

TECTONIC AND STRUCTURAL EVOLUTION OF THE MESOPOTAMIA PLAIN

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ABSTRACT

The geological setting of the Mesopotamia Plain, which is a part of the Mesopotamia Foredeep within the tectonic framework of Iraq, has been reviewed and redefined according to the modern concepts of foreland basins, and new structural boundaries are introduced. The Mesopotamia Plain of the central part of Iraq is a large subsiding basin covered by thick Quaternary sediments of the Tigris and Euphrates Rivers with their tributaries and distributaries. It has been receiving pre-Quaternary sediments from the adjacent rising mountains, in the north, northeast and east, and from the Inner Platform, in the west and south, too.

The Mesopotamia Plain is an epicontinental basin formed above an earlier platformal and marginal basin. Accordingly, the Phanerozoic stratigraphic sequence of the basin can be broadly categorized into three major tectono-stratigraphic assemblages; Cambrian – Early Permian intraplate assemblage, Late Permian – Middle Cretaceous Neo-Tethys passive margin assemblage, and Late Cretaceous – present foreland basin assemblage.

The Mesopotamia Plain is a mobile tectonic zone and contains several buried structures including folds, faults and diapiric structures. Recent tectonic activity of some of these structures is recorded through their effects on the Quaternary stratigraphy and present 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.

النشأة التركيبية للسهل الرسوبي

صفاء الدين فخري فؤاد و فاروجان خاجيك سيساكيان

المستخلص

تمت مناقشة الوضع الجيولوجي للسهل الرسوبي في وسط وجنوب العراق وهو جزء من حوض ما بين النهرين ضمن الهيئة التكتونية للعراق، وتمت إعادة تعريفه وفق المفاهيم الحديثة للأحواض الأمامية، واقتُرحت حدود تركيبية جديدة له. إن السهل الرسوبي هو حوض كبير مستمر بالهبوط ومغطى بكامله بترسيبات العصر الرباعي السمكية لنهري دجلة والفرات وروافدهما وكذلك تفرعاتهما. أُستلم هذا الحوض ترسيبات ما قبل العصر الرباعي من بقية أجزاء حوض ما بين النهرين وحزام زاكروس الجبلي، من الشمال والشمال الشرقي والشرق، وكذلك من الجزء الداخلي المستقر من المسطبة العربية، من الغرب والجنوب.

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إن السهل الرسوبي هو حوض قاري تشكل على جزء من أحواض المسطبة والحافة السابقتين. ويمكن تقسيم التتابع التكتوني-الطباقي فيه إلى ثلاثة مجاميع رئيسية هي: مجموعة داخل الصفيحة من عمر الكامبيري – البيرمي المبكر، مجموعة الحافة الخاملة لمحيط التيثس الحديث من عمر البيرمي المتأخر – الطباشيري الأوسط ومجموعة الحوض الأمامي من عمر الطباشيري المتأخر – الحاضر.

إن حوض السهل الرسوبي هو نطاق بنيوي متحرك ويضم العديد من الطيات والصدوع والاندساسات الملحبة. كما إن للعديد من هذه التراكيب تأثيرات على رواسب العصر الرباعي والأشكال السطحية الحالية، مثل مجاري الأنهار المتروكة، المراوح الفيضية النشطة والخامدة، والأشكال الطبوغرافية لبعض الطيات تحت السطحية، جميعها دلائل على وجود حركات بنيوية حديثة في هذا الحوض.

INTRODUCTION

The Mesopotamia Plain of the Iraq is addressed to the area that is covered by the Quaternary fluvial sediments of the Tigris and Euphrates rivers. This area, which occupies central and southern Iraq is a flat terrain in general with gentle slope from northwest to southeast towards the Arabian Gulf. Geomorphological features related to recent fluvial accumulations such as natural levees, river terraces, alluvial fans, flood plains etc, are very common on the surface, whereas significant features of tectonic origin are almost absent. Because of the thick Quaternary cover, structural information is extremely limited, and can only be obtained indirectly.

Fouad (2010a) considered the Mesopotamia Plain as part of the present day Mesopotamia Foredeep, which represents intern the terrestrial remnant of the Zagros Foreland Basin. This consideration will be the base of the present article, which aims to shade light on the structure and the tectonic evolution of the plain.

GEOLOGICAL SETTING

▪ General

The Mesopotamia Plain is covered by different Quaternary sediments that range in age from Pleistocene to Holocene, and in thickness from few meters up to 180 m; they are represented by fluvial sediments of the Tigris and Euphrates Rivers; and their distributaries (Domas, 1985). Considerable parts are covered by sand dunes, some of them are still active (Sissakian, 2000). Therefore, no structural features can be seen on surface within the area, except a main fault escarpment that extends from south of Al-Najaf city to south of Nasiriyah city (Al-Mubarak and Amin, 1983; Sissakian and Deikran, 1998 and Sissakian, 2000). It forms part of the western borders of the plain, with the adjacent Iraqi Southern Desert. However, the rolling topography, in the northern parts indicates subsurface anticlines that are still rising up, such as Balad, Samarra, Tikrit and Baiji anticlines (Al-Kadhimi *et al.*, 1996). These anticlines, with other surface features, like the drainage pattern, shifting of the main river courses, abandoned river channels active and inactive alluvial fans are good indications for neotectonic movements (Kumanan, 2001 and Cohen *et al.*, 2002). However, the relative sea level and climatic changes, which controlled discharge and sediments supply; should not be ignored in aforementioned phenomenon (Cohen *et al.*, 2002).

The Mesopotamia Plain forms the central and the southern parts of Iraq. Early workers have considered it a part of the Unstable Shelf of the Arabian Platform (Henson, 1951; Dunnigton, 1958; Ditmar, 1971; Iraqi – Soviet Team, 1979 and Buday, 1980). Buday and Jassim (1984 and 1987) have referred to this area as the Mesopotamian Zone, and considered it as a separate structural unit within the Unstable Shelf. According to their consideration, it is bordered from the northeast by the first superficial and topographic prominent anticlinal ranges represented by Makhoul, Himreen, Badra and Buzurgan. On the other hand, the southwestern boundary of the zone coincides with the Euphrates Fault Zone, extending NW to

Al-Ramadi city, then swings sharply in N – S direction to follow the Tharthar valley and terminates against Makhoul Range, south of Al-Hatra town. Al-Kadhimi *et al.* (1996) followed almost the same line of definition in their tectonic divisions of Iraq (Fig.1). Jassim and Goff (2006) have introduced a major change by considering the Mesopotamian Zone as a part of the Stable Shelf of the Arabian Platform. A change that is not compatible with the regional tectonics of Iraq and the surrounding region. In this regard, it is highly important to mention that almost all of the mentioned tectonic divisions of Iraq have considered the Mesopotamia Plain to represent the entire Mesopotamia Basin (or foredeep). In the present article, however, the tectonic framework of Iraq as introduced by Fouad (2007 and 2010b) and Fouad and Nasir (2009) will be adapted; in which the Mesopotamia Plain is considered as a portion of the major Mesopotamia Foredeep.

The Zagros Fold – Thrust Belt 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, 2010a). The Mesopotamia Foredeep is a continental basin that lies between the Zagros deformational front from the northeast and the stable interior of the Arabian Platform (Fouad, 2010a). The Mesopotamia Plain occupies the central and the southern parts of the Mesopotamia Foredeep within the Iraqi territory. It is a potential region of subsidence in the Neogene, and a significant basin of alluvial sediment accumulation in the Quaternary. It is a very mobile basin and contains several evidences pointing to its recent tectonic activity.

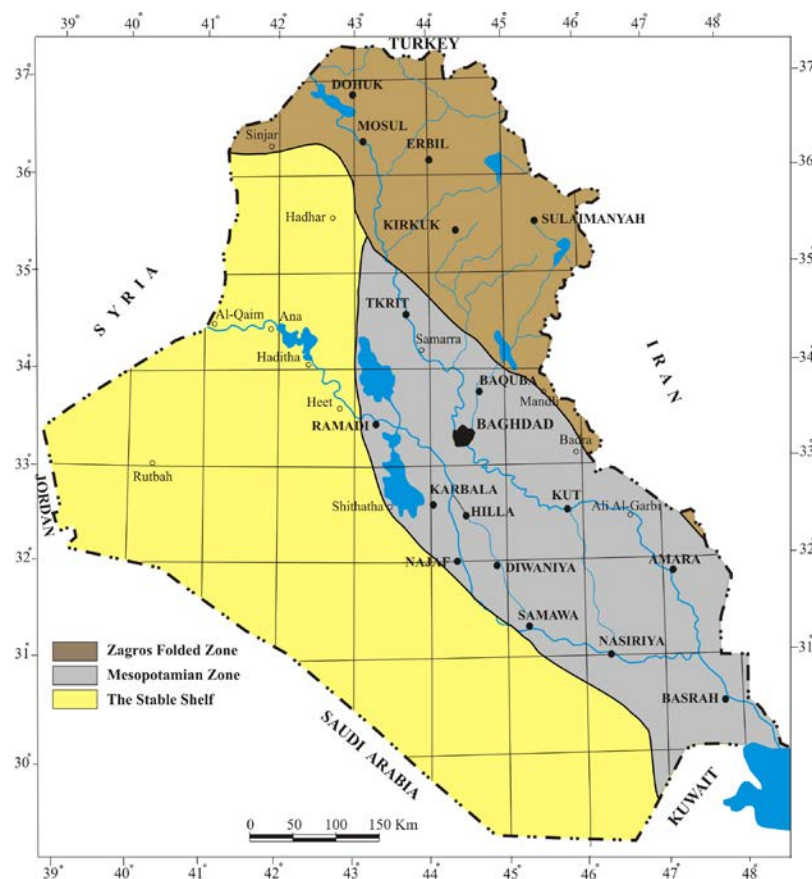


Fig.1: Mesopotamian Zone of Iraq, after Buday and Jassim (1984 and 1987); Al-Kadhimi *et al.* (1996), and Jassim and Goff (2006)

▪ **Stratigraphy**

The Mesopotamia Plain is covered entirely by Quaternary sediments; no pre-Quaternary rocks are exposed. The CGG (1974), using magnetic and gravity data, estimated the depth of the basement to be between 8 Km, in the western part and 14 Km, in the eastern part of the area. The area contains almost a complete sedimentary succession without significant breaks (Jassim and Buday in Jassim and Goff, 2006).

The complete thickness of the Paleozoic sequence is not penetrated in any borehole in Iraq. Only very few wells in the Mesopotamia Plain have reached the upper most part of the Paleozoic sequence. However, the thickness of the Paleozoic sequence is estimated to be around 5 Km. By correlations with other parts of Iraq, as well as in most of Arabia, it is believed that the Paleozoic sequence is dominated by siliciclastic sediments deposited in a shallow epicontinental sea (Beydoun, 1991; Alsharhan and Nairn, 1997 and Sharland *et al.*, 2001).

The Mesozoic sequence is composed of an almost complete sedimentary succession without significant breaks. The average thickness of the sequence is about 5 Km (Jassim and Buday in Jassim and Goff, 2006). The sequence usually consists of neretic and lagoonal evaporites, shales and carbonates that grade up into an alternation of carbonates and sandstones of shallow marine nature.

The Cenozoic sequence usually consists of Paleogene open marine carbonates that grades up into Neogene lagoonal and restricted marine evaporite facies, followed by molasses type deltaic and continental clastics (Fouad, 2010b). The average thickness of the sequence is highly variable, in different parts of the Iraqi territory.

The Quaternary sediments exhibit an exceptional development in the Mesopotamia Plain. They consist of gravels, sands, silts and clays that are mainly related to the cyclic fluvial sediments of the Tigris and Euphrates Rivers, with their tributaries and distributaries. These sediments form extensive, flood plains with a complex network of natural levees and channels, and terraces.

The Quaternary sediments of the Mesopotamia Plain, exhibit progressive thickening from northwest to southeast. They reach their maximum thickness near Basrah city, about 180 m (Yacoub and Barwari, 2002).

▪ **Structure**

The Mesopotamia Plain is a flat terrain, slopping very gently toward the Arabian Gulf. Structural features are absent on surface. It contains several subsurface structures including faults, folds and diapiric structures that are entirely concealed beneath the Quaternary cover.

— **Folds:** Surface folds are almost absent in the Mesopotamia Plain. The NW – SE trending Tikrit and Samarra folds are the only exception, though they are hardly recognized on surface because of the Quaternary cover. Due to the continuous growth, the Quaternary sediments are uplifted along these structures with about (10 – 15) m relief in comparison with the surrounding. Consequently, local drainage divide lines are developed along the crests of these structures (Fouad, 2010a).

Subsurface folds and structural noses are rather common structures within the Mesopotamia Plain. They are hidden beneath Quaternary cover, usually with NW – SE trend in the central and eastern parts, following the general trend of the Zagros Fold – Thrust Belt, but deviate largely in the extreme southern part where the folds are N – S trending (Fig.2).

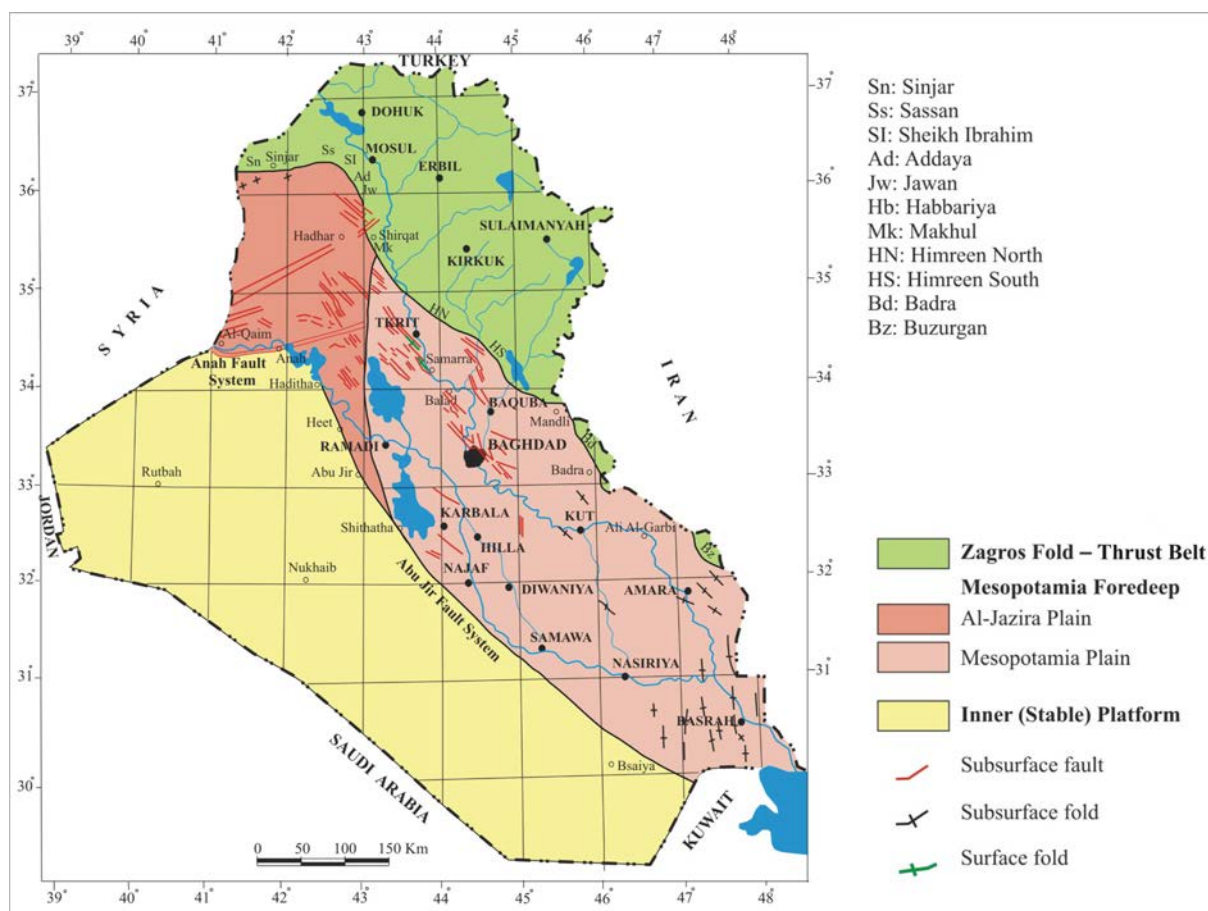


Fig.2: Structural Map of Iraq, showing the Mesopotamia Foredeep (after Fouad, 2010b)

The folds of the Mesopotamia Plain are of three genetic types (Fouad, 2010a): The first is the **fault-related folds** that have developed above an initial fault bounded structural troughs (grabens or half grabens) because of structural inversion phenomenon. Consequently, the geometry and the trend of such folds match the trend and geometry of the underlying initial structural trough. Tikrit and Samarra are examples of this type. The second type is the **simple buckle folds**, which formed as a result of the regional compression that was generated by the Arabian – Eurasian (Iranian) Plates collision. Such folds are NW – SE trending following the regional trend by the Zagros Fold – Thrust Belt. The third type is limited to the extreme southern part of Mesopotamia Plain. These folds are N – S trending, following the old inherited fractures of N – S Arabian trend, which is best developed in the north of the Arabian Gulf region. The folds are usually long, broad and with low amplitudes (such as Zubair and Rumaila structures), and are thought to be related to movement of salt substratum (Colman – Saad, 1978). The presence of the Late Precambrian – Early Cambrian Hormuz Salt (Colman – Saad, 1978 and Alavi, 2004) and its active movement in the north of the gulf region, in general and in this part of the Mesopotamia Plain, in particular is the reason behind the development of these folds. According to Fouad (2010a), the diapiric salt structures beneath the folds in Iraq have pierced the overlying sedimentary sequence to different stratigraphic levels, but have reached the surface only in one locality, to the south of Basrah city, known as Jabel Sanam. It is a circular dome of about 4 Km diameter and more than

100 m of relief. Igneous rock blocks and fragments have been reported in the core, and are surrounded by Miocene – Pliocene sedimentary rock units dipping towards the peripheries. The igneous rocks were classified as dolerite and of Infracambrian age (Jassim and Goff, 2006). Similar to other igneous rock fragments that have been reported in southwest Iran salt structures (Colman – Saad, 1978), it is believed that these rocks were stripped off the basement and brought to the surface by the upward movement of the salt. Recent tectonic activities within the Mesopotamia Plain are well reflected on the present day geomorphological landforms.

— **Faults:** A network of NW – SE trending faults have been developed in the northern part between south Mosul and south Baghdad, in particular. 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 above them, whereas others have not. Fouad (2007 and 2010b) and Fouad and Nasir (2009), using stratigraphic correlation, boreholes and seismic data have concluded that these extensional faults are Late Cretaceous structures.

It is critically important to mention that almost all of the mentioned tectonic divisions of Iraq, have 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 areally extensive, than that of the Mesopotamian Zone or Mesopotamia Plain, which forms only a part of it (Fouad, 2010a). The present day Mesopotamia Foredeep (Basin) extends from northeast Syria to the Straits 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 Gulf Basin (Berberian, 1995; Alsharhan and Nairn, 1997; Brew, 2001; Sharland *et al.*, 2001; Alavi, 2004 and Fouad and Nasir, 2009).

NEOTECTONICS

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 a NW – SE trend and of oval shape. The maximum subsidence, as expressed by means of contour lines, is 2500 m, being measured on the top of the Fatha Formation (Middle Miocene), it forms an elongated oval shape, with NW – SE trend and extends from east of Al-Khalis, for about 30 Km, to west of Badra, for about 10 Km (Fig.3). The basin is asymmetrical, indicating 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 Viridi, 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.3).

Within this huge continuously subsiding Mesopotamia Basin, there are many uplifted areas, which are still active, indicating neotectonic movements. The Neotectonic Map of Iraq (Sissakian and Deikran, 1998) does not show the uplifted areas, because of the scale limitations. Those 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-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).

It is worth to mention that the majority of the uplifted areas, within the Mesopotamia Plain represent nowadays oil fields. Their trend 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 the those uplifted areas (oil fields).

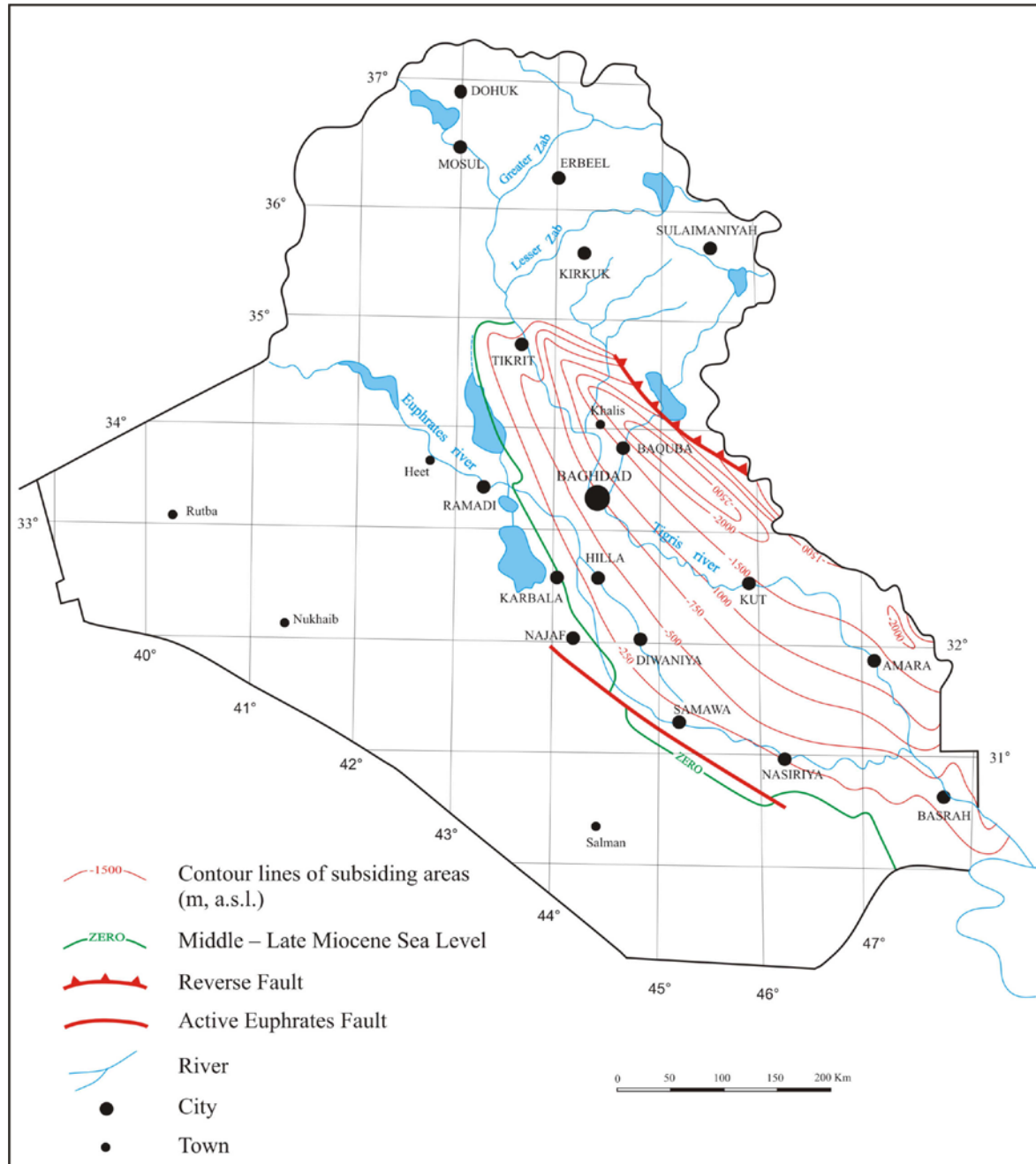


Fig.3: Neotectonic map of the Mesopotamia Plain
(after Sissakian and Deikran, 1998)

NEOTECTONIC INDICATIONS

Within the Mesopotamia Plain, many indications were observed, which indicate Neotectonic activities. The indications are mentioned hereinafter.

▪ Topographic Indications

The most obvious topographic indication for the presence of a growing subsurface anticline, in the Mesopotamia Plain is that of Samarra subsurface anticline (Fig.4). The area involved is covered by Quaternary sediments (Sissakian, 2000), but the presence of the subsurface anticline is proved by geophysical studies (C.E.S.A., 1992 and Al-Kadhimi *et al.*, 1996), besides the morphology of the area that indicates clearly a double plunging anticline. Such Quaternary landform is clear indication for a neotectonic activity (Markovic *et al.*, 1996).



Fig.4: Google Earth image for the Samarra subsurface anticline

▪ Abandoned River Channels

The Tigris River has abandoned channels in different places within the Mesopotamia Plain. The main one is between Al-Ghar'raf River and the current river channel (Fig.5) (Sissakian, 2000). 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 anticlines in the area was the main factor for abandoning of the river its original channel. Many authors (Al-Sakini, 1993; Mello *et al.*, 1999; Bhattacharya *et al.*, 2005 and Philip and Viridi, 2007) recorded such cases.

The Euphrates River has also abandoned its channel, between Samawa and Nasiriyah cities; it is south of the current river course (Sissakian, 2000). The authors believe that the main reason for abandoning of the channel is the activity of the Abu Jir Fault Zone. The activity of this fault is proved by Fouad (2007).

Al-Sakini (1993) claimed that the Euphrates River has shifted its course twice. The first one is west and south of the current course. Whereas, the second one runs east of the present course. For the latter course, we could not find any clear indication, because the supposed course is either vanished by cultivation or hindered by the active main sand dune field, between Diwaniyah and Nasiriyah cities. However, for the former course, only small part is clear, which runs south of Samawa city to Nasiriyah city. The authors are not in accordance with Al-Sakini (1993) for the remaining supposed course, because it runs in a far distance from the current course. Moreover, it is hard to suppose two old trends on both sides of the current course, unless they are not related to Neotectonic activity.



Fig.5: Google Earth image showing the old trends of Al-Ghar'raf River,
due to growing of subsurface Ahdab and Abu Amood anticlines

(Ahdab is few kilometers NW off the image area, Abu Amood is marked by **AA**)

Note: The dashed lines represent the ancient courses of the rivers, the small arrows indicate the exact location of the river course

▪ Shifting of River Channels

The Tigris River has continuously shifted its course and is still shifting (Al-Sakini, 1993). Interpretation of the Google earth image confirms the shifting of the river course between Samarra town and southeast of Baghdad, that was previously running in the middle part of a huge alluvial fan (Jassim, 1981), which is called Al-Fatha Alluvial Fan (Sissakian, 2000), whereas the nowadays course is exactly along the eastern limits of the fan. The traces of the old channel are still clear in small parts, although the major part is vanished by urbanization

and agricultural activities. The eastwards shifting of the channel is attributed, by the authors to the growing of Balad subsurface anticline.

The Tigris River has also shifted its course south of Nu'maniyah town to south of Kut city, most probably due to growing of subsurface Azizziyah anticline (Fig.6). Al-Ghar'raf River also has shifted its course in two areas (Fig.5); the reason is the growing of subsurface Ahdab and Abu Amood anticlines (Al-Sakini, 1993). Such activities are attributed to neotectonic movements by many authors (Mello *et al.*, 1999; Philip and Virdi, 2007, and Woldai and Dorjsuren, 2008).



Fig.6: Google Earth image showing traces of the old Tigris River course, SE of Baghdad (Azizziyah anticline is few kilometers off the image, towards south)

Note: The dashed line represents the ancient courses of the river

▪ Alluvial Fan Activities

Alluvial fans are developed, mainly due to the drop in the energy of the stream that carries the sediments, due to drop in the gradient of the stream. On the other hand, the active fan indicates continuous subsiding of the distal part of the fan, whereas inactive fan indicates uprising of the distal part of the fan. However, the climatic changes should not be ignored (Cohen *et al.*, 2002). It is worth to mention that the activity of the fan is also attributed to neotectonic movements (Cohen *et al.*, 2002, and Jones and Arzani, 2005).

Along the eastern margin of the Mesopotamia Plain, a well developed system of alluvial fans is developed (Figs.7 and 8). They all are of Pleistocene age (Sissakian, 2000). Some of them are still active (Fig.7) indicating continuous subsidence of the Mesopotamia Plain, as it is shown in the Neotectonic Map of Iraq (Sissakian and Deikran, 1998), and interpretation of satellite images. The inactive nature of other alluvial fans (Fig.8) may be attributed to growing of Buzurgan and Halfaya subsurface anticlines, as the authors believe. However, the influence of water supply and climatic changes should not be ignored.

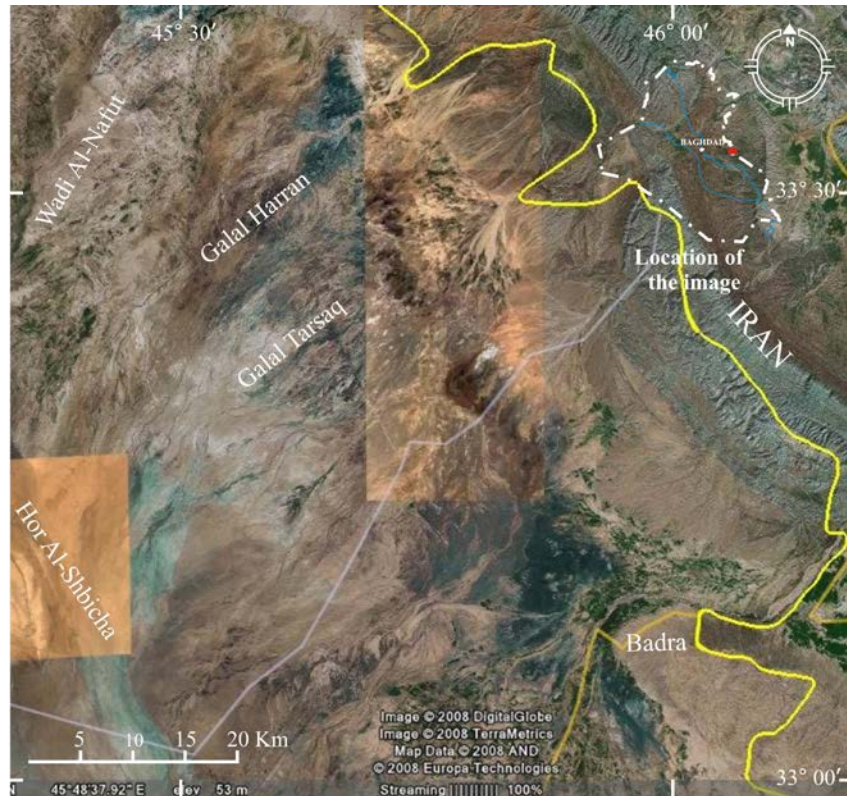


Fig.7: Google Earth image showing complex alluvial fans system, near Badra, developed due to continuous subsiding of the Mesopotamia Plain



Fig.8: Google Earth image showing a big inactive alluvial fan, between Kumait and Amara, the fan is inactive most probably due to uplifting of Buzurgan (**B**) and Halfaya (**H**) subsurface anticlines

CONCLUSIONS

The following could be concluded from this study.

- The Mesopotamia Plain is an integral part of the Zagros Fold-Thrust Belt. It is the extension of the present day expression of the continental part of the major Zagros Foreland Basin.
- The Mesopotamia Plain is an elongated basin lies between the first topographic mountain front of the Zagros Orogenic Belt that extends from Buzurgan to Sinjar, and the stable interior of the Arabian Platform, which is bounded by Anah – Abu Jir Fault Systems.
- The new proposed boundaries of the Mesopotamia Foredeep imply that the Mesopotamia Plain forms only the central and southern parts of the foredeep, and not the entire basin as previously was confused by many workers.
- The Mesopotamia Plain is an asymmetric basin with a wedge-shaped profile. The maximum sediment thicknesses; within the basin occur adjacent to the orogenic front and gradually decreases southwest towards the undeformed continental interior.
- The Mesopotamia Plain is an epicontinental basin that has formed above a part of the Mesopotamia Foredeep, which is an earlier platformal and marginal sedimentary basin.
- The Mesopotamia Plain is a mobile zone, and contains a number of buried tectonic structures including folds, faults and diapiric structures.
- The maximum recorded subsidence, in the Mesopotamia Plain is 2500 m, as measured on the top of the Fatha Formation. The basin is asymmetrical, indicating very steep eastern rim as compared to the western one. The asymmetry is attributed to the collision of the Arabian and Persian Plates, manifesting the shape of the subsiding foreland basin, in front of rising Zagros Fold – Thrust Belt.
- Many of the buried structures are still active, indicating Neotectonic movements. Their recent activity can be observed through their effects on the Pleistocene – Holocene stratigraphy.
- Different landforms, like abandoned river channels, shifting of river courses active and inactive alluvial fans and topographic expression of some subsurface anticlines, all together are good indications for Neotectonic movements in the Mesopotamia Plain.

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