaries inside Turkey, Syria and Iran are very briefly mentioned too.

The Tigris River inside Turkey flows in its upper reaches within Mesozoic metamorphic and Tertiary volcano – sedimentary rocks. North of Diyar Bakir city, it flows between Plio – Quaternary basalts and Plio – Quaternary alluvial basin. From Diyar Bakir city and eastwards for about 100 km, the river flows between Eocene limestones and Plio - Quaternary alluvial basin. More south-eastwards, the river flows between Eocene limestones, Mesozoic metamorphic and Tertiary volcano – sedimentary rocks. Before entering the Iraqi territory, the river flows in Plio – Quaternary alluvial basin.

The Tigris River in its entrance to the Iraqi territory runs in the Mukdadiya (ex-Lower Bakhtiari) Formation of Upper Miocene – Pliocene in age (11.6 – 3.6 Ma). The formation consists of sandstone; occasionally pebbly, alternating with claystone and siltstone. After that, the river continues flowing alternatively in two main formations; the Injana (ex-Upper Fars) Upper Miocene (11.6 Ma) and Fatha (ex-Lower Fars) Middle Miocene (15.97 Ma). The former consists of sandstone, siltstone and claystone. The latter consists of marl, claystone, limestone and gypsum. In a very short distance of the river course, near Mashorah Mountain the river flows within the rocks of the Pila Spi Formation of Eocene age (56.0 Ma). The formation consists of dolomite and dolomitic limestone. The Tigris River continues flowing between the rocks of the Fatha and Injana formations until crossing Al-Fatha gorge.

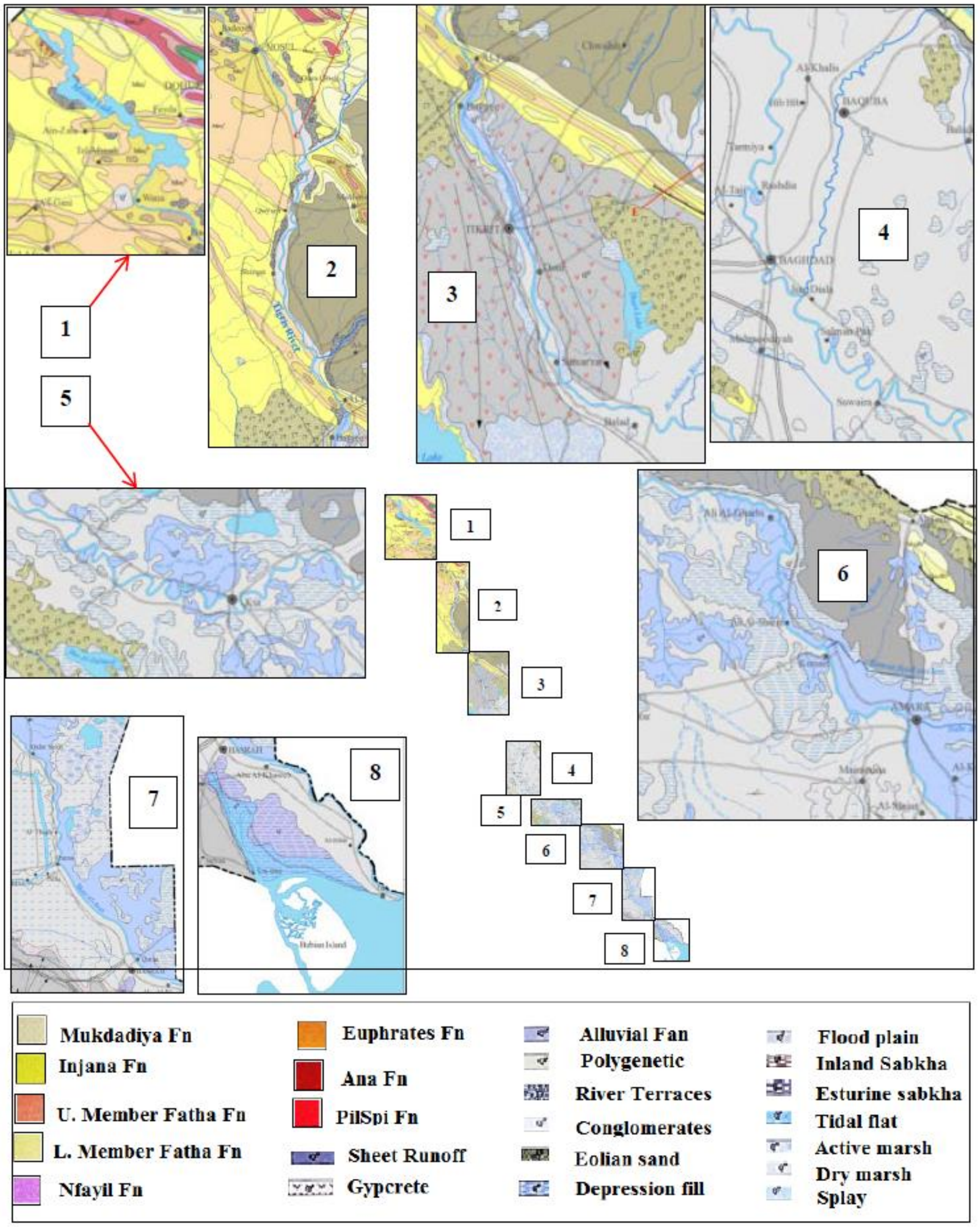

Figure 6: Geological map of the Tigris River's course.
The small portions show the geographic relation between the eight parts of the geological map (After Sissakian and Fouad 2012)

It is worth mentioning that along the course of the Tigris River, it flows locally within the sediments of its flood plain, which are mainly silt, clay with rare sand. These sediments are Holocene age (11.7 Ka). Moreover, the banks of the river are characterised by the presence of terraces along the river are present; they are of Pleistocene age (2.58 Ma). The pebbles are of different sizes and shapes, consists mainly of silicates, carbonates and fewer abundant igneous and metamorphic rocks.

Passing Al-Fatha Gorge, the Tigris River flows in the sediments of Al-Fatha Alluvial Fan; deposited by the river. The sediments are almost the same as those of the river terraces, with the same age. However, the top is covered by gypsiferous soil (Gypcrete).

At Balad town, the Tigris River starts flowing in the sediments of the Mesopotamian Plain and continues until it merges with the Euphrates River near Al-Qurnah town. The sediments of the Mesopotamian Plain consist mainly of silt and clay; however, locally some depressions occur. They may have some organic soil with silt and clay. After Qalat Salih town; south of Al-Amarah city, the Tigris River starts flowing in marshy areas (Fig. 6). The sediments there are highly contaminated with organic materials. The age of all those sediments is Holocene (11.7 Ka).

The stratigraphy of the basins of the tributaries of the Tigris River is briefed hereinafter.

The Khabour Tributary

The Khabour River flows inside Turkey in vey rugged mountainous area, where Mesozoic metamorphic rocks and Tertiary sedimentary – volcanic rocks are exposed.

Inside Iraq, the Khabour River runs in a very rugged mountainous area; in its upper reaches, and in undulatory plains in its lower reaches. The river; in its upper reaches flows in the oldest exposed rocks in Iraq called the Khabour Quartzite of Ordovician age (485.4 Ma). It continues flowing southwards crossing rocks of different ages (Ordovician – Eocene); mainly of carbonate rocks; within the Imbricate and High Folded Zones. After crossing the ridge of the main thrust fault (Fig. 6), the river flows westwards in rocks of Neogene age; mainly of plastics within the Low Folded Zone.

The Greater Zab Tributary

The Greater Zab River flows inside Turkey in Mesozoic metamorphic rocks and Tertiary sedimentary – volcanic rocks forming very rugged mountainous area.

Inside Iraq, the Greater Zab River flows southwards in rugged mountainous areas crossing many mountains in form of gorges and/ or canyon like valleys; until it flows out of Bekhme gorge; after that the river flows in undulatory plains; there the river flows in a wide flood plain with tens of meanders indicating the maturity of the river. The course of the Greater Zab river, in the mountainous areas flows in areas built up by rocks of different ages, mainly carbonates with some flysch type clastics. The age of the rocks ranges from Triassic – Eocene. Whereas, in the undulatory plains, the river flows mainly in clastic rocks of Miocene – Pliocene age with different types of Quaternary sediments; among them are the river terraces and flood plain sediments (Sissakian and Fouad, 2012 and Sissakian and Al-Jiburi, 2014). Tectonically, the mountainous areas belong to the Imbricate and High Folded Zones. After crossing Bekhme gorge, the river flows in NE – SW trend; crossing many anticlines in the Low Folded Zone (Fouad, 2012). The straight course of the river is controlled tectonically (Sissakian et al., 2014 a) with many developed meanders. The meandering is attributed to structural forms, mass movements and growth of alluvial fans (Sissakian et al., 2014 b).

The Greater Zab River has four tributaries

Rawandouz River, Shamdinan River, Haji Beg River and Amadia River, they all have the same characteristics of the upper reaches of the Greta Zab River. The basin is tectonically active (Sissakian, 2013). In the lower reaches of the river, a main tributary called Khazir – Gomel River merges with the Greater Zab River, before it meets the Tigris River by about 30 km downstream.

The Lesser Zab Tributary

The Lesser Zab River flows inside Iran within sedimentary rocks of Tertiary age forming rugged mountainous area; crossing many anticlines within the Zagros Thrust – Fold Belt.

Inside Iraq, the Lesser Zab River flows west wards in rugged mountainous areas crossing many mountains in form of gorges and/ or canyon like valleys; until it flows out of the mountainous area south of Dokan town; however, between Qalat Diza and Ranya towns, the river flows in very large alluvial fans, which consists mainly of gravels of different sized capped by thick reddish brown soils. After leaving Dokan Dam, the river flows in undulatory plains crossing many anticlines; there the river flows in a wide flood plain with tens of meanders indicating the maturity of the river.

The course of the Lesser Zab River flows in areas built up by igneous and metamorphic rocks of Cretaceous age; along the Iraqi – Iranian borders and sedimentary rocks of Cretaceous age too, mainly of carbonates with some clastics of flysch type. Whereas, in the undulatory plains, the river flows mainly in clastic rocks of Miocene – Pliocene age with different types of Quaternary sediments; among them are the river terraces and flood plain sediments (Sissakian and Fouad, 2012 and Sissakian and Al-Jiburi, 2014). In the undulatory plains, the course of the river is almost in a straight line controlled tectonically in NE – SW trend (Sissakian et al., 2014 a); with many meanders, which are attributed to structural forms, mass movements and growth of alluvial fans (Sissakian et al., 2014 b).

Al-Adhaim Tributary

Al-Adhaim River is the only tributary of the Tigris River that originates inside Iraq. The river includes three main tributaries called Khassa Chai, Tawooq Chai and Tuz Chai (all are local names indicating the term river and/ or stream), all these are intermittent streams; but during the heavy rainy showers, high floods are formed in the three of them supplying Al-Adhaim River by considerable quantities of water.

The Khassa Chai tributary is 143 km passing through Kirkuk City. The exposed rocks within the basin of the river are mainly of clastics with very rare limestone and gypsum of the Fatha Formation. The age of the exposed rocks ranges from Middle Miocene up to Pliocene; with different types of Quaternary sediments; such as river terraces, flood plain and valley fill sediments (Sissakian and Fouad, 2012 and Sissakian and Al-Jiburi, 2011). Tectonically, the whole river flows within the Low Folded Zone. All existing anticlines trend in NW – SE direction and the northeastern limb is thrusted over the north southern limb; the main one is Kirkuk Structure (Fouad, 2012).

The Tawooq Chai tributary is 178 km passing through Daqooq town. The exposed rocks at the upper reach of the river are clastics of the Gercus Formation (Eocene age) and limestone of the Pila Spi Formation (Upper Eocene age). After Basara gorge, the exposed rocks within the basin of the river are mainly clastics; with very rare limestone and gypsum of the Fatha Formation. The age of the exposed rocks ranges from Middle Miocene up to Pliocene; with different types of Quaternary sediments; such as river terraces, flood plain and valley fill sediments (Sissakian and Fouad, 2012 and Sissakian and Al-Jiburi, 2011). Tectonically, the upper reaches of the river until Basara gorge is within the High Folded Zone. Southwards of Basara gorge, the river flows within the Low Folded Zone. All existing anticlines trend in NW – SE direction and the northeastern limb is thrusted over the north southern limb, the main one is Kirkuk Structure, Jambour and Pulkana anticlines (Fouad, 2012).

The Tuz Chai tributary is 138 km passing through Tuz Khurnatu town. The exposed rocks within the basin of the river are mainly of clastics with very rare limestone and gypsum of the Fatha Formation. The age of the exposed rocks ranges from Middle Miocene up to Pliocene; with different types of Quaternary sediments; such as river terraces, flood plain and valley fill sediments (Sissakian and Fouad, 2012 and Sissakian and Al-Jiburi, 2011). Tectonically, the whole river flows within the Low Folded Zone. All existing anticlines trend in NW – SE direction and the northeastern limb is thrusted over the north southern limb, the main one is Pulkhana anticline (Fouad, 2012).

Al-Adhaim River starts from the junction point of its three main tributaries. However, after construction of Al-Adhaim Dam, the junction point is inundated by the reservoir’s water. The river course is within the sediments of the Mesopotamia Plain, which consists mainly of silt and clay with some aeolian sand. Tectonically, Al-Adhaim River crosses Hemren North anticline, which is considered as the boundary between the Low Folded Zone and the Mesopotamia Plain. Hemren North anticline is NW – SE trending anticline with the northeastern limb being thrusted over the northwestern limb (Fouad, 2012).

The Diyala (Sirwan) Tributary

This is the last tributary of the Tigris River; it originates from Iran. In the upper reaches of the river it is called as Sirwan River, downstream; south of Derbendikhan Dam it is called as Diyala River.

Inside Iran, the Sirwan River flows in a mountainous area built up by carbonates of Cretaceous age within Zagros Thrust and Zagros Fold Zones.

Inside Iraq, the Diyala Zab River flows southwards in rugged mountainous areas crossing many mountains in form of gorges and/ or canyon like valleys; until it flows out of the mountainous area south of Derbendikhan town; after that the river flows in undulatory plains crossing many anticlines; there, the river flows in a wide flood plain with tens of meanders indicating the maturity of the river. The course of the Sirwan river flows in its upper reaches into areas built up by carbonates of Cretaceous age; along the Iraqi – Iranian borders and until it enters in Derbendikhan Reservoir, which is surrounded by rocks from Cretaceous up to Pliocene ages of different rock types. Whereas, in the undulatory plains, the Diyala River flows mainly in clastic rocks of Miocene – Pliocene age with different types of Quaternary sediments; among them are the river terraces and flood plain sediments (Sissakian and Fouad, 2012 and Sissakian and Al-Jiburi, 2014). Tectonically, the upper reaches of the river course belong to the Imbricate Zone, near Halabja town, the river flows within the High Folded Zone. After crossing Derbendikhan Dam, the river flows in N – S trend; crossing many anticlines in the Low Folded Zone, until Hemren North anticline, after that the river flows in the Mesopotamia Zone (Fouad, 2012). The straight course of the river is controlled tectonically (Sissakian et al., 2014 a); however, many meanders are developed. The meandering is attributed to structural forms, mass movements and growth of alluvial fans (Sissakian et al., 2014 b).

The Diyala (Sirwan) River has many tributaries; among them are the Tanjerou and Al-Wind rivers, which are the main two tributaries. However, others are Dewana stream, Kifri Chai and Nareen Chai. Moreover, the Diyala River after crossing Hemren North Mountain and 8 kilometers downstream of Hemren Dam feeds two large main canals to irrigate the Diyala Irrigation project system and the Khalis irrigation projects system; which are two of the largest irrigation systems in Iraq. It is believed that some of them are historic artificial irrigation channels.

4 Mineral Resources

The mineral resources along the courses of the Tigris River and its tributaries in Iraq are mentioned hereinafter.

The following mineral resources and/ or industrial rocks occur along the course of the Tigris River and its basin area. The presented data are acquired mainly from (Al-Bassam, 2011, and Mustafa and Benni, 2014).

- Sulphur

The Tigris River course from Mosul city until Al-Fatha gorge is considered as sulphur a district (Al-Bassam, 2007). Many sulphur deposits are developed in this district; due to anaerobic bacteria that acts with the gypsum rocks and the presence of water; consequently, native sulphur is deposited. Among the main deposits in the Sulphur District along the Tigris River is Al-Mishraq Sulphur Mine.

Al-Mishraq Sulphur Mine: The Mishraq native sulphur deposit is about 40 km southeast of Mosul and 315 km north of Baghdad. This deposit is the largest known occurrence of stratiform bioepigenetic sulphur, containing at least 1000 million tons of sulphur (Barker et al., 1979). It is the largest deposit in the word. Frasch Process is used in extraction of the native sulphur.

- Oil and Gas

Although “oil and gas” are not mineral; but, they are mentioned here as “Mineral resources”.

Many oil and gas fields with different annual production and different oil and gas types are located along the course of the Tigris River and its tributaries (Fig. 12). Parts of the oil fields are on the surface; i.e. with surface expression, these are north of Al-Fatha Gorge; such as Mashura, Ain Zala, Butmah, Qayarah. Along the tributaries are: Kirkuk, Bai Hassan, Jmbur, Chai Surkh, Taq Taq, Cahmchamal, Jambour, Pulkana, Khor Mor, Qumar, Gillabat, Injana, Damir Dagh, Barda Rash, Quwair, Naft Khana, Chia Surkh, Nao Duman, Mansouriya. Others are subsurface oil fields; such as Balad, Baghdad East, Amara, Kumait, Halfaya, Rifae, and Majnoon.

In reviewing the oil and gas fields maps of Iraq (Fig. 7), it is clear that tens of oil fields occur at slightly far distance from the course of the Tigris River. Moreover, after merging of the Tigris and Euphrates rivers; forming Shat Al-Arab, three giant oil fields are located along its course, they are Nahr Umr and Zubair and Siba (Fig. 7).

- Limestone and Dolostone

Limestone and dolostone form the main constituent of the many formations of different ages, which are exposed along the Tigris River and its basin. However, the only used rocks belong to the Sinjar, Ana, Euphrates and Fatha formations, especially the first one. Limestone is widely used for different purposes; such as cement production, building and as a decorative stone. The main uses are mentioned hereinafter; briefly.

a) Cement Production: The main use of the limestone is in cement production. All existing cement plants in the northern part of Iraq are located within the Tigris River’s basin, apart from Sinjar cement plant (Fig. 8). The total production is over 15 million tons/ year.

b) Building Stone: Tens of local quarries occur along the Tigris River and its basin in the Iraqi territory until Al-Fatha Gorge. All quarries are small and private; the owners have quarrying licences from the Ministry of the Industry and Minerals with cooperation of the concerned governorates. The quarried limestone and dolostone are transferred to local small rock slabbing factories. There they are cut in different dimensions and supplied to many governorates for building and decorative purposes. Locally, the used rock is called “Hillan”

c) Aggregates: The flood plain sediments of the Tigris River and its tributaries are excellent source for aggregates; used in different construction purposes. Moreover, the terrace sediments are also good source for construction purposes. However, the latter should be washed to be free from SO4. It is worth to mention that the tributaries of the Tigris River include enormous amounts of aggregates. The flood plain sediments are quarried along the courses of the rivers from small quarries by local people; usually used either for agricultural uses and/ or construction purposes.

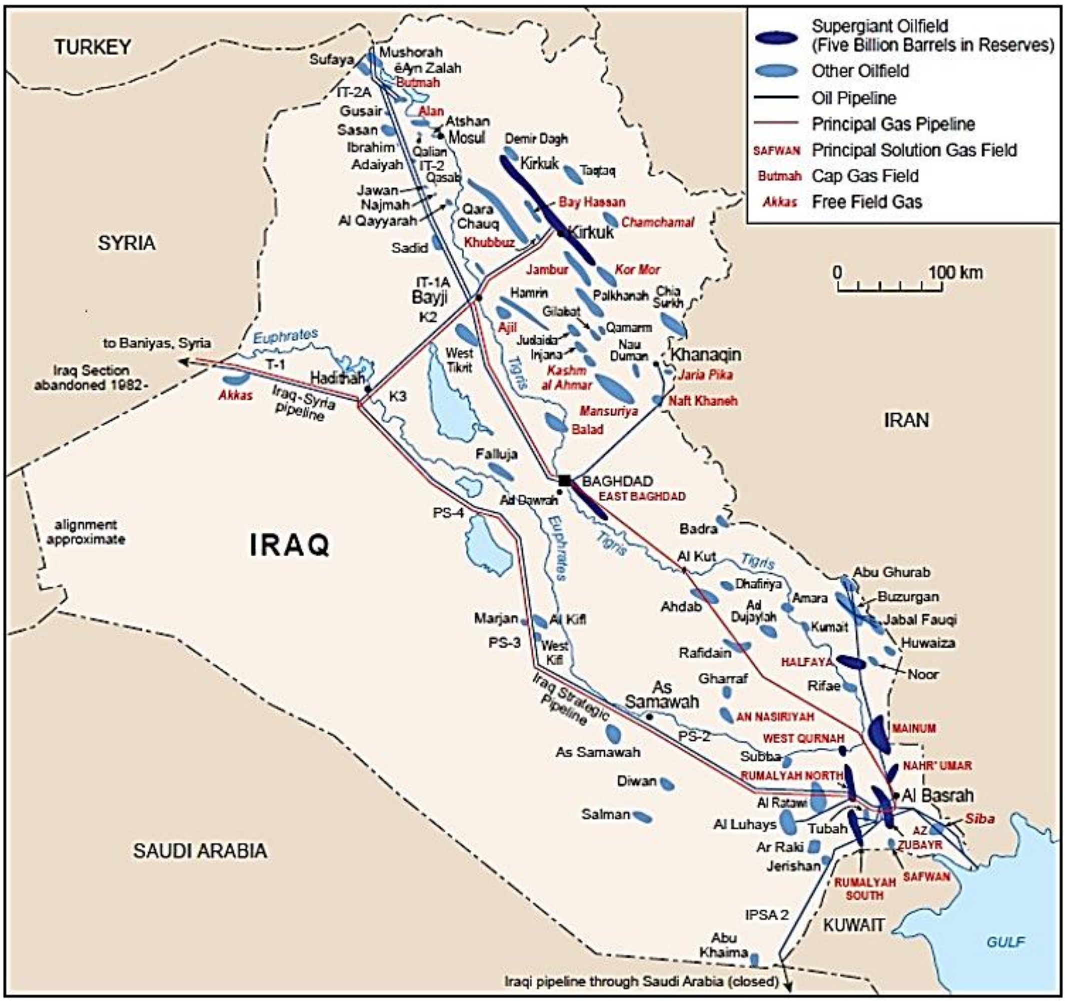

Figure 7: Distribution of oil and gas fields along the course of the Tigris River and its tributaries (from Judicial Watch, 2002)

- Gypsum: Gypsum is one of the main constituents of the Fatha Formation, which is exposed widely in the basin of the Tigris River (Fig. 6). It is exposed along the courses of the Greater Zab, Lesser Zab, Al-Adhaim and Diyala (Sirwan) rivers. Near Kifri town the maximum exposed thickness of gypsum beds (40 M) occurs (Sissakian, 1978). Gypsum is used different purposes; such as cement production and building.

a) Cement Production: Gypsum is used in cement production; after production of the clinker gypsum is added in different ratios depending on the used raw mix in cement production. Gypsum is quarried from the exposures of the Fatha Formation. The quarries are nearby the cement plants along the right side of the Tigris River and its basin.

b) Building and Decorative Stone: Gypsum is used as a decorative stone after being quarried, slabbed in different sizes. It is also burnt and crushed into powder size in local furnaces called “Koora”. The product is used as thin plaster in the inner walls. Locally, it is used in production of the gypsum board, which is also used in decoration of the inner walls.

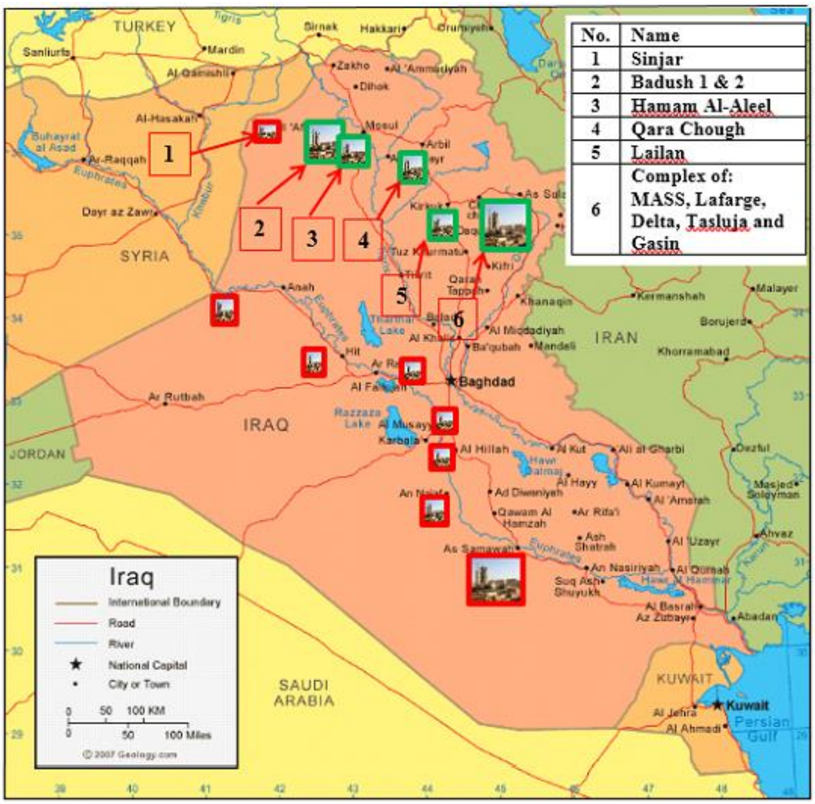

Figure 8: Cement plants in Iraq. Those in green colour are in the Tigris River’s basin (Sissakian, 2016)

- Claystone

Claystone is one of the main constituents of many formations exposed in the basin of the Tigris River and the Mesopotamian Plain sediments (Sissakian and Al-Jiburi, 2011, Sissakian and Fouad, 2012 and Yacoub, 2011). The main industrial use is in cement and brick productions. Unfortunately, the existing claystone beds are not well studied in different parts of the Tigris River's basin, especially in the Iraqi Kurdistan Region.

a) Cement Production: Clay is mixed with the limestone as one of the main raw materials used in cement production. The percentage of the used claystone may reach 45 % of the raw mix for cement production (I.S.C.P, 1984). The claystone is quarried from the Injana Formation and/ or other Quaternary sediments for cement production.

b) Brick Production: Clay is the main constituent of the brick production. Enormous amounts of clay from the Mesopotamian Plain sediments are quarried for brick production. The main complex of brick plants is located SE of Baghdad; it is called Al-Nahrawan Complex. Downwards from Al-Nahrawan, many other brick plants are located along the course of the Tigris River; the clay is quarried from the Mesopotamian Plain. All the plants are using crude oil in their furnaces and are considered as a pollution source (Sissakian and Ibrahim, 2005). Moreover, two modern brick plants are established in the Tigris River's basin. One is north of Erbil city, whereas the second is in north of Cham Chamal town, both use the claystone of the Injana Formation.

- Bentonite

Bentonite is exposed within the Mukdadiya Formation along Pulkhana and Hemren North anticlines. Locally, it is quarried in very primitive methods and very rarely mined; such as in Qara Tappa town; along Nareen chai (tributary of Diyala River) and near Na Salih village, west of Kifri town (Sissakian, 1978).

- Bitumen

Different types of bitumen and/ or heavy oil are exposed within the Fatha, Injana and Mukdadiya formations, which are exposed along the course of the Diyala River and its tributaries. Locally, bitumen is mined in very primitive methods; such as near Na Salih village, west of Kifri town, it is used as fuel for daily consumptions, especially during winter for heating of houses (Sissakian, 1978).

5 Age Estimation of the Tigris River and the Mesopotamian Plain

The Mesopotamia Plain is formed by the sediments of the Tigris and Euphrates rivers in which they flow; nowadays. The plain is a mobile tectonic zone since Pliocene (3.6 Ma); it is continuously subsiding and contains several buried structures including folds and faults. Recent tectonic activity of some of these structures is recorded through their effects on the Quaternary stratigraphy and presence of Geomorphological landforms such as abandoned river channels, active and inactive alluvial fans and topographic expressions of some active subsurface anticlines, all together indicating Neotectonic activity of the plain.

The Tigris River has been flowing in its course since long time ago; although a lot of changes occurred during the past geological time to its course. It shifted from its original course due to tectonic forces and climatic changes, especially within the Mesopotamian Plain (Fouad and Sissakian, 2011). The deposited terraces along the course of the Tigris River are Pleistocene in age (about 2.8 Ma); accordingly, the river is older. Moreover, the present alluvial fans; such as Al-Fatha Aluuvial Fan (Fig. 6) and those in Badra and Zurbatyah vicinities are also Pleistocene in age and since the growth of the latter are eroded by the Tigris River; therefore, the river should be older. The mentioned data are good indications about the age of the Mesopotamia Plain and of the Tigris River. The estimated age is at least Pliocene, which means 3.6 Ma.

6 Conclusions

From this study, we may conclude the following:

The Tigris River's basin lies in different tectonic zones. The structures in the upper reaches of the river belong to Taurus style of folding; whereas in Iraq and after crossing Mosul city the structures follow the Zagros style of folding. All the anticlines in the basin are on surface; however, some are subsurface anticlines, especially in the Mesopotamia Plain. The exposed rocks in the river's basin range in age from Paleozoic to Pliocene with many types of Quaternary sediments. The exposed rocks are mainly of sedimentary types; including carbonate, with some claystone, shale, sandstone gypsum, conglomerate and rare igneous and metamorphic rocks. The main deposition environment of the rocks is marine, with some continental environment too. However, From Upper Miocene onwards, no more marine rocks exist in the basin. Neotectonic activities are very common with good indications, especially in the Mesopotamia Plain, which is continuously sinking basin; however, local uplifts occur within the basin. The age of the river is estimated to be Pliocene, based on the terraces and the alluvial fans. Many potential resources occur within the basin, the most common and significant is the crude oil and gas, followed by limestone for cement productions. However, huge quantities of claystone are exposed in the basin, but not explored to indicate their industrial assessment.

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