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Tectonics and Neotectonics of the Mesopotamian Plain: A Critical Review

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Abstract

The Mesopotamian Plain is a part of the Mesopotamia Foredeep of the Zagros Foreland Basin and is a part of the Zagros Fold – Thrust Belt. The plain covers the central part of Iraq and extends south eastwards. It is a large continuously subsiding basin since the Upper Miocene (11.62 Ma). The plain is covered by thick Quaternary sediments of the Tigris and Euphrates rivers with their tributaries and distributaries. Therefore, the plain shows no structural features on the surface, except a main fault escarpment that extends from south of Al-Najaf city to south of Nasiriya city representing part of Abu Jir Active Fault Zone. However, the rolling topography, in the northern parts of the plain indicates subsurface anticlines that are still growing up, such as Balad, Samarra, Tikrit and Baiji anticlines. Moreover, many buried subsurface anticlines are present in different parts of the plain. All are growing anticlines and have caused continuous shift to the Tigris and Euphrates River and their distributaries indicating Neotectonic activities. The minimum and maximum subsidence amounts in the plain are zero and – 2500 m, respectively.

Keywords: Mesopotamia Foredeep, Subsurface anticlines, River migrations, Neotectonic activities, Folds growth, Iraq.

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1. Introduction

Mesopotamia is a historical region in West Asia situated within the Tigris–Euphrates river system. In modern days, roughly corresponding to most of Iraq, Kuwait, parts of Northern Saudi Arabia, the eastern parts of Syria, Southeastern Turkey, and regions along the Turkish–Syrian and Iran – Iraq borders (Collon, 2011) (Figure 1).

Mesopotamia, in modern times, has been more generally applied to all the lands between the Euphrates and the Tigris, thereby incorporating not only parts of Syria but also almost all of Iraq and southeastern Turkey (Foster and Polinger Foster, 2009). The neighboring steppes to the west of the Euphrates and the western part of the Zagros Mountains are also often included under the wider term Mesopotamia (Canard, 2011, Wilkinson, 2000 and Mathews, 2000). A further distinction is usually made between Upper or Northern Mesopotamia and Lower or Southern Mesopotamia (Miquel et al., 2011). Upper Mesopotamia, also known as the Jazira (Al-Jazira Plain), is the area between the Euphrates and the Tigris from their sources down to Baghdad (Canard, 2011). Lower Mesopotamia is the area from Baghdad to the Persian Gulf (Miquel, 2011). In modern scientific usage, the term Mesopotamia often also has a chronological connotation. In modern Western historiography of the region, the term "Mesopotamia" is usually used to designate the area from the beginning of time, until the Muslim conquest in the 630s, with the Arabic names Iraq and Jazira being used to describe the region after that event (Foster and Polinger Foster, 2009 and Bahrani, 1998).

Figure 1: Geographical extension of Mesopotamia showing the Mesopotamian Plain (Approximate limits shown by dashed red line) (Internet data, 2013).

The Mesopotamian Plain; however, is different geographically, geologically and historically from the Mesopotamia. The Mesopotamian Plain represents part of Mesopotamia, and nowadays it represents the existing plain between the Tigris and Euphrates rivers, which is limited south of Al-Fatha gorge in the north. The alluvial plains along the Iraqi – Iranian borders in the east. From the west (northern part), it is limited by wadi Al-Tharthar and (southern part) the eastern limits of the Western Desert; then extending with the northern limits of the Southern Desert (almost parallel to the Euphrates River); forming the southern limits of the plain. From the southeast, it is limited by the upper reaches of the Arabian Gulf (Figure 1). Tectonically, the Mesopotamian Plain extends farther northwest wards from that shown in Figure (1) to cover the whole Jazira Plain and even extends more in Syria. Towards southeast, it includes the whole Arabian Gulf until the strait of Hormuz (Fouad, 2012). However, in the current study, only the plain which is covered by the fluvial sediments of the Tigris and Euphrates rivers (Figure 1) is considered.

2. Tectonics, Structural Geology and Neotectonics

2.1 Tectonics and Structural Geology

The Mesopotamian Plain is a part of the Mesopotamia Foredeep of the Zagros Foreland Basin. The plain is a large continuously subsiding basin since the Upper Miocene (11.62 Ma), it is covered by thick Quaternary sediments of the Tigris and Euphrates rivers with their tributaries and distributaries (Sissakian and Fouad, 2012). Therefore, the plain shows no structural features on the surface, except a main fault escarpment that extends from south of Al-Najaf city to south of Nasiriya city (Al-Mubarak and Amin, 1983; Sissakian and Deikran, 1998; Sissakian, 2000 and Sissakian and Fouad, 2012). However, the rolling topography, in the northern parts of the plain indicates subsurface anticlines that are still rising up, such as Balad, Samarra, Tikrit and Baiji anticlines (Al-Kadhimi et al., 1996). The plain is of epicontinental type basin formed above an earlier platformal and marginal basin.

The Mesopotamian Plain forms the central and the southern parts of Iraq (Figure 1). Many researchers like Henson (1951); Dunnington (1958); Ditmar (1971); Iraqi – Soviet Team (1979), and Buday (1980) have considered the plain as a part of the Unstable Shelf of the Arabian Platform. Buday and Jassim (1984 and 1987) referred to this area as the Mesopotamian Zone considering it as a separate structural unit within the Unstable Shelf (Figure 1 A). Al-Kadhimi et al. (1996) followed almost Buday and Jassim (1987) in their tectonic divisions of Iraq (Figure 2 B). Jassim and Goff (2006) considered the Mesopotamian Zone as a part of the Stable Shelf of the Arabian Platform (Figure 2 C). However, Fouad (2012) considered the Mesopotamian Plain within the Outer Platform (Unstable Shelf) of the Arabian Plate (Figure 2 D). It is worth to mention that in all mentioned tectonic divisions of Iraq the Mesopotamian Plain is considered to represent the entire Mesopotamia Basin (or Foredeep) (Figure 2). We adopted the opinion of Fouad (2012) in considering of the Mesopotamian Plain (Figure 2 D) as a portion of the major Mesopotamia Foredeep (Figure 1).

The Mesopotamian Plain is a part of the Zagros Fold – Thrust Belt (Fouad, 2010), which is the product of the structural deformation of the Zagros Foreland Basin, whose present day remnant is the continental Mesopotamia and the Marine Arabian Gulf Basins (Berberian, 1995; Alsharhan and Nairn, 1997; Hessami et al., 2001 and Fouad, 2010 and 2012). The Mesopotamia Foredeep is a continental basin which lies between the Zagros deformational front from the northeast and the stable interior part of the Arabian Platform (Fouad, 2010). The Mesopotamia Plain occupies the central and the southern parts of the Mesopotamia Foredeep within the Iraqi territory. It is a depo-center due to subsidence in the Neogene, and a significant basin of alluvial sediment accumulation in the Quaternary, being very mobile basin with maximum estimated subsidence from the Upper Miocene onwards to be about 2500 m (Sissakian and Deikran, 1998).

Three genetic types of folds occur in the Mesopotamia Plain (Fouad, 2010), these are: 1) Faultrelated folds, which have developed above an initial fault bounded structural troughs (grabens or half grabens) because of structural inversion phenomenon. Good examples are Tikrit and Samarra growing anticlines, 2) Simple buckle folds, which have formed due to the compressional exerted forces by Arabian – Eurasian (Iranian) plates collision. The developed folds are NW – SE trending following the regional trend by the Zagros Fold – Thrust Belt, and 3) North – South trending folds, which are developed in the extreme southern part of Mesopotamia Plain. These folds are following the old inherited fractures of N – S Arabian trend. They are long, broad and with low amplitudes; such as Zubair and Rumaila structures. However, according to Colman-Saad (1978), the folds are related to the movement of salt substratum. It is worth to mention that almost no indication exists on surface to indicate the mentioned folds because they are subsurface folds.

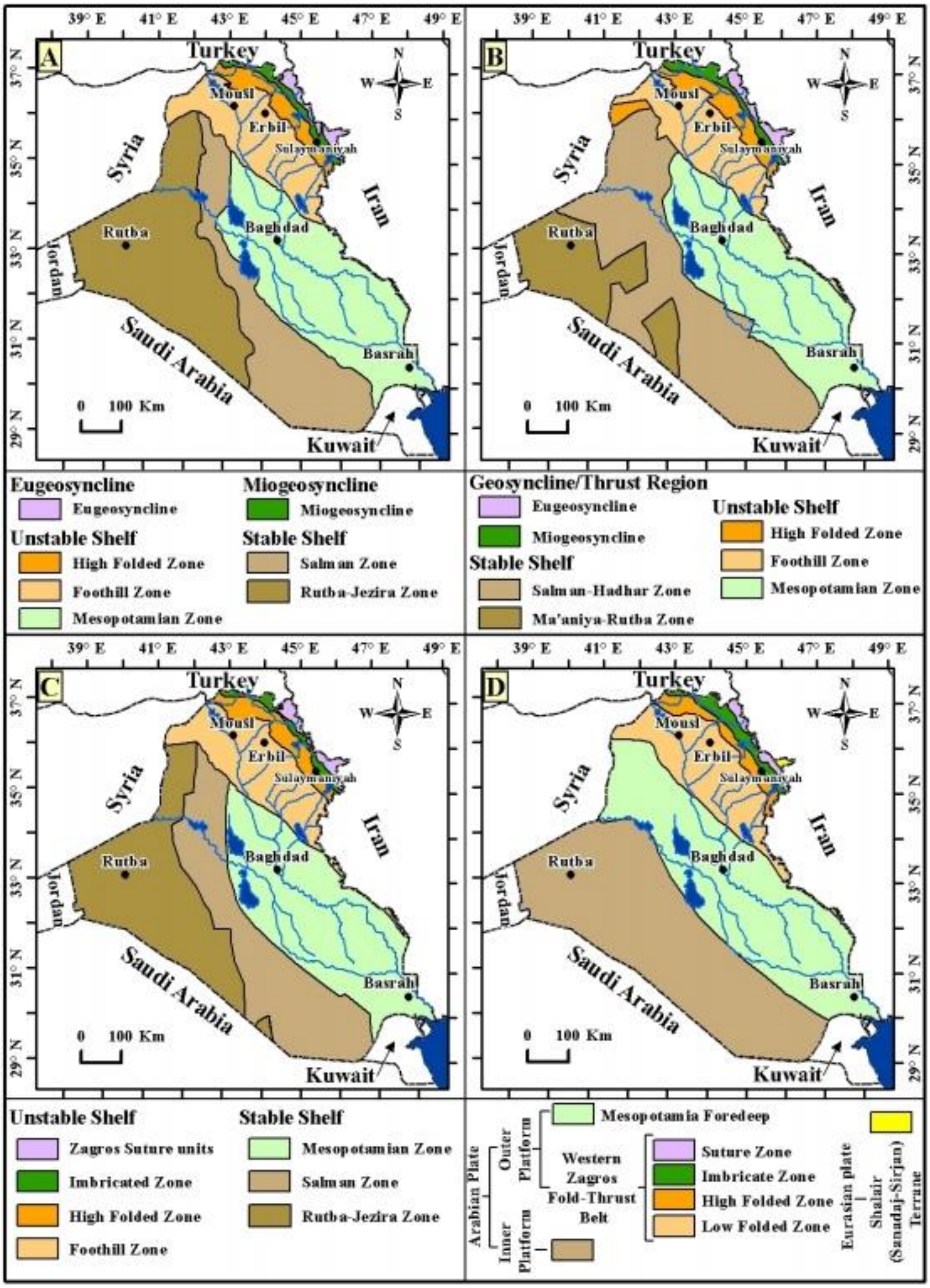

Figure 2: Main tectonic division zones of Iraq, A) after Buday and Jassim (1984 and 1987, B) after Al-Kadimi et al. (1997), C) after Jassim and Goff (2006), and D) modified from Fouad (2012) (Modified from Sissakian et al., 2017).

No surface indication exists to indicate faults in the Mesopotamia Plain. However, a network of NW – SE trending faults have been developed in south Baghdad. These faults are of normal type and forming a complex set of grabens, half grabens and solitary faults. Some of the grabens have been partially inverted, forming anticlinal folds or structural noses (Fouad and Sissakian, 2011). It is worth to mention that Fouad (2012) has mentioned that "almost all of the mentioned tectonic divisions of Iraq, had considered the present day "Mesopotamia Plain" as the entire Mesopotamian Basin (or zone). This consideration has caused a lot of confusion and uncertainties to the true structural nature of the basin. Actually, the Mesopotamia Foredeep (Basin) is much larger and aerially extensive, than that of the Mesopotamian Zone or Mesopotamian Plain, which forms only a part of the plain. The present day Mesopotamia Foredeep (Basin) extends from northeast Syria to the Strait of Hormuz. It consists of two domains, the first is terrestrial one that covers parts of northeast Syria, Iraq, and parts of Kuwait and the coastal plains of Iran, and the second is marine, represented by the Arabian/ Persian Gulf Basin (Berberian, 1995; Alshrhan and Nairn, 1997; Brew, 2001; Sharland et al., 2001; Alavi, 2004 and Fouad and Nasir, 2009)". The present authors would like to clarify the statement of Fouad (2012) by referring to Figure 1 as the Mesopotamia Foredeep and the Mesopotamian Plain.

2.2 Neotectonics

Generally, in Iraq the concept of Obruchev (1948); Pavlides (1989), and Koster (2005) is considered in defining the Neotectonic movements. Sissakian and Deikran (1998) adopted the opinion of Obruchev (1948) during construction of the Neotectonic Map of Iraq. The constructed map shows that the Mesopotamian Plain is a subsiding basin; as all the concerned studies have showed. The basin has NW – SE trend with oval shape. The maximum subsidence in the basin is 2500 m as measured on the top of the Fatha Formation (Middle Miocene). The subsiding basin forms an elongated oval shape, and extends from east of Al-Khalis twon, for about 30 km, to west of Badra town, for about 10 km (Figure 3). The basin is asymmetrical with very steep eastern rim. This asymmetry is a typical of foreland basins formed due to the plate collision manifesting the shape of the subsiding foreland basin formed due to the collision of Arabian and Eurasian Plates 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 city and Badra town, 230 Km between Samawa city and Ali Al-Gharbi town, and 40 km near Basra city (only the included part in Iraq) (Figure 3).

There are many uplifted areas within this huge continuously subsiding Mesopotamian Basin which are still active indicating Neotectonic movements. However, these areas are not shown in Figure 3 due to the scale limitations. These areas are evidenced by many Quaternary landforms, like topographic indications, abandoned river channels, shifting of river courses, active and inactive alluvial fans.

Such features are evidences for Neotectonic activities (Al-Sakini, 1993; Markovic et al., 1996; Mello et al., 1999; Kumanan, 2001; Bhattacharya et al., 2005; Jones and Arzani, 2005; Philip and Virdi, 2007 and Woldai and Dorjsuren, 2008). 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 the trend changes to NW – SE. Another fact is that the distal parts of the majority of the alluvial fans, both active and inactive, which are developed in the eastern margin of plain, are parallel to those uplifted areas (Fouad and Sissakian, 2011).

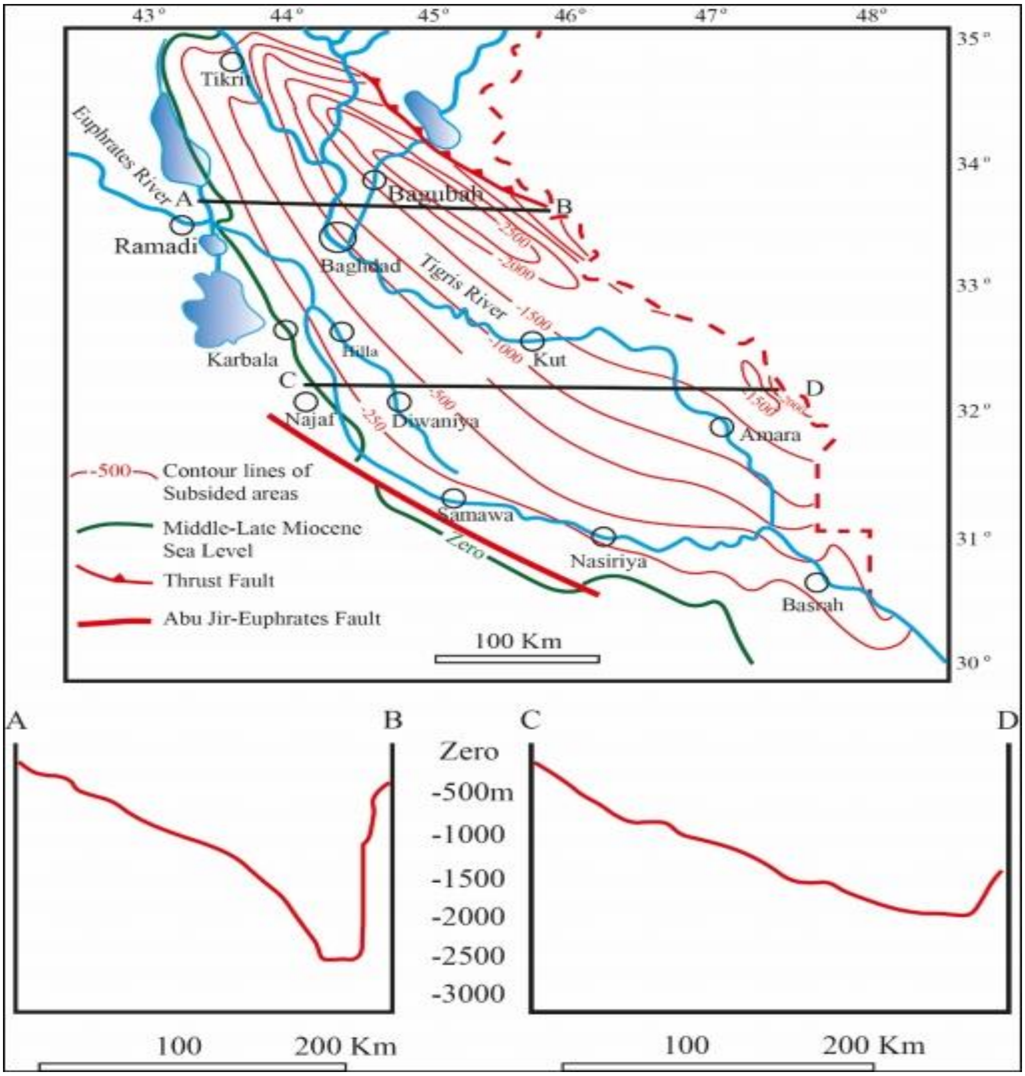

Figure 3: Neotectonic map of the Mesopotamian Plane and two cross sections (Modified from Sissakian and Deikran, 1998).

2.2.1 Rate of the Neotectonic Movements in the Mesopotamian Plane

Sissakian and Deikran (1998) have calculated the rate of the subsidence and uplift During the Neotectonic period (11.62 Ma) in the whole Iraqi territory depending on the constructed Neotectonic Map of Iraq. The rate of subsidence in the Mesopotamian Plain was calculated by dividing the amount of the subsidence by the values of the maximum and minimum contour values by 11.65 Ma (The age of the Upper Miocene, I.C.S., 2012). In order to calculate the rate of the subsidence in the Mesopotamian Plain (Figure 3), we have divided the plain into five parts:

1) The Eastern Edge which extends along the Iraqi- Iranian borders until the latitude N 31^{o}.

2) The Northern Edge which extends few kilometers north of the latitude N 34^{o}

3) The Western Edge which extends almost along the Euphrates River until the latitude N 31^{o}

4) The Southern Edge which extends south of the latitude N 31^{o}, and

5) Central part which covers the area between the Tigris and Euphrates rivers. From the constructed contour maps of the Neotectonic map (Figure 3), the minimum and maximum subsidence amounts are recorder in the five parts of the Mesopotamian Plain (Table 1). The minimum and maximum rates of the subsidence during the Neotectonic period are calculated by dividing the subsidence amounts by 11.62 Ma which is the duration of the Upper Miocene until present day (I.C.S., 2012). The minimum and maximum rates of the subsidence during the Pleistocene and Holocene periods are also calculated by dividing the subsidence amounts by the 2.588 Ma and 0.0117 Ma which are the durations of Pleistocene and Holocene, respectively (I.C.S., 2012) (Table 1). It is worth to mention that the Zero line which represents the Middle Miocene level runs almost along the Western Edge of the plain (Figure 3).

Table 1: Amounts and rates of subsidence in the Mesopotamian Plain.

	Subsidence amounts and rates during					
	Neotectonics (11.62 Ma)		Pleistocene (2.588 Ma)		Holocene (0.0117 Ma)	
	Subsidence (– m)		Subsidence (– m)		Subsidence (– m)	
	Min	Max	Amount		Amount	
	Rate (m/ 100 years) X 10– 4		Min	Max	Min	Max
1	750	2500	167.04	555.36	1.14	2.52
	63.5	315.0				
2	0	2000	0	445.44	0	15.2
	0	161.2				
3	0	250	0	55.68	0	1.90
	0	21.5				
4	0	250	0	55.68	0	1.90
	0	21.5				
5	0	1000	0	222.72	0	7.60
	0	80.6				

1= Eastern Edge, 2 = Northern Edge, 3 = Western Edge, 4 = Sothern Edge, 5 = Central part, (The used data is from Sissakian and Deikran, 1998)

2.2.2 Neotectonic Indications

Many indications occur in the Mesopotamia Plain which indicate Neotectonic activities. These are mentioned hereinafter.

Topographic Indications: Samarra subsurface anticline (Figure 4) is the most obvious topographic indication in the Mesopotamian Plain for the presence of a growing subsurface anticline. Although the area is covered by Quaternary sediments (Sissakian and Fouad, 2012), but the presence of the subsurface anticline is proved by geophysical studies (C.E.S.A., 1992 and Al-Kadhimi et al., 1996). Moreover, the morphology of the area indicates clearly a double plunging anticline (Figure 4). Such Quaternary landform is clear indication for a neotectonic activity (Markovic et al., 1996).

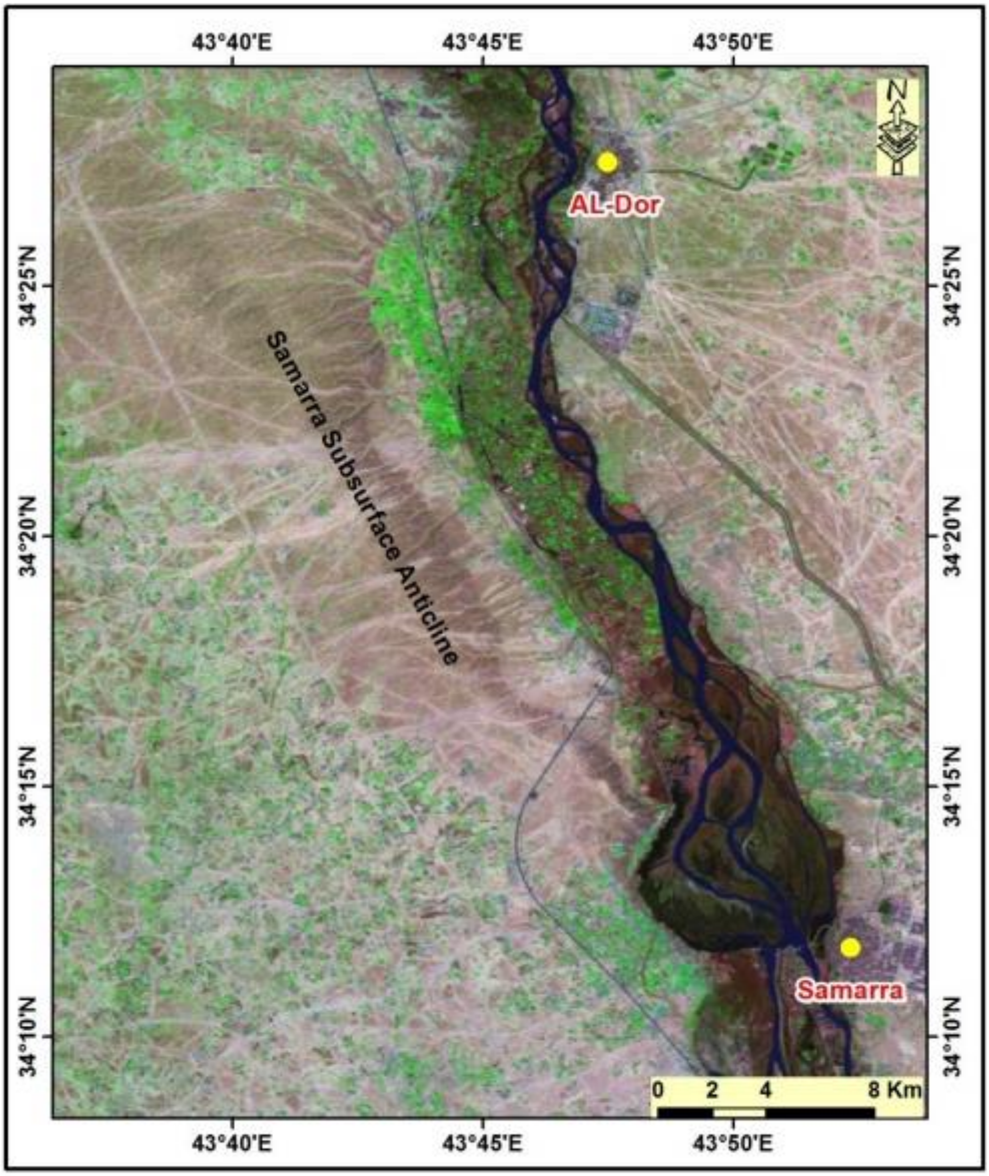

Figure 4: Satellite image showing Samarra subsurface growing anticline.

Abandoned River Channels: Different abandoned channels of the Tigris and Euphrates Rivers can be seen in different places within the Mesopotamian Plain. The reason for abandoning the rivers their channels is a matter of debate. In Neotectonic view, the reason is the growing of subsurface anticlines. However, this is not in all cases, some are related to huge floods which back to tens of centuries when the course (channel) of the river was changed, especially in meandering areas. Another case is construction of irrigation canals during ancient civilizations.

Among the main abandoned channels, is the channel between the Tigris and Al-Ghar'raf rivers (Figure 5). This abandoned channel is either the old course of the Tigris River or that of Al-Ghar'raf River. The authors believe that the growing of the subsurface Ahdab anticline in the area was the main reason for abandoning of the channel. Many authors (Al-Sakini, 1993; Mello et al., 1999; Bhattacharya et al., 2005 and Philip and Virdi, 2007) recorded such cases as Neotectonic activity.

The Euphrates River also had abandoned its course in different places and more than once (Al-Sakini, 1993). He claimed two abandoned courses. The first one is west and south of the current course, whereas the second one runs east of the present course. For the former course, only small part is clear, which runs south of Samawa city to Nasiriya city (Figure 6). The authors found many indications for this course (Figure 6, A and B), apart from the locations of Eridu and Ur archeological sites (Figure 6) which are supposed that they were located along the Euphrates River. However, no clear indication can be seen from the satellite images for the latter course, because the supposed course has been either obliterated by cultivation or covered by the active sand dune fields, between Diwaniya and Nasiriya cities.

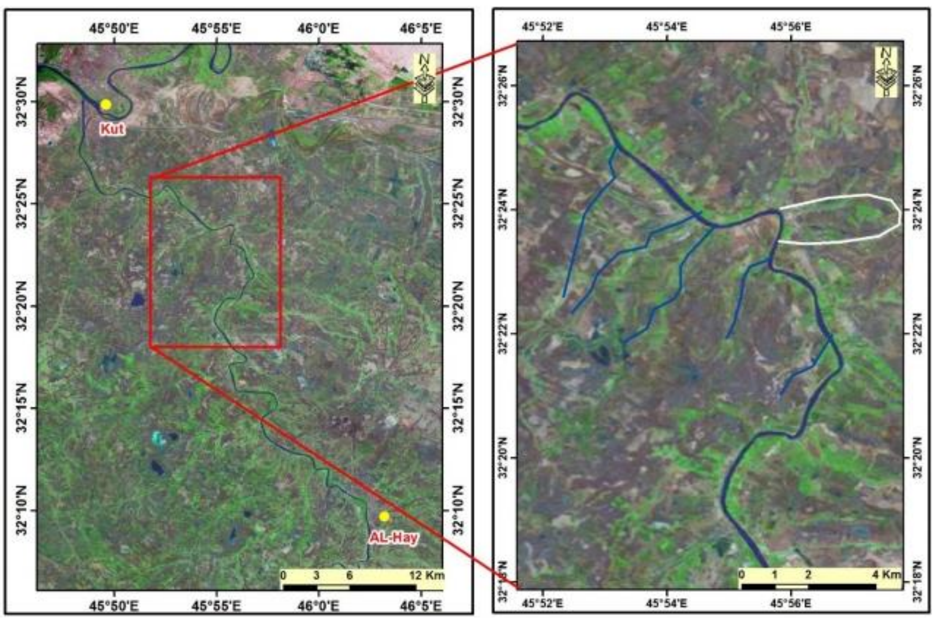

Figure 5: Left) Satellite image showing abandoned courses of Al-Ghar'raf River (in blue color) and Ox-bow lake (in white color), Right) The enlarged red caption.

It is worth mentioning that Elison (1978, p. 21 – 22) mentioned that "In the Warka are, it seems that two branches of the Euphrates served the region, the Purattu which flowed from Nippur to Warka and then on to Ur, and the Iturungal which flowed from Adab (Bismaya) to Umma, Bad Tabira and Larsa, joining the Purattu at about Larsa. The joint river then flowed on into the Ur area". This idea gives sound explanation for the water source in Ur and even may be to Eridu".

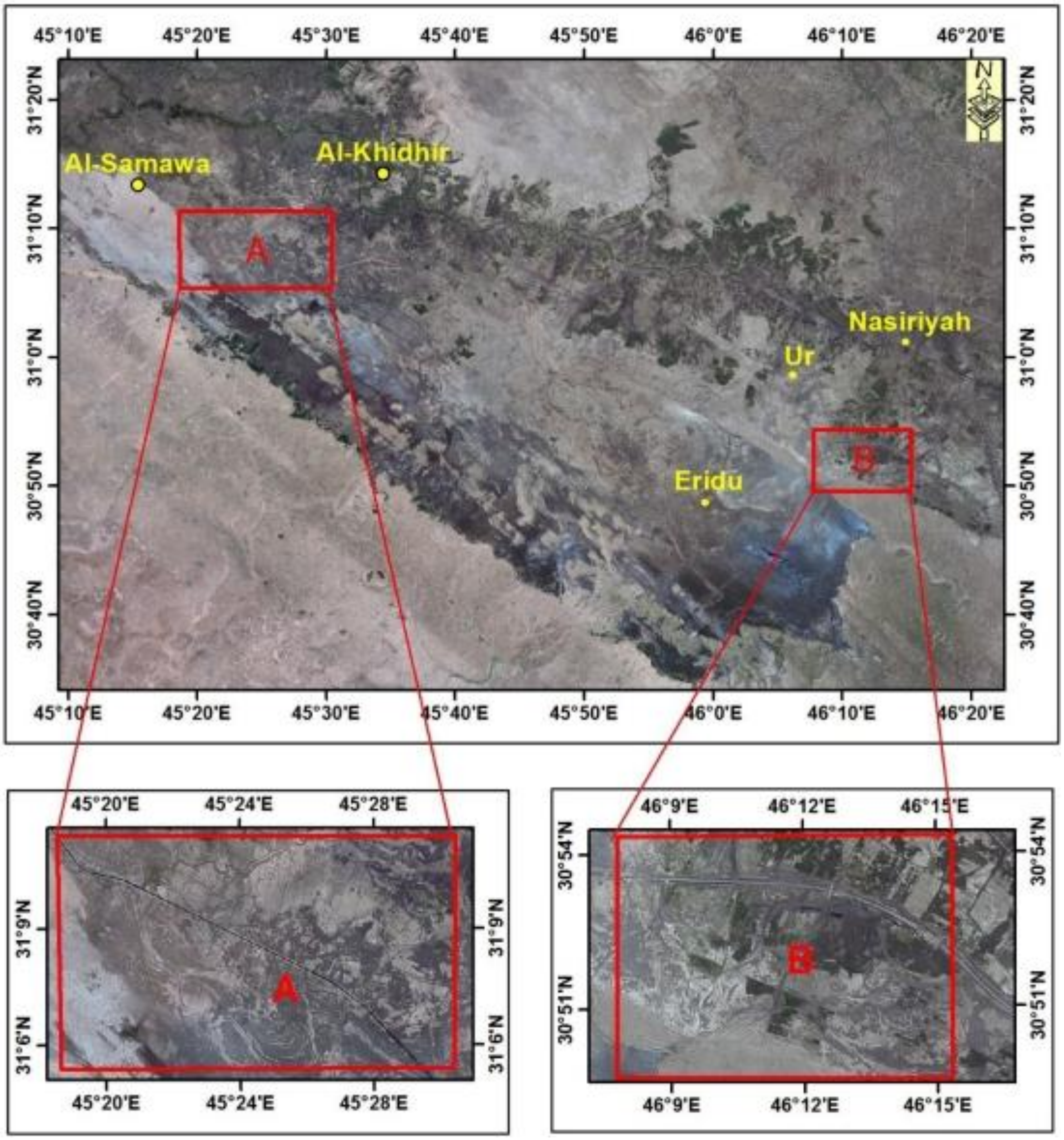

Figure 6: Satellite image of the Euphrates River between Samawa and Nasiriya cities. Note the abandoned river courses in two captions (A and B), and the locations of, Eridu and Ur towns.

2.3 Changing of the River Courses

The two main rivers Tigris and Euphrates and their distributaries have changed their courses within the Mesopotamian Plain; the most significant changes were during the Holocene (0.0117 Ma). This is attributed to the fact that the indications for the changes of the courses during Pleistocene (2.558 Ma) have almost vanished due to weathering and erosional process, and human activities. Many authors (mentioned above) have assumed different changes in river courses; each of them has postulated his opinion in reconstructing of ancient courses. Some of them even have presented the ancient courses. However, Al-Sakini (1993) presented excellent maps for the ancient courses of the Tigris and Euphrates Rivers. He assumed that all changes in the river courses are attributed to the growing of subsurface anticlines in the Mesopotamian Plain, which are shown in Figure 7.

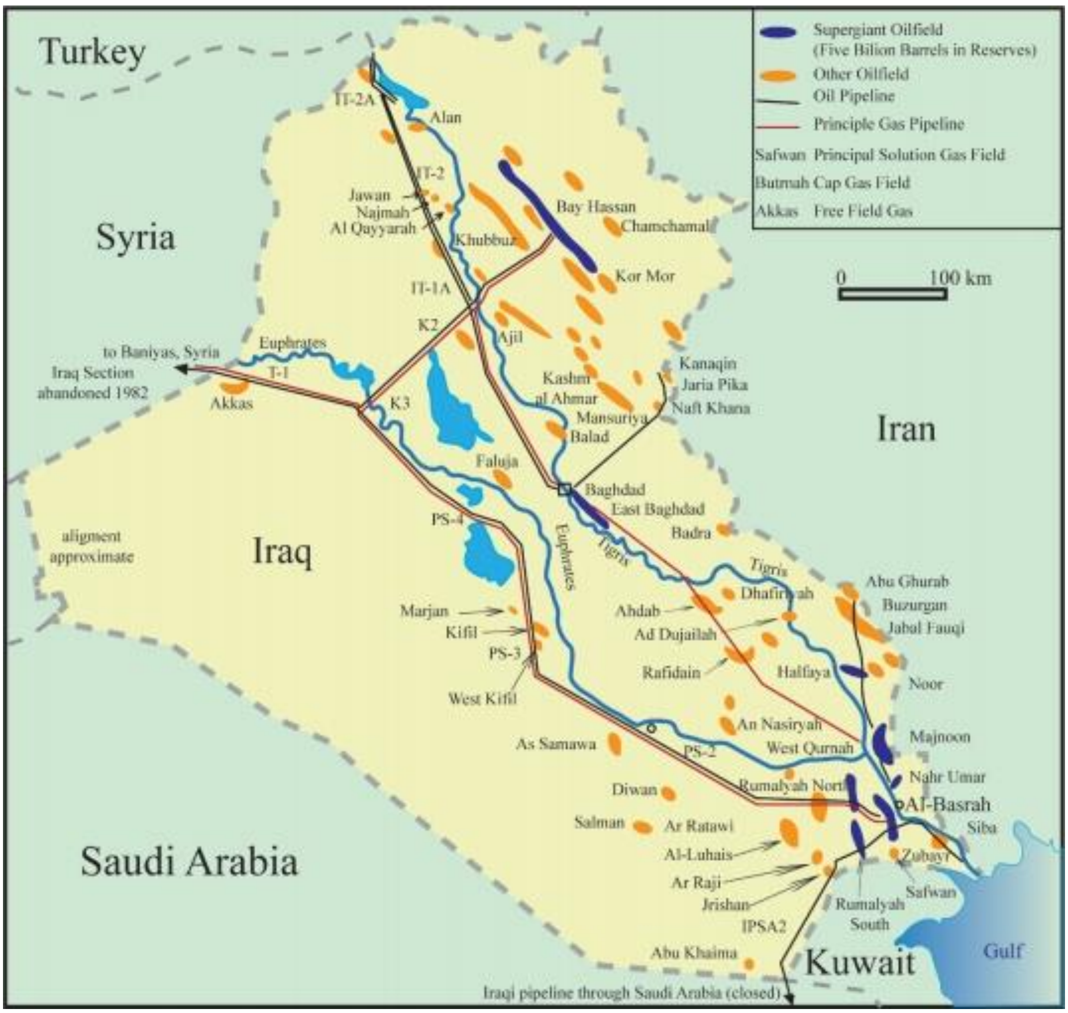

Figure 7: Distribution of oil and gas fields along the course of the Tigris River and its tributaries (from Judicial Watch, 2002)

We have selected many examples from the ancient courses of the Tigris and Euphrates rivers, besides many others of the distributaries of the latter within the Mesopotamian Plain (Figure 8). However, some of the abandoned river courses may represent artificial irrigation canals constructed during ancient civilizations (Ellison, 1978, p.21 – 22). Figure 9 represents abandoned ancient courses of the Tigris River and its distributaries. We believe the change in the course is due to the growth of the subsurface Al-Dujail and Kumait anticlines (Figure 7). Figure 10 represents abandoned ancient courses. It is very difficult to decide whether it belongs to the Tigris River or the Euphrates River, because it is almost in half distance between the nowadays river courses. We believe; however, it most probably belongs to the Tigris River. The change in the course is due to the growth of the subsurface Ahdab, Rafidian, Gharraf and Al-Nasiriya anticlines (Figure 7). Another possibility is old course of Al-Gharraf River.

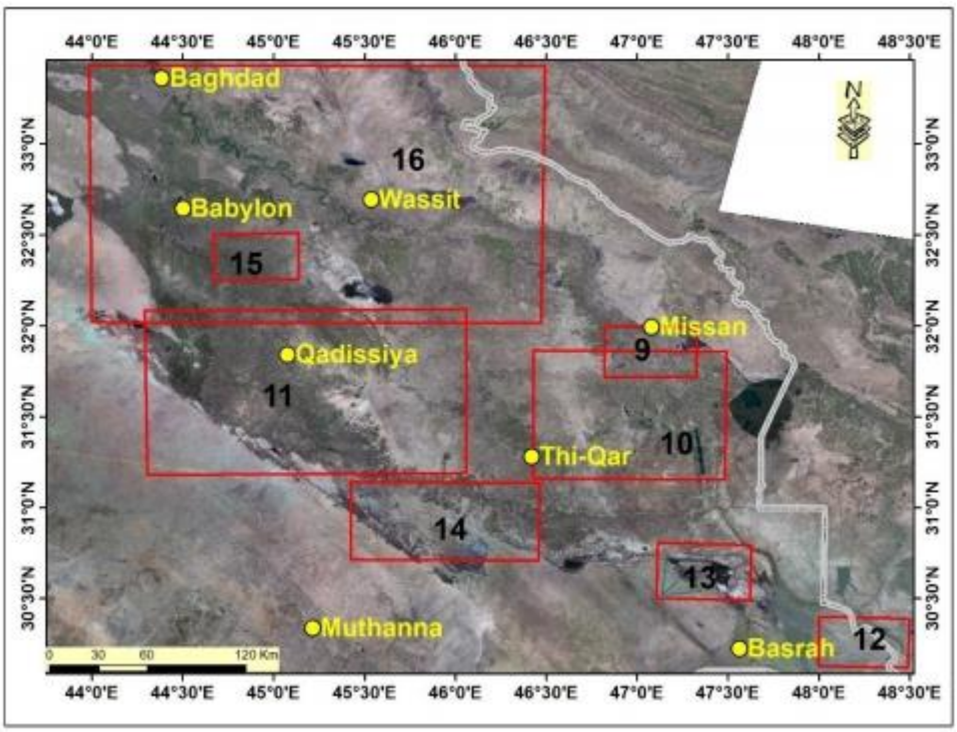

Figure 8: Satellite image showing the location of the presented images (Figures 8 – 15).

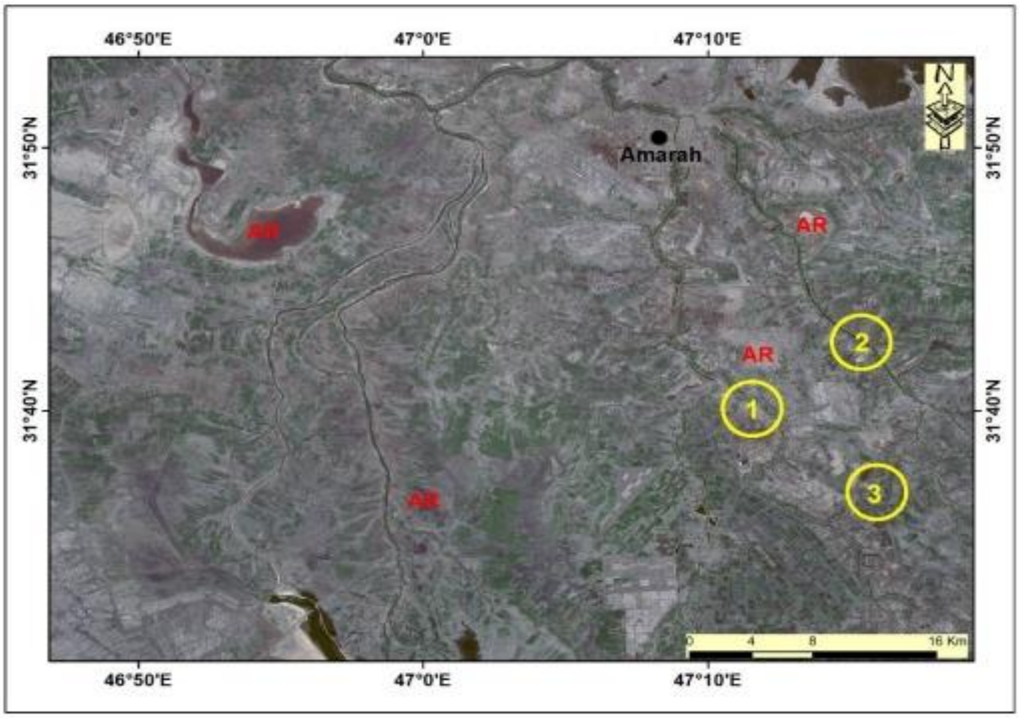

Figure 9: Satellite image showing: Rivers: 1 = Tigris, 2 = Al-Majar, 3 = Al-Kahla'a, AR = Abandoned river courses.

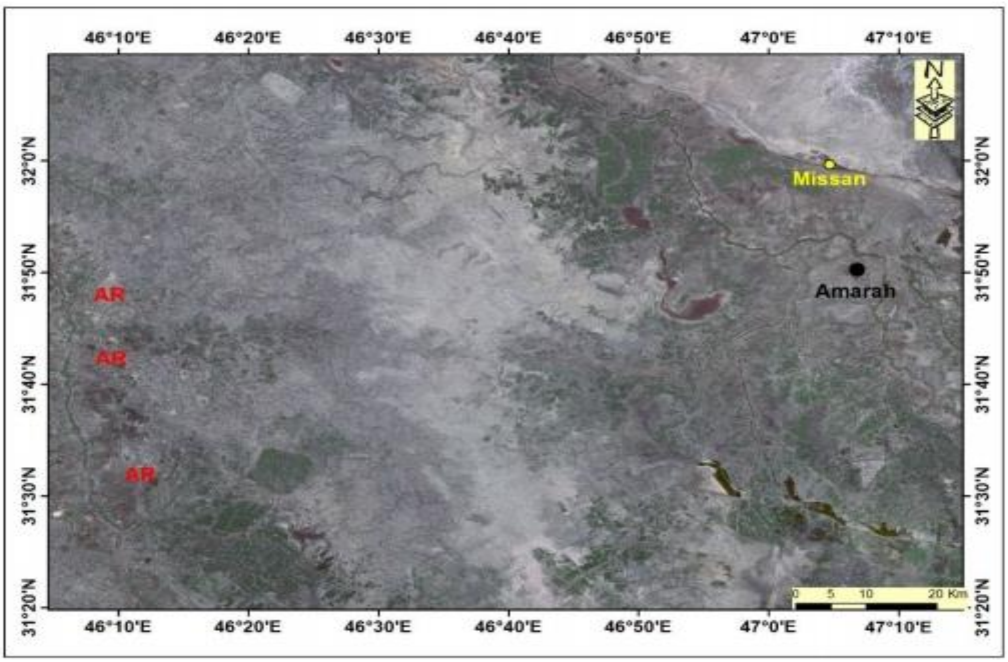

Figure 10: Satellite image showing abandoned river course (AR), most probably of the Tigris River or Al-Ghar'raf River.

Figure 11 represents abandoned ancient courses of the Tigris and Euphrates Rivers. Those which are east of the Longitude 45° 18' belong to the Tigris River, whereas those to the west belong to the Euphrates River. The change in the course of the Euphrates River is due to the growth of Al-Samawa subsurface anticline (Figure 7) and active Abu Jir Fault Zone. That of the Tigris River is most probably not related to tectonic activities, since no subsurface anticline is recorded in the area (Figure 7). It may be an ancient irrigation canal; part of it is covered by active sand dunes field.
Figure 12 represents abandoned ancient courses of Shat Al-Arab (the conflict of the Tigris and Euphrates rivers). Two main abandoned courses can be seen indicating that Shat Al-Arab is moving eastwards. We believe it is due to the growth of the Siba subsurface anticline Figure 7. Sissakian et al. (2018) also confirmed Neotectonic activity from the concerned area as related to the upper reaches of the Arabian Gulf.
Figure 13 represents abandoned ancient course of the Euphrates River. We believe it is due to the growth of Al-Batin alluvial fan. Yacoub (2011) mentioned that the fan consists of four stages which were continuously growing northeast wards (Sissakian et al., 2014). They also confirmed the Neotectonic activity of the concerned area.
Figure 14 represents abandoned ancient course of the Euphrates River. We believe it is due to the growth of the subsurface Al-Samawa anticline Figure 7 and the effect of active Abu Jir Fault Zone (Fouad, 2012). We also believe that Al-Slaiabt Depression is a remnant of an old marsh through which the Euphrates River was passing.

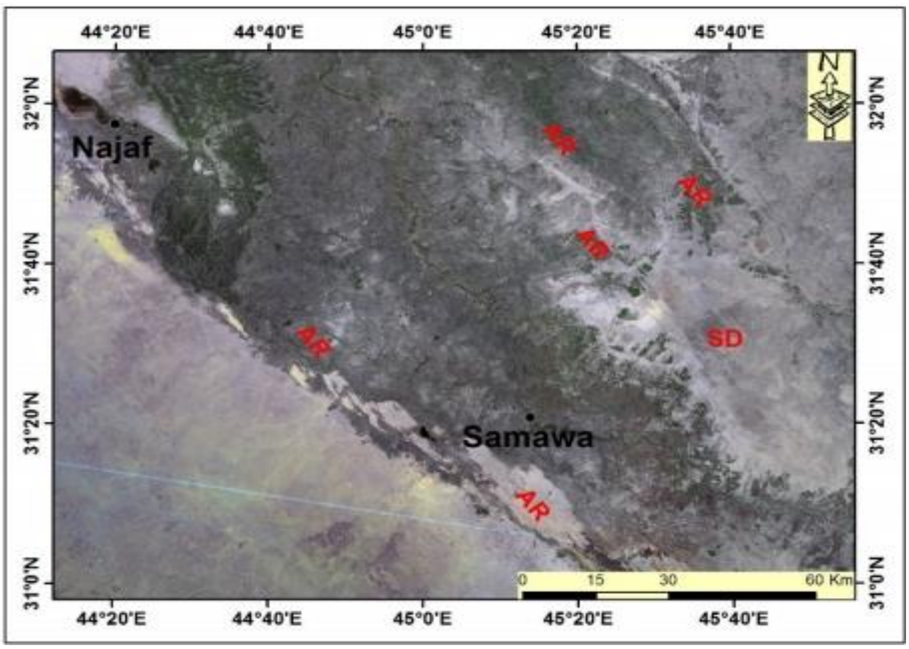

Figure 11: Satellite image showing abandoned river course (AR) of the Tigris and Euphrates Rivers and large sand dunes field (SD).

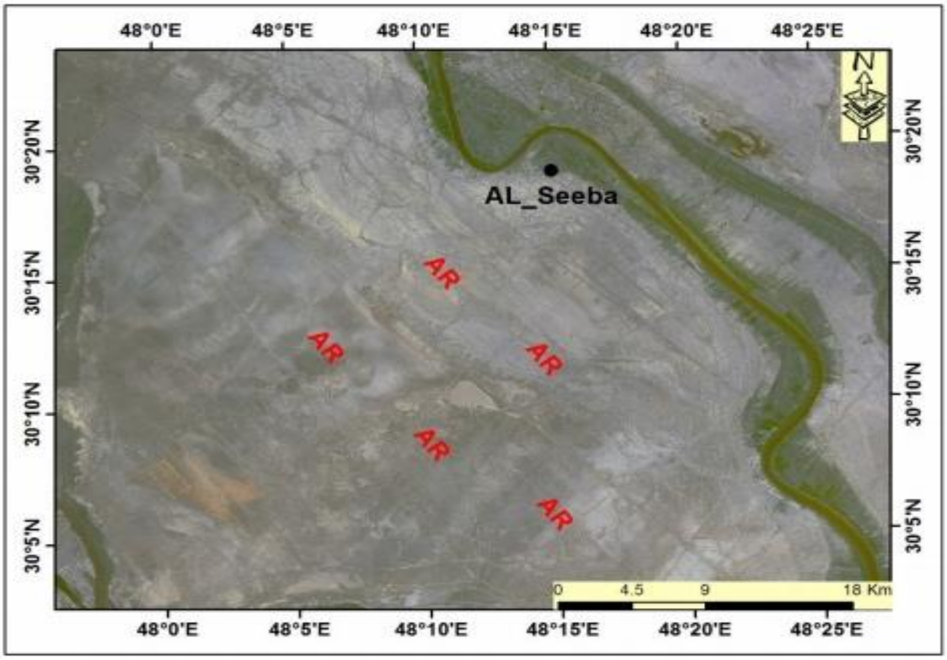

Figure 12: Satellite image showing abandoned river courses (AR) of Shat Al-Arab due to the growth of Siba subsurface anticline.

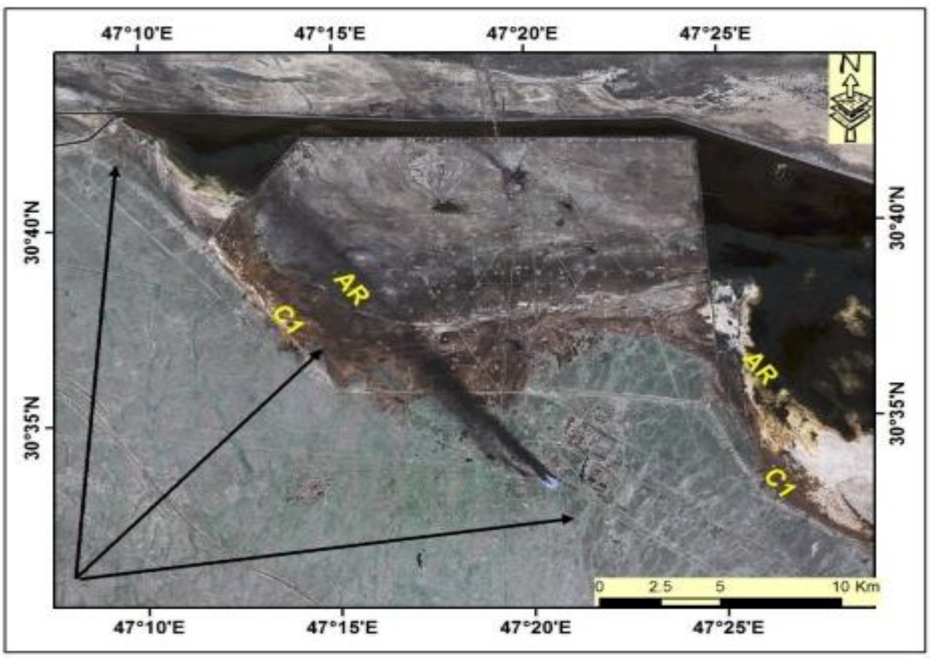

Figure 13: Satellite image showing abandoned river course (AR) of the Euphrates River due to the growth of Al-Batin alluvial fan, note the ancient cliff of the river (Cl)

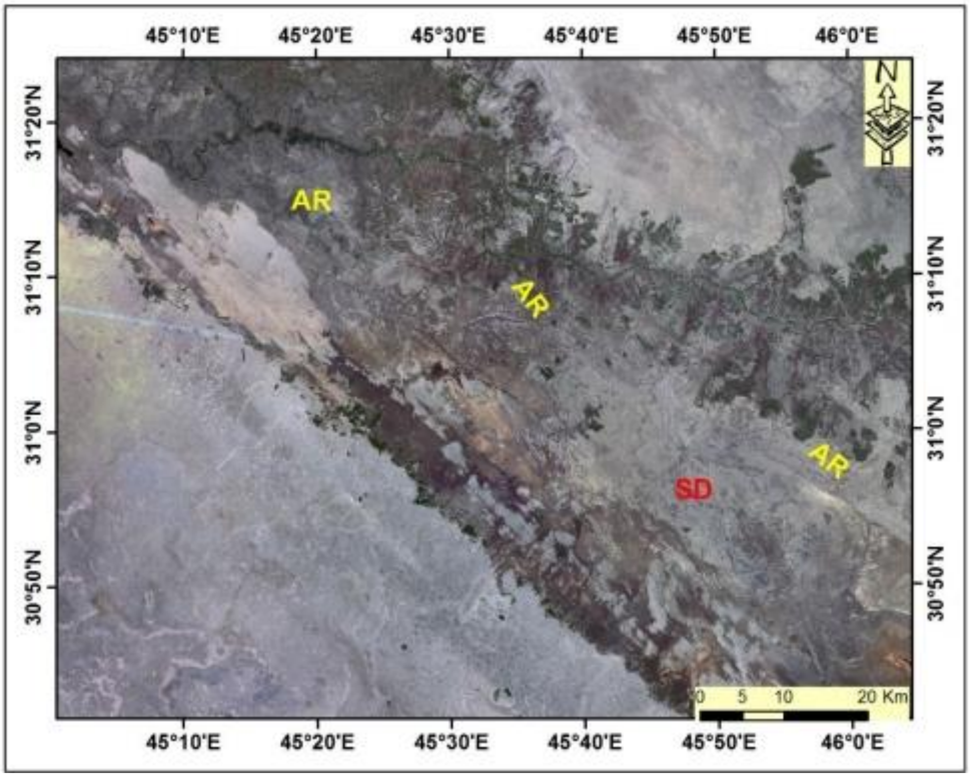

Figure 14: Satellite image showing abandoned river course (AR) of the Euphrates River. Note Al-Slaiabt Depression (SD) which was most probably an old marsh.

Figure 15 represents abandoned ancient course of the Euphrates River. We believe it is an ancient irrigation channel and/ or the river changed its course to flow in irrigation channel which was constructed during ancient civilizations. This assumption is attributed due to absence of any subsurface anticline in the area (Figure 7).

Figure 16 represents abandoned ancient course of the Tigris River. We believe it is an ancient irrigation channel which was constructed during ancient civilizations. This assumption is attributed due to absence of any subsurface anticline in the area (see Figure 7) besides its regular shape which resembles irrigation channel rather than a course of a river.

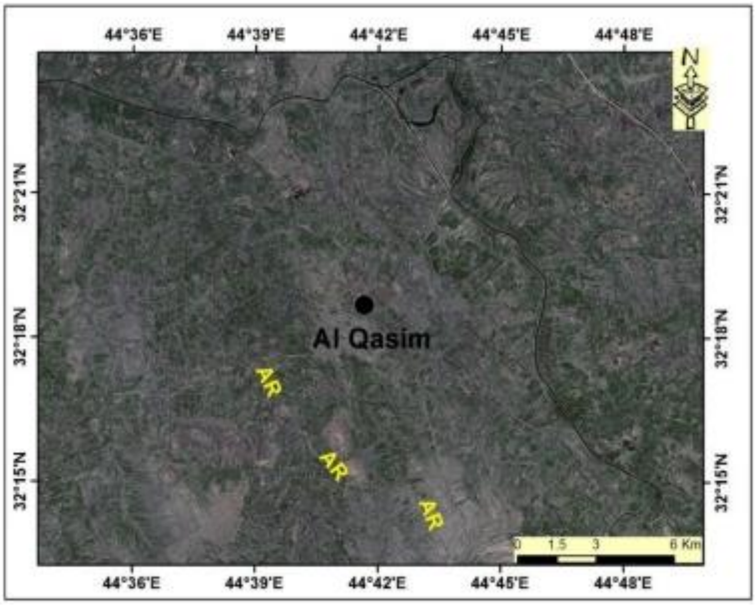

Figure 15: Satellite image showing abandoned river course (AR) of the Euphr ates River.

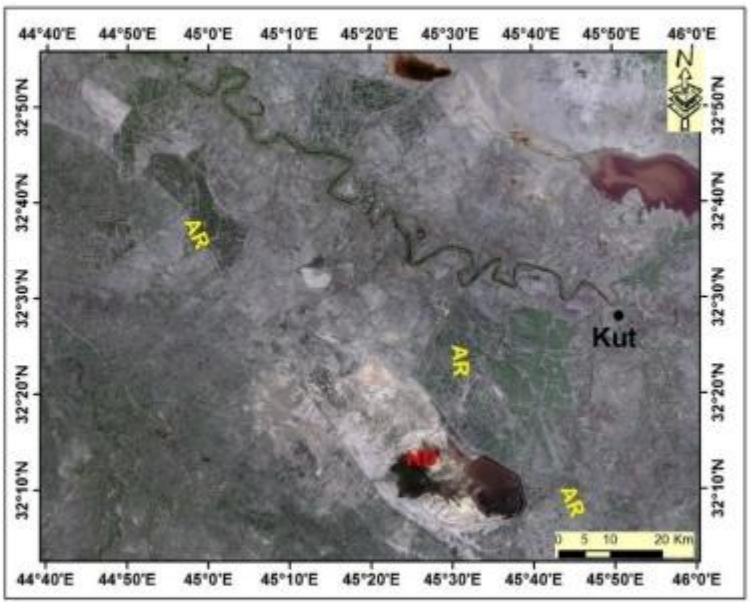

Figure 16: Satellite image showing abandoned river course (AR) of the Tigris River. Note Hor Al-Dalmaj (HD) where possibly the river was passing through

It is worth to mention that there are tens of abandoned river courses and/ or ancient irrigation canals within the Mesopotamian Plain. All of them belong to the Tigris River and its distributaries, and the Euphrates River, and very rarely to Shat Al-Arab (Figure 17). Some of them are almost vanished due to human activities (cultivation) others are hindered by sand dunes, and others are very old; therefore, their traces are very difficultly visible on satellite images.

Figure 17: Left, aerial photograph (General Directorate of Survey, 1962); Rig ht, satellite image, 2006 showing the tidal channels system of Khor Al-Zubair. Note the differences due to Neotectonic activity.

2.4 Umm Al-Binni Lake

The Southern Mesopotamia is characterized by vast marshlands of shallow-water lakes and vegetated mashes mostly by reeds (locally called Ahwar) (Aqrawi, 1993; Aqrawi and Evans, 1994). Among those Ahwar, tens of open lakes of different sizes and shapes are developed and scattered across the southern parts of the Mesopotamian Plain. One of these lakes is called the Umm Al-Binni Lake (Figure 18). It is located about 40 km south of the Amara city and about 45 km north of the present confluence of the Tigris and Euphrates rivers at Qurna Town. The centre of this lake is defined by 31°14′29″ N and 47°06′21″ E coordinates. The Umm Al-Binni Lake is, however, almost dry nowadays. The previous studies of the Umm Al-Binni Lake mentioned that it is an impact meteorite crater (e.g. Master, 2001 and 2002) suggested that this 3.4 km diameter, dry lake may be a meteorite impact crater due its nearly circular and slightly polygonal rimmed shape that contrasts with the shape of other surrounded lakes in the region. Master (2001) and Master and Woldai (2004 and 2006) proposed that the alleged Umm Al-Binni impact had been responsible for the sudden climate change and catastrophic events around 2200 BCE; including the collapse of the Sumerian civilization. Sissakian and Al-Bahadily (2018) investigated the origin of the Umm AlBinni Lake using geophysical data and remote sensing techniques. The results of magnetic and gravity analyses showed that the Ahwar area of southern Mesopotamia, including the Umm AlBinni Lake, was subjected to the differential subsidence of the basement faulted blocks, as the distribution of the lakes is mostly controlled by such basement tectonic zones of weakness. The straight northeastern and southwestern rims indicate that the lake is tectonically controlled, and since the lake is developed in the fluvial sediments of the Mesopotamian Plain of Quaternary age; therefore, it is considered as a Neotectonic activity.

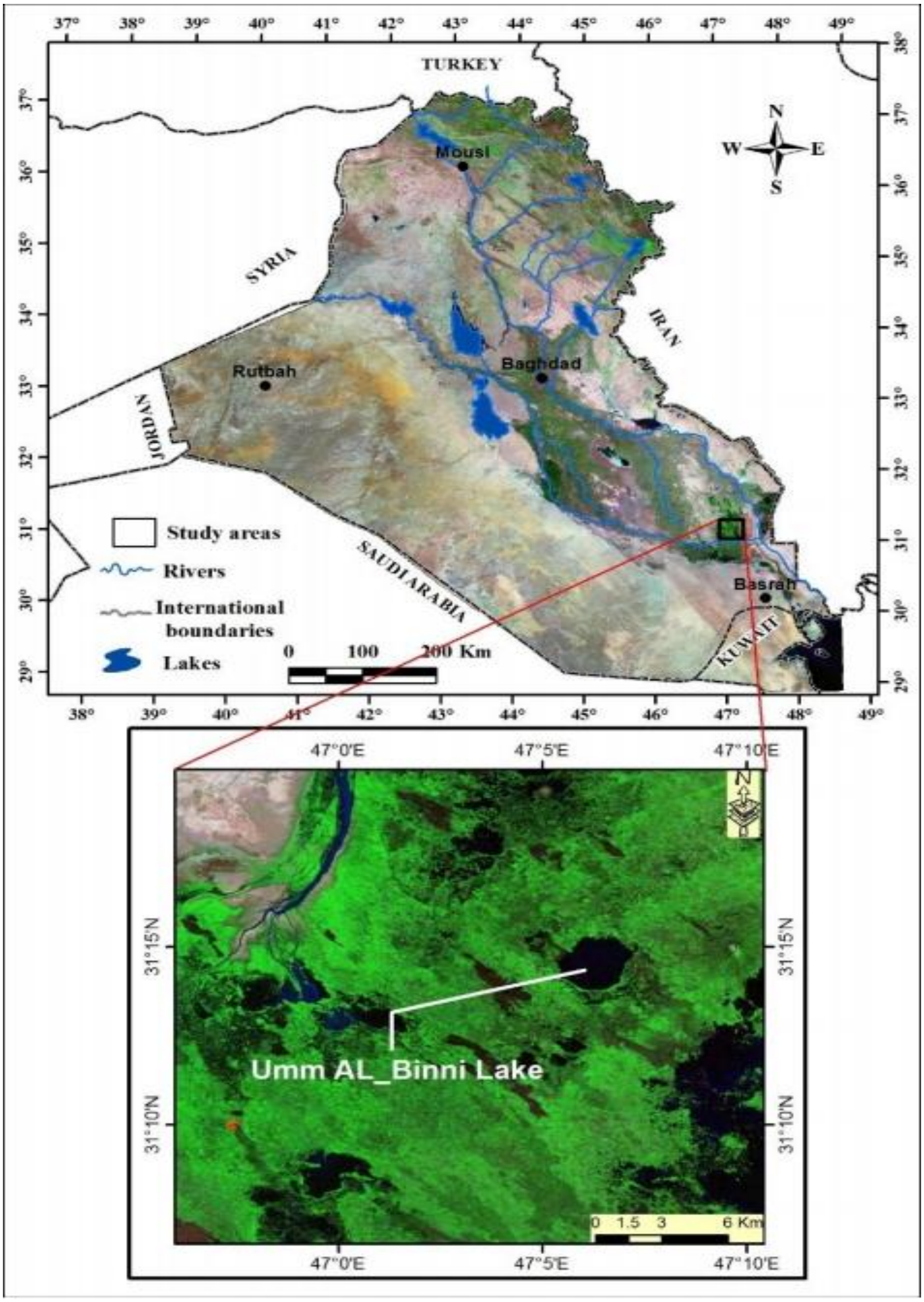

Figure 18: Top) Location map of Umm Al-Binni Lake, Bottom) Google Earth image of Umm Al-Binni Lake.

3. Discussion

Only three main aspects are discussed: 1) Changing of river courses, 2) Tectonic activity of the Mesopotamian Plain, and 3) Neotectonic activities. Other aspects such as structural units are well discussed in many published works (e.g. Henson, 1951; Dunnington, 1958; Ditmar, 1971; Iraqi – Soviet Team, 1979; Buday, 1980; Buday and Jassim, 1984 and 1987; Al-Kadhimi et al., 1996; Buday and Jassim, 1987; Jassim and Goff, 2006; Fouad, 2012 and Sissakian, 2013).

1) Changing River Courses: A significant issue which needs discussion is the changing of the river courses during the Pleistocene and Holocene. There is a big difference in the considered reasons between the archeological and geological studies. The archeological studies assume that all the changes in the river courses are related to major floods and/ or constructed irrigation canals (e.g. Ellison, 1978, p.68 - 69). Whereas the geological studies assume that the main reason for changing of the river courses is the Neotectonic activities mainly related to the growth of the subsurface anticlines (Figure 7) (Al-Sakiny, 1993, Fouad and Sissakian, 2012, Sissakian, 2013, Sissakian et al., 2017 and 2018). Moreover, the activity of the Abu Jir – Euphrates Active Fault Zone also has played role in shifting the course of the Euphrates River (Figure 14) and is still shifting the river course more towards northeast. Some large alluvial fans also have shifted the river courses during their growth, especially during Late Pleistocene and Holocene. A good example is Al-Batin alluvial fan (Figure 13), which has shifted the course of the Euphrates River towards northeast (Sissakian et al., 2014). However, the influence of major floods and the mechanism of river's hydraulic, especially during large floods are also considered in majority of geological studies. Moreover, the presence of main irrigation canals which were constructed during early civilizations are considered too in geological studies as a main factor which had contributed in shifting of the river courses (Williams, 2001, Ortega et al., 2014). The humid conditions associated with very heavy rain showers during wet stages of the Pleistocene and even early Holocene also had contributed in changing the river courses. This is attributed to the erosional forces and the weight of the carried sediments in entrenching the courses of the rivers into more straight courses, especially when acute meanders existed in the river courses, and especially where the irrigation canals were constructed perpendicularly on large meanders. This is called rapidly varied flow (Kindsvater, 1958).

We have added the ancient courses of the Tigris and Euphrates rivers (Figure 19) with their names, ancient (historical) towns as well as the recent courses of the two rivers for comparison purposes.

2) Tectonic activity of the Mesopotamian Plain: The only authors who suggested that the Mesopotamian Zone belongs to the Stable Shelf are Jassim and Goff (2006). However, it is worth to mention that Buday and Jassim (1984 and 1987) have considered the Mesopotamian Zone as a part of the Unstable Shelf as all other workers have considered. The current study also has considered the Mesopotamia Plain to be within the Unstable Shelf or the Outer Platform. This is attributed to: i) The presence of tens of subsurface anticlines (Figure 7) in different parts of plain, ii) The recorded Neotectonic activities in different parts of the plain, iii) The subsidence amounts and rates within the Mesopotamian Plain confirm its instability, and iv) The continuous changes in the river courses.

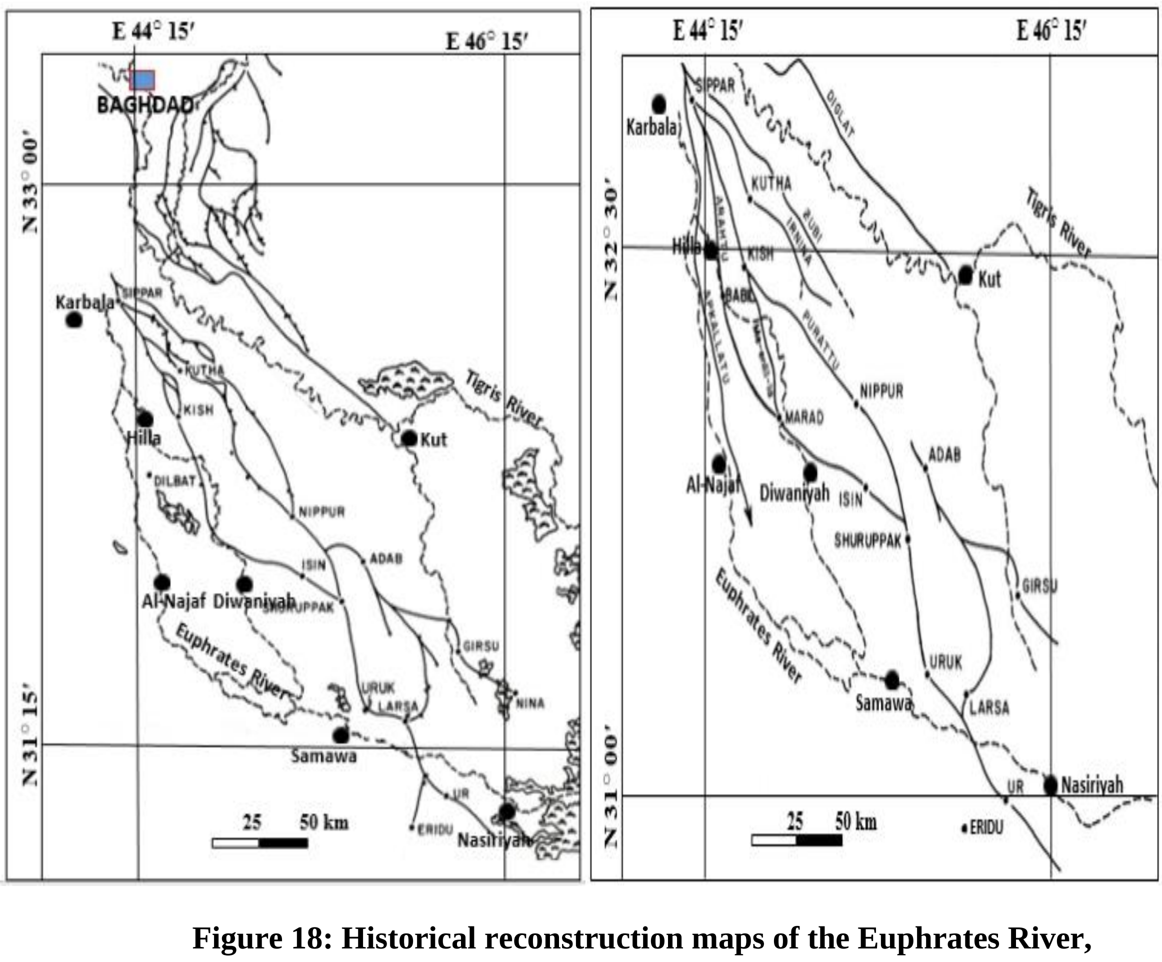

Figure 18: Historical reconstruction maps of the Euphrates River, Left) Before 3000 B.C. (After Adam and Nissen, 1975), Right) About 1000 B.C. (After Gibson, 1972). Approximate scale, coordinates and main cities are added by the current authors.

3) Neotectonic activities: The continuous subsidence of the Mesopotamian Plain is confirmed by the constructed Neotectonic maps (Figure 7). The constructed two cross sections within the Neotectonic map (Figure 7) show that the eastern part is very steep as compared to the central and western parts. This asymmetry is a typical of foreland basins formed due to the plate collision manifesting the shape of the subsiding foreland basin formed due to the collision of Arabian and Eurasian plates in front of the rising Zagros Mountain. Such asymmetry also indicates tectonic tilting of the basin (Philip and Virdi, 2007).

4. Conclusions

In conclusion from the current study, we will not deal with the conventional conclusions about normal tectonic aspects; simply because they are well known as the tectonic activity of the Mesopotamian Plain is concerned. Our main conclusions deal with the Neotectonic activities of the Mesopotamian Plain which are indicated everywhere in the plain. The maximum and minimum subsidence amounts in the plain are (< 3000 and 2500 >) m below sea level and (< 250 and Zero >) m below sea level, respectively. The maximum and minimum rates of subsidence during the Neotectonic period are (315.0 and 63.5 m/ 100 years X 10– 4), respectively. The second main conclusion deals with the changes of the river courses. We do believe that the majority of the rivers have changed their courses due to the growth of subsurface anticlines in different parts of the Mesopotamian Plain, and the growth is still ongoing. However, the role of the major floods and the constructed irrigation channels have played a big role in changing the river courses as they contributed with the Neotectonic forces represented by the growth of the subsurface anticlines. The third and last conclusion is that the plain is still active tectonically and will continue in subsidence within the main Mesopotamian Foredeep in front of the rising Zagros Mountains and being part of the Zagros Foreland Basin.

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