

TECTONIC AND STRUCTURAL EVOLUTION OF THE MESOPOTAMIA FOREDEEP, IRAQ

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ABSTRACT

The geological setting 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 Foredeep, which is the present day expression of the terrestrial part of the Zagros Foreland Basin, is an integral part of the Zagros Fold – Thrust Belt that lies between the deformational front of the Zagros orogenic belt and the stable interior of the Arabian Platform.

The Mesopotamia Foredeep is an elongated epicontinental basin formed above an earlier platform 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 Foredeep is a mobile tectonic zone and contains several buried structures including folds, fault and diapiric structures. Recent activity of some of these structures is recorded through their effects on the Quaternary stratigraphy and present geomorphological landforms.

النشأة التركيبية لحوض ما بين النهرين، العراق

صفاء الدين فخري فؤاد

المستخلص

تمت مناقشة الوضع الجيولوجي لحوض ما بين النهرين ضمن الهيئة التكتونية للعراق، وتمت إعادة تعريفه وفق المفاهيم الحديثة للأحواض الأمامية، واقتُرحت حدود تركيبية جديدة له. إن حوض ما بين النهرين الذي يعبر حالياً عن الجزء البري من حوض زاكروس الأمامي، هو جزء من نطاق طي – تصدع زاكروس الذي يقع بين جبهة التشويه الأمامية لحزام زاكروس الجبلي وبين الجزء الداخلي المستقر من المسطبة العربية.

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

يعتبر حوض ما بين النهرين نطاق تكتوني مرن ويحتوي على العديد من التراكيب تحت السطحية، كالطبقات والصدوع والاندساسات الملحية. كما إن للعديد من هذه التراكيب تأثيرات على رواسب العصر الرباعي والأشكال السطحية الحالية مما يشير إلى نشاطها المستمر حالياً.

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INTRODUCTION

The Mesopotamia Basin, which historically referred to the area between the Tigris and Euphrates Rivers, is basically a flat terrain with gentle slope from northwest to southeast towards the Arabian Gulf. It is mainly covered by different kinds of Quaternary deposits, except at the northwestern part, where Late Neogene sediments are exposed. Except in very few cases, no significant feature of tectonic origin can be observed on the surface. Nevertheless, geomorphological features related to recent fluvial accumulations, such as natural levees, river terraces, alluvial fans, flood plains... etc. are very common.

Many earlier workers have considered the present day Mesopotamian Flood Plain, as the entire Mesopotamia Basin, whereas others believe that the basin has much more areal extension. Accordingly, the tectonic and the structural characteristics of this region remained problematic and subject to many uncertainties and controversial ideas. The aim of this work is to help in resolving these uncertainties by using the modern tectonic concepts in redefining the present day Mesopotamia Foredeep and its structural boundaries, and to shed light on its evolution within the tectonic framework of Iraq.

STRATIGRAPHY

The Mesopotamia Foredeep contains a thick sedimentary pile that thickens northeastwards. On the surface, it is covered mainly by different types of Quaternary deposits that thicken southeastwards.

Magnetic and gravity data are the only source of information about the basement. According to the CGG (1974), the basement is 8 Km deep in the western part of the foredeep, and sloping eastwards to 14 Km deep, near the Iraqi – Iranian borders.

The full thickness of the Paleozoic sequence is not penetrated in any borehole in Iraq. Only few deep exploration wells in central and southern Iraq reached the uppermost part of the Paleozoic sequence. Nevertheless, at the northwestern part of the foredeep, the deep Khleissia-1 exploration well penetrated 2098 m of the Paleozoic sequence. The penetrated sequence is assigned to the Ordovician Khabour, Pirispiki, Carboniferous Ora and Harur formations. The Paleozoic sequence, as it is the case in most Arabia, is dominated by siliciclastic sediments deposited in a shallow epicontinental sea (Beydoun, 1991; Alsharhan and Nairn, 1997 and Sharland *et al.*, 2001). The sediments reflect a considerable uniformity around the Paleo-Tethys passive margin.

The Mesozoic sequence within the foredeep consists of an almost complete sedimentary succession without significant breaks. The thickness of the sequence progressively increases from the west to the east to be around 5 Km. The sequence often begins with Triassic evaporites, shales and carbonates of neretic to lagoonal nature, passes upwards into an open and shallow marine carbonates with subordinate evaporites of Jurassic age, then to an alternation of carbonates and sandstones, followed by an open marine carbonates of Cretaceous age. The Mesozoic sediments are the main source rock and reservoir forming sequence in central and south Iraq.

The Cenozoic succession usually consists of Paleogene open marine carbonates that grades up into a Neogene lagoonal and restricted marine evaporitic facies, followed by molasse type deltaic and continental clastics.

The Quaternary deposits exhibit an exceptional development within the foredeep, in comparison to that in other places in the Iraqi territory. These deposits, which cover three quarters of the basin, progressively thicken from northwest to southeast. The maximum recorded thickness is about 300 m near Basra city. Depending on their location, Quaternary deposits show variable stratigraphic relationship to the underlying pre-Quaternary sediments, ranging from conformable gradational, unconformable erosional, and unconformable angular.

GEOLOGICAL SETTING

The Iraqi territory is the northeastern extension of the Arabian Platform that surrounds the Arabian Shield. Early workers have subdivided the Arabian Platform within the Iraqi territory into two major parts: a stable part to the southwest and an unstable part to the northeast (Henson, 1951; Dunnington, 1958). These broad lines of definition were adapted latter by many workers, either under the same names or others, then further subdivided it into smaller and smaller zones and subzones to describe the structural framework of Iraq (e.g. Ditmar, 1971; Buday, 1980; Iraq – Soviet Team, 1979... etc).

Perhaps the first comprehensive tectonic division of Iraq was introduced by Buday (1980), then by Buday and Jassim (1987). In their work, the Iraqi territory was divided into a Stable Shelf (to the southwest) and Unstable Shelf (to the northeast). Then, further subdivided the Unstable Shelf into Mesopotamian, Foothill, High Folded and Geosynclinal Zones. According to this division, the Mesopotamian Zone as a part of the Unstable Shelf, is bordered from the northeast by "the first superficially and morphologically prominent anticlines starting with Makhul, continuing southeastward with Himreen, Badra and Buzurgan". The southwestern boundary of the zone coincides with the Euphrates Fault, extending in a NW direction to Al-Ramadi, then swings sharply in a NS direction to follow the Tharthar valley, and then terminates against Makhul Range near Al-Hatra (Fig.1). Furthermore, they have subdivided the Mesopotamian Zone into a minor eastern (Tigris), western (Euphrates), and southern (Zubair) Subzones. The same major divisions were adapted by Al-Kadhimi *et al.* (1996), but with minor modifications. Jassim and Goff (2006) made a crucial modification to the tectonic divisions by considering the Mesopotamian Zone as a part of the Stable Shelf. Moreover, they significantly changed the boundaries between the subzones that constitute the major zone.

It is critically important to mention that almost all of the mentioned tectonic divisions of Iraq, have had considered the present day "Mesopotamian Flood 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 Basin is much larger and areally extensive, than that of the Mesopotamian Zone (or Flood Plain), which consists only a part of it. The present day Mesopotamia Basin extends from northeast Syria to the Straits of Hormuz. It consists of two domains, the first is a terrestrial one that covers parts of northeast Syria, Iraq, and parts of Kuwait and the coastal plains of Iran, and the second is a marine, represented by the Arabian Gulf Basin (Berberian, 1995; Alshrhan and Nairn, 1997; Brew, 2001; Sharland *et al.*, 2001; Alavi, 2004 and Fouad and Nasir, 2009).

In the present work, however, the term "Mesopotamia Foredeep" will be used instead of the Mesopotamia Zone, because of its comprehensive dynamic and tectonic implications. Moreover, the Mesopotamia Foredeep will be redefined as well as its geological setting and boundaries, to fit the modern tectonic and structural concepts.

STRUCTURES OF THE MESOPOTAMIA FOREDEEP

The Mesopotamia Foredeep within the Iraqi territory consists of two distinct physiographic provinces; Al-Jazira Area in the northwest and the Mesopotamian Flood Plain in the center and southeast (Fig.2). The structural evolution of Al-Jazira Area has been discussed earlier in details by Fouad (2007) and Fouad and Nasir (2009), and will be briefly reviewed here, whereas the central and the southeastern parts of the basin are the prime concern of this article.

The Mesopotamia Foredeep is a flat terrain in general. Significant surface structures of tectonic origin are rare. Nevertheless, the foredeep contains several structures including faults, folds, and diapiric structures that are almost entirely concealed beneath the Quaternary deposits (Fig.2).

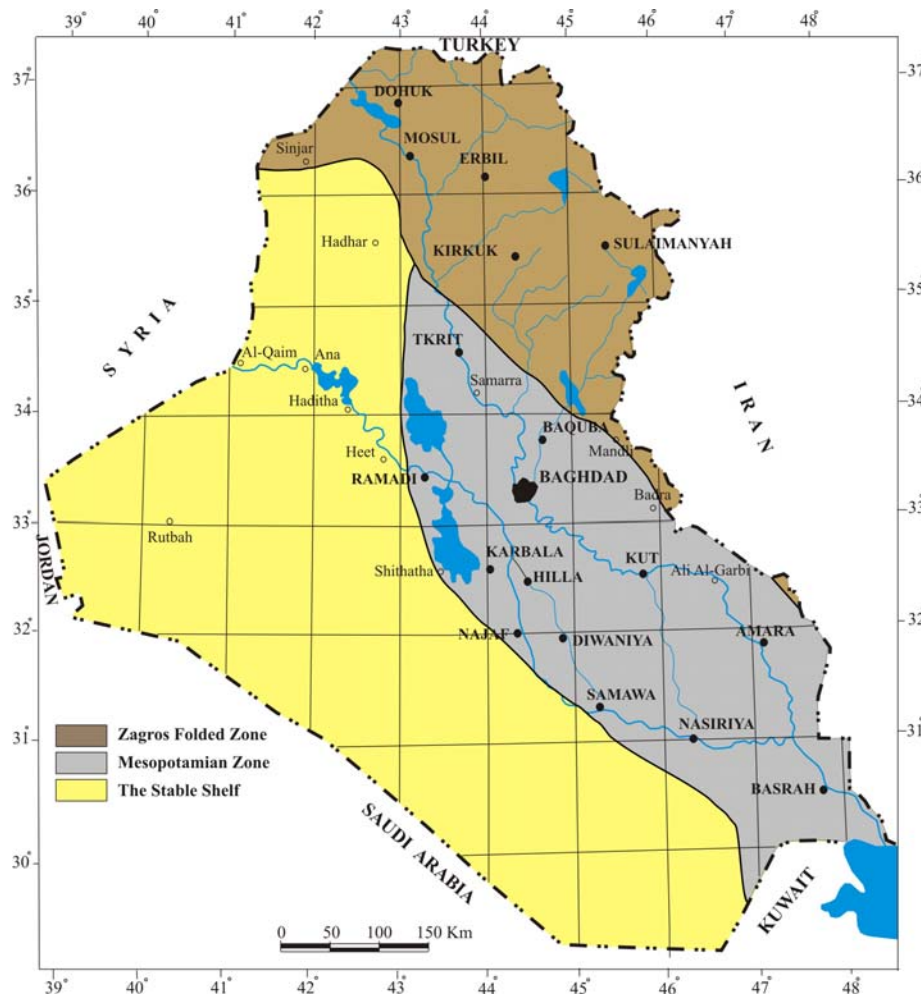


Fig.1: Mesopotamian Zone of Iraq, after Buday and Jassim (1984 and 1987); Al-Kadhimi *et al.*, (1996), and Jassim and Goff (2006)

■ Faults

A network of subsurface faults is present in the Mesopotamia Foredeep. These faults are basically of the normal type, consisting two main systems trending NW – SE and ENE – WSW (Fig.2).

— The ENE – WSW fault system dominates the northwestern part of the foredeep and forming series of troughs as grabens and half grabens including Anah, Tayarat, Khlesia and Tel Hajar. Some of these structural basins were partially inverted, forming fault-propagation folds above them (Fouad, 1997; Nasir, 2001). Other structural basins such as Tayarat North, Tayarat South escaped the inversion and remained stable tectonically (Fouad, 1997 and 1998), whereas Khlesia exhibits recent active subsidence after a considerable period of quiescence (Fouad and Nasir, 2009).

— The second fault system consists of NW – SE trending normal faults, forming a complex network of grabens, half grabens and solitary faults. The system extends between south Mosul and south Baghdad. Some of the grabens of this system such as Tikrit and Samarra were partially inverted, forming anticlinal folds above them, whereas others have not. Stratigraphic correlation, boreholes and seismic data indicate that the extensional fault systems of the Mesopotamia Foredeep are Late Cretaceous structures (Fouad, 1998 and 2007; and Fouad and Nasir, 2009).

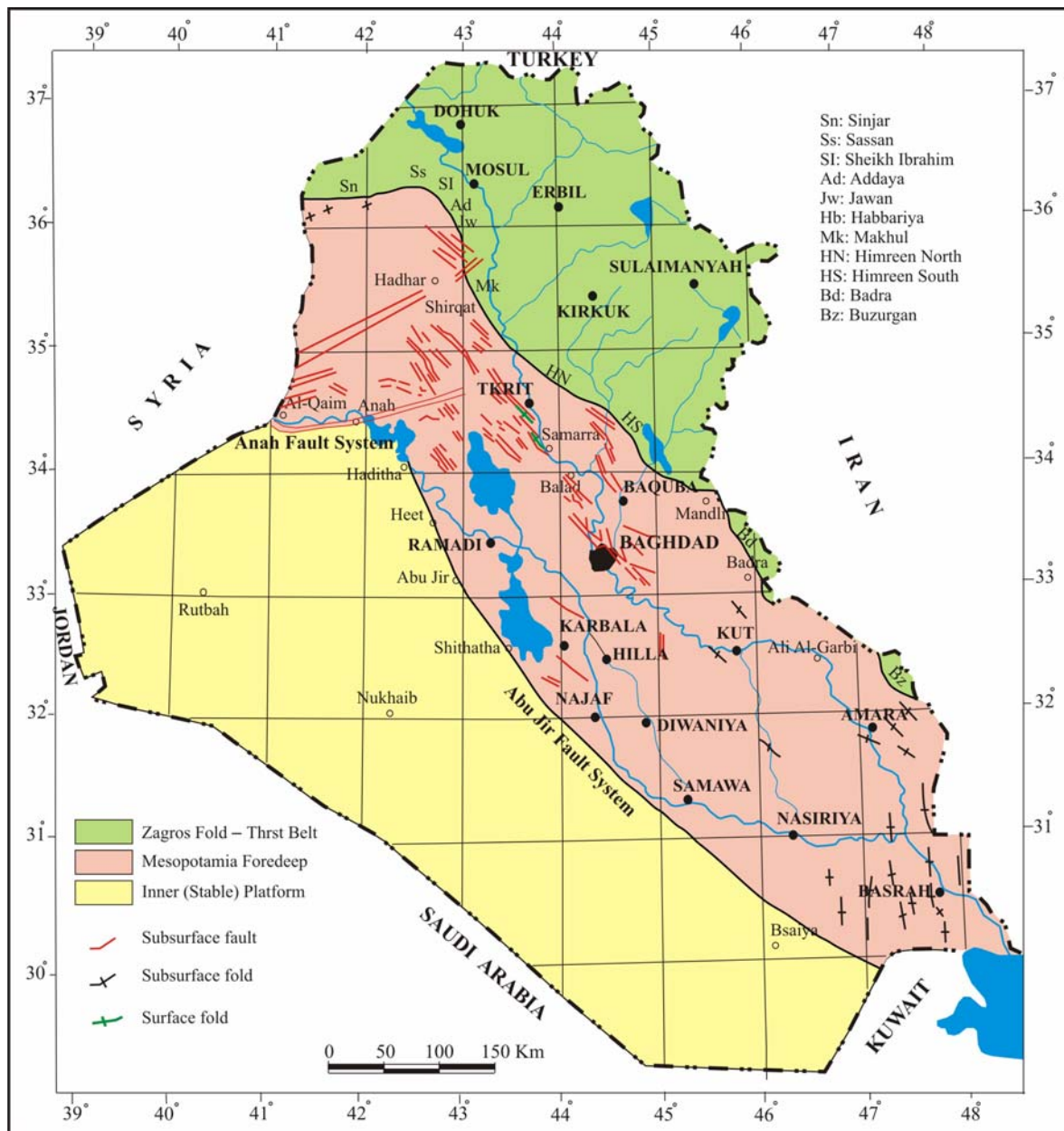


Fig.2: Structural map of the Mesopotamia Foredeep
(The present study)

■ Folds

As already mentioned, folds visible at the surface are almost absent in the Mesopotamia Foredeep. Anah, Tikrit and Samarra anticlines are the only exception. In contrast to the persistent Anah, Tikrit and Samarra anticlines are hardly expressed on the surface because of the Quaternary cover. Nevertheless, because of their continuous growth, Quaternary deposits are uplifted along these structures with about (10 – 15) m relief, with respect to the surrounding, forming local drainage divide lines coincide with the crests of these structures.

On the contrary, to the surface folds, subsurface folds are rather common structures within the Mesopotamia Foredeep. These folds are usually hidden beneath Quaternary cover. The folds are roughly E – W trending in the northwestern part of the foredeep and NW – SE in the central and eastern parts, following the general trend of the surface folds of the Zagros Fold – Thrust Belt, but deviated largely in the extreme southern part, where the folds are N – S trending (Fig.2).

Genetically, folds of the Mesopotamia Foredeep are of three types: The first is the compressional fold propagation folds. They usually have developed above an initial fault bounded structural basins (grabens or half grabens) as a result of structural inversion phenomenon. The trend and geometry of such folds reflect and match the trend and geometry of the underlying initial structural basin. Tikrit and Samarra folds are examples of this category. The second type is the simple buckle folds, which formed as a result of the regional compression exerted by Arabian – Eurasian Plates collision. Such folds usually follow the trend of the Zagros Fold – Thrust Belt. The third type is the least common and limited to the extreme southern part of Iraq. These folds do not follow the common Zagros fold trend, but they follow the old inherited N – S Arabian trend, which is best developed in the north Gulf region. These folds are related to the movement of the salt substratum, therefore can be described as bending folds (i.e. folds generated as a result of forces acting at high angle to the initial bedding). However, this type of folds is usually long, broad and with low amplitudes such as Zubair and Rumaila structures. It is believed that the presence of the Late Precambrian – Early Cambrian Hormuz Salt (Colman-Saad, 1978; Alavi, 2004) in this particular part of the Mesopotamia Foredeep and its subsequent active halokinesis movement is the reason behind the development of these folds. The diapiric structures beneath the folds have pierced the overlying sedimentary sequence to different stratigraphic levels, but have had reached the surface at only one locality known as Jabel Sanam. Dolerite rock blocks and fragments of Precambrian (?) age are exposed in the core of the domal structure and thought to be stripped off the basement and brought to the surface by the upward movement of the buoyant salt. The surrounding sedimentary rocks, which are of Miocene – Pliocene age, exhibit radial dip toward the peripheries, forming a circular dome of about 4 Km diameter and more than 100 m of relief (Fig.3).

The Mesopotamia Foredeep is an extremely mobile zone, and contains many active structures. Evidences, such as tilted Pleistocene – Holocene river terraces, deviated stream channels, recent subsidences and uplift movements add another indication to the Neotectonic activity of the foredeep structures. This will be discussed in details in a following article.

BIRTH OF THE ZAGROS FORELAND BASIN

Late Cretaceous emplacement of ophiolite – radiolaritic thrust sheets over the Arabian passive margin was the sign of the continental convergence between the Arabian and the Eurasian (Iranian) Plates. The ophiolite obduction on the Mesozoic Arabian Plate margin resulted in the distraction of the margin and the formation of an epicontinental basin on the destroyed passive margin ahead of the thrust ophiolite sheets. This epicontinental basin known as the Zagros Foreland Basin (Kazmin *et al.*, 1987; Daly, 1990; Peel and Wright, 1990;

Alsharhan and Nairn, 1997; Alavi, 2004; Bahroudi and Koyi, 2004, and Leturmy and Robin, 2010). Foreland basins are formed primarily as a result of the down flexing of the continental lithosphere in response to the excess load imposed by the adjacent growing fault – fold belt (Dickinson, 1974; Alan and Alan, 1990; Macqueen and Leckie, 1992; DeCells and Giles, 1996; Chahil, 2006; Egan and William, 2006).

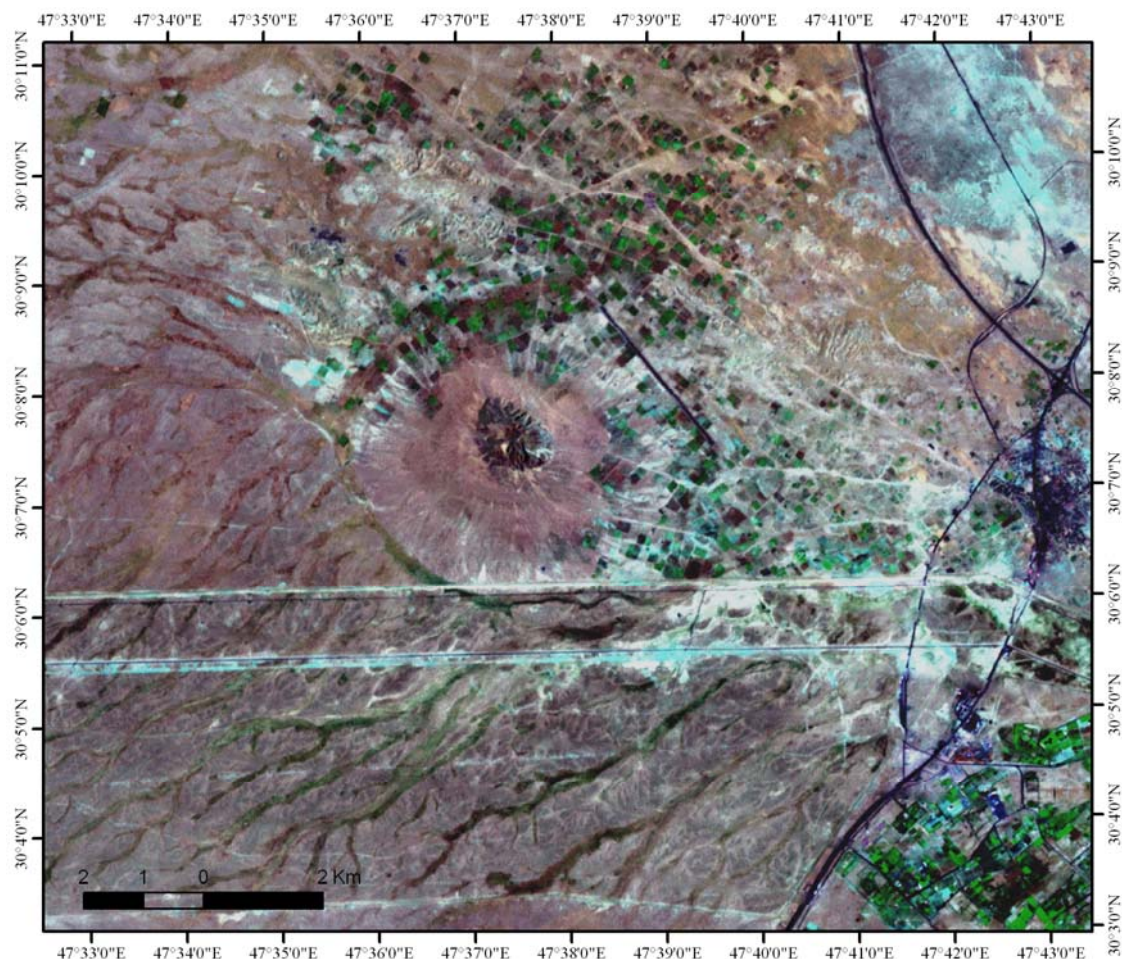


Fig.3: Sanam salt diapiric structure

By the end of the Cretaceous, the following three tectonic element can be distinguished along the Arabian Plate margin (Fig.4):

- 1) An elevated zone corresponding to the obducted ophiolites and the associated radiolaritic mélange that was periodically emerging, and submerging.
- 2) An asymmetric foreland basin with deep part adjacent to the mountain front, swallowing towards the undformed continental interior; and
- 3) A shallow Arabian Shelf that terminates against the exposed Nubia – Arabian Shield (Fig.4).

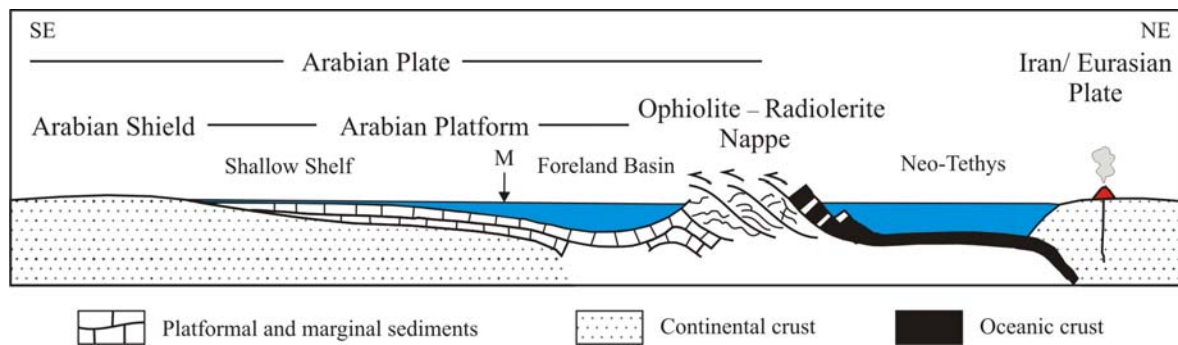


Fig.4: Geological scheme of Arabia by the end of the Cretaceous Period.
(M) approximate position of Mesopotamia (Based on Kazmin *et al.*, 1986)

The foreland basin, which was potential region of sediment accommodation, was sharply asymmetrical with steep and deep proximal part adjacent to the mountain front and a gentler craton-wards shallowing distal part. In the proximal part of the basin, detritus were derived mainly from the orogenic belt. The accumulated deposits reach their maximum thickness at the vicinity of the mountain front and progressively thin away from it, giving the basin its characteristic wedge-shaped profile. At that time however, the Mesopotamia was an integral portion of the distal part of the foreland basin (Fig.4).

The first influx of northeasterly derived detritus on the Arabian Plate margin marked two important events: The first, is the formation of a foreland basin in front of a rising orogene, and the second is a reversal in the sediment transport direction from the customary southwest (i.e. from the Nubia – Arabian Craton) to the northeast direction (i.e. the newly evolving mountain front).

As the overthrust wedge continue to advance southwestwards up the continental margin, the foreland basin continue to migrate in that direction too. Consequently, the foreland basin structure and stratigraphy were continually modified (Stockmal *et al.*, 1992; Fermor and Moffat, 1992).

While the Arabian – Eurasian (Iranian) Plates collision continued from the Late Cretaceous and on, the Zagros Fold – Thrust Belt (ZFTB) propagated southwestwards, forcing the Zagros Foreland Basin to propagate ahead of it further and further onto the Arabian (foreland) Plate. Eventually, the proximal or earlier deposited foreland basin sediments as well as the pre-foreland basin platformal and marginal rock units are progressively incorporated into the deformed orogene as a new uplifted fold and fault structures. This intern forced the depoaxis of the foreland basin to a continual migration southwest towards its distal part and the stable continental interior.

THE MESOPOTAMIA FOREDEEP (MF)

The ZFTB 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). The Mesopotamia Foredeep, which is an integral part of the ZFTB, is an elongated (≈ 900 Km long and 200 Km wide) terrestrial sedimentary basin, running parallel to the ZFTB. It lies between the Zagros deformational mountain front and the stable interior of the Arabian Platform. The sedimentary pile across the basin thickens northeastwards toward the Zagros Orogenic Zone, and thins southwest towards the platform interior, reflecting the characteristic wedge-shaped profile of foreland basins (Fig.5).

The Phanerozoic sedimentary sequences of the MF can be broadly categorized into three major tectono-stratigraphic assemblages: A Cambrian – Early Permian Gondwana intraplate assemblage dominated by siliciclastic deposits, Late Permian – Cretaceous Neo-Tethys passive margin assemblage dominated by carbonates, and Late Cretaceous – Present foreland basin assemblage dominated by marine grading upwards into continental deposits. Moreover, the foreland basin assemblage can be further subdivided into two secondary sedimentary packages: **1)** An early Late Cretaceous – Middle Miocene package denoting the under filled stage of the basin, where deposition occurred in marine conditions and **2)** A late Upper Miocene – Recent package denoting the overfilled stage of the basin in which deposition occurred in terrestrial conditions.

It should be pointed out however, that present day NW – SE tectonic strike parallel regional profile along the basin exhibit sediment progradation from the terrestrial overfilled part to the marine (Arabian Gulf) under filled part, with large delta occupying the transition zone.

When the modern concepts and characteristics of the foreland basins are considered (e.g. Dickinson, 1974; Macqueen and Leckie, 1992; De Cells and Giles, 1996; Chahil, 2006), the structural boundaries of the Mesopotamia Basin as delineated by earlier workers (e.g. Budy and Jassim, 1987; Al-Khadhimi *et al.*, 1996; Jassim and Goff, 2006) should be modified and changed to fit the new concepts. In this study, the present day Mesopotamia Foredeep structural boundaries as proposed by Fouad (1997 and 2007), and Fouad and Nasir (2009) were adapted. In their work, they have extended the northern structural boundary of the basin further northwest, and significantly changed the western one.

It is proposed here that the northeastern structural boundary of the MF with the Low Folded Zone of the ZFTB coincides with the first topographic mountain front of the Zagros Orogeny made by Buzurgan, Badra, Himreen South, Himreen North and Makhul Mountain chains, and continues northwest to follow Habbariya, Jawan, Ad'daya, and Sheikh Ibrahim, then swings westwards following Sasan and Sinjar Mountain front (Fig.2).

On the other side, the MF southwestern boundary forms the tectonic boundary between the Stable (the Inner) and the Unstable (the Outer) Shelves of the Arabian Platform. The boundary coincides with Abu Jir Fault System from Al-Batin lineament, southwest of Basrah, extending more than 600 Km northwestwards along the Euphrates River valley, through Samawa, Shithatha, Abu Jir, Awasil, Heet, Al-Baghdadi, and Haditha, then swings westwards for about 100 Km following Anah Fault System to Al-Qaim near the Iraqi Syrian borders, where it meets the NW – SE trending Euphrates Fault System of eastern Syria (Fig.2).

These new proposed boundaries imply the following significant geological aspects that were long being subject to confusion and uncertainties:

- The Mesopotamian Plain consists only the central and southern parts of the major Mesopotamia Foredeep, and not the entire basin as confused by many (e.g. Budy and Jassim, 1987, Al-Kadhimi *et al.*, 1996; Jassim and Goff, 2006).
- Al-Jazira Area, which is located between the Zagros Orogenic Zone and the stable interior of the Arabian Platform, eventually represents the northwestern extension of the Mesopotamia Foredeep. Its Cenozoic tectonic and stratigraphic history strongly supports this consideration (Fouad, 2007; Fouad and Nasir, 2009).
- The new boundaries of the Mesopotamia Foredeep are in accordance with the tectonic zonation of both Iran and the Arabian Gulf region to the southeast (Berberian, 1995), and that of Syria to the west and northwest (Brew, 2001), and eventually with the Arabian Plate tectonic framework.

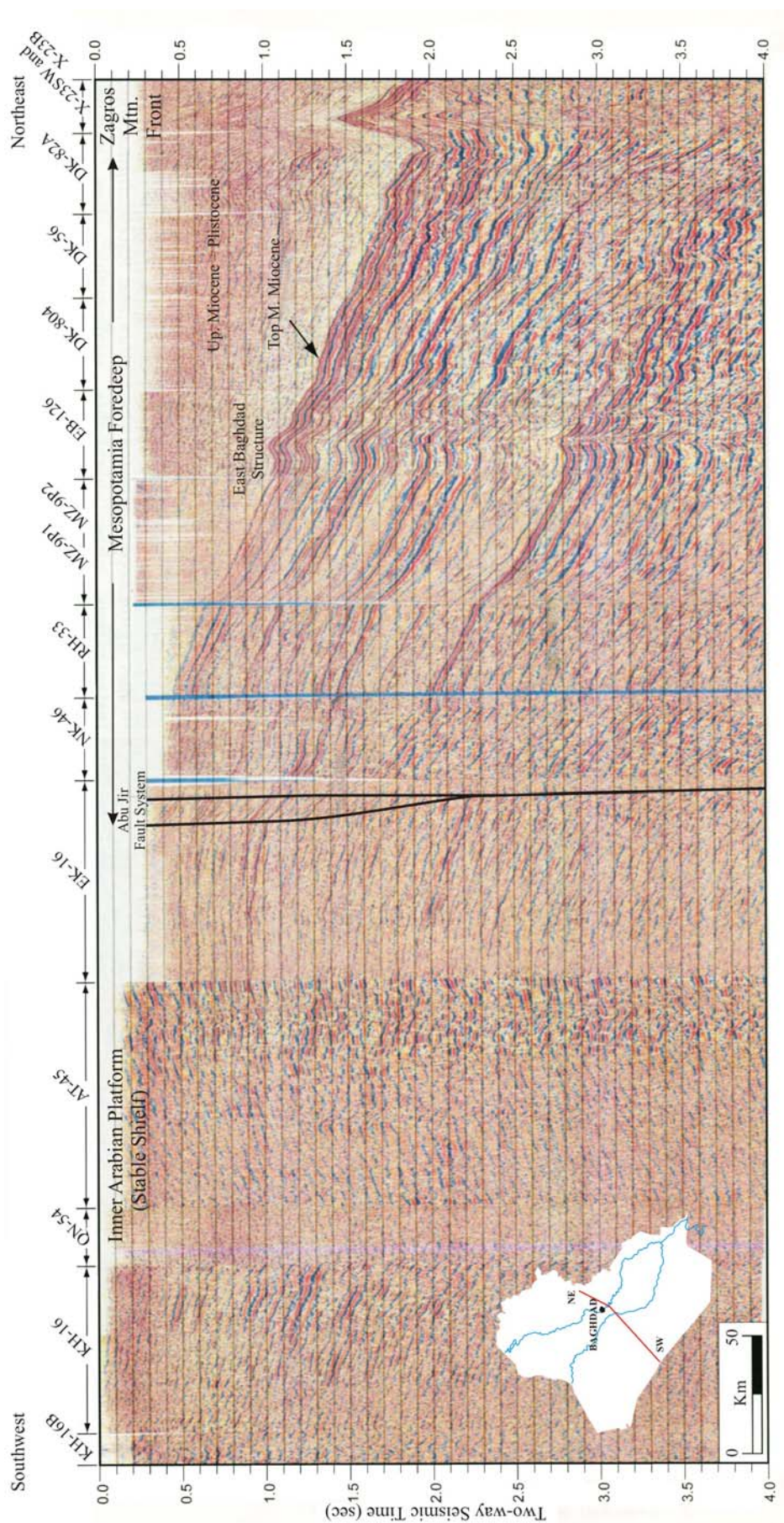


Fig.5: Megaseismic Line 7, showing the Inner (Stable) Arabian Platform, Mesopotamia Foredeep and Zagros Mountain Front.
Note the wedge-shaped profile and the growing structures of the Mesopotamia Foredeep.

(Megaseismic Line is taken from Mohammed., 2006)

CONCLUSIONS

The following could be concluded from this study.

- The Mesopotamia Foredeep is an integral part of the Zagros Fold – Thrust Belt. It is the present day expression of the continental part of the major Zagros Foreland Basin, whereas the Arabian Gulf Basin represents its marine counterpart.
- Based on the modern tectonic concepts of foreland basins, new structural boundaries to the foredeep are introduced. The boundaries are in accordance with the regional tectonic zonation of the Arabian Plate.
- The Mesopotamia Foredeep is an elongated basin lies between the first topographic and physiographic 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 foredeep is an asymmetric basin with a wedge-shaped profile. Maximum sediment thicknesses within the basin occur adjacent to the orogenic front and gradually decrease southwest towards the un-deformed continental interior.
- The Mesopotamia Foredeep is an epicontinental basin that has formed above an earlier platformal and marginal sedimentary basin. Eventually, the Phanerozoic sedimentary sequence of the basin could be broadly divided into three major tectono – stratigraphic complexes: Cambrian – Early Permian Gondwana intraplate assemblage; Late Permian-Mid Cretaceous Neo-Tethys opening and passive margin assemblage; and Late Cretaceous – Present foreland basin assemblage. Moreover, the foreland basin assemblage can be further subdivided into two sedimentary groups denoting an early under filled and late overfilled stages of the basin.
- The Mesopotamia Foredeep is an extremely mobile zone, and contains a number of buried tectonic structures including folds, faults and diapiric structures. Many of the buried structures are neotectonically active. Their recent activity can be observed through their effects on the Pleistocene – Holocene stratigraphy and the present geomorphological landforms.

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