TECTONIC AND STRUCTURAL EVOLUTION OF AL-JAZIRA AREA

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ABSTRACT

A comprehensive tectonic and structural analysis of Al-Jazira Area (including Khleissia Heigh) using seismic, drill-hole and surface geological data is carried out, and some new obtained information is introduced. Though it lacks significant surface structures, Al-Jazira Area is dominated by a network of subsurface intracontinental ENE – WSW and NW – SE trending Late Cretaceous rift basins with Campanian – Maastrichtian synrift sediments. Several geological evidences point out to the recent activity of Khleissia Graben after a considerable period of quiescence.

The nature of the stratigraphic sequence and the associated truncations reflect that the area was a subject to a repeated geological activity during the Mesozoic Era, but became almost stable during most of the Paleogene – Neogene Period. However, by considering its Late Mesozoic – Cenozoic stratigraphic and structural evolution, and its relation to the main tectonic zones of the Iraqi territory, Al-Jazira Area has been regarded as the northwestern extension of the Mesopotamia Foredeep of the Unstable Shelf of the Arabian Platform rather than a part of the Stable Shelf as proposed earlier.

النشأة البنيوية والتركيبيـــة لمنطقة الجزيرة

صفاء الدين فخري فؤاد و وفاء عبد الأمير ناصر

المستخلص

أجري تحليل بنيوي وتركيبي شامل لمنطقة الجزيرة (يتضمن مرتفع الخليصية) باستخدام المعطيات الزلزالية والآبار الاستكشافية والجيولوجيا السطحية وتم عرض بعض المعلومات المستنتجة الجديدة. على الرغم من افتقار منطقة الجزيرة الى الظواهر التركيبية السطحية المهمة، إلا أنها تعج بشبكة تحت سطحية من الانهدامات داخل القارية باتجاهات شرق شمال شرق – غرب جنوب غرب وشمال غرب - جنوب شرق وتشغلها رسوبيات مصاحبة للانهدام من عمر الكمباني – الماسترختي.

ان طبيعة التتابعات الطبقية والإنقطاعات المرافقة لها تدل على ان المنطقة كانت تحت تأثير نشاط جيولوجي متكرر خلال فترة الدهر الميسوزوي، ولكنها أصبحت شبه مستقرة خلال معظم فترة عصر الباليوجين - النيوجين. من جهة أخرى، هناك العديد من الدلائل الجيولوجية التي تشير لتجدد النشاط الجيولوجي لمنخسف الخليصية بعد فترة ليست بالقصيرة من توقف نشاطه. عند الأخذ بنظر الاعتبار النشأة الطباقية والتركيبية خلال فترة أواخر الدهر الوسيط (الميسوزوي) والدهر الحديث (السينوزوي)، إضافة الى العلاقة مع الانطقة البنيوية الرئيسية للعراق، فقد تم اعتبار منطقة الجزيرة الامتداد الشمالي الغربي لحوض ما بين النهرين العائد للجزء غير المستقر من المصطبة العربية وليس للجزء المستقر منها، كما كان يعتقد سابقا.

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INTRODUCTION

Al-Jazira Area is a geographic name addressed to the region located in Western Iraq that extends between Sinjar mountain, in the north to the Euphrates River valley in the south, and between Al-Tharthar valley and the Iraqi – Syrian international borders from the east and west, respectively (Fig.1). The Jazira Area is of low relief character, dissected by shallow valleys with scattered hills. The extensive evaporate exposures made the area a prone to solution and karstification. Accordingly, numerous numbers of sinkholes with variable dimensions had been developed. Some of them may flood during rainy seasons and eventually may become ephemeral lakes, but dry up later on to become salt pans.

Al-Jazira Area is one of the least studied areas in Iraq .The earliest geological work was related to oil exploration, which led to the drilling of Khleissia -1 oil well at the early fifties of the last century. The first reliable surface geological information was introduced by GEOSURV field geologists (Ibrahim and Sissakian, 1975; Al-Jumaily *et al.*, 1976 and Ma'ala, 1976). Their work has covered different geological aspects including stratigraphy, structure, geomorphology and economic geology. Fouad (1997 and 1998) presented the first tectonic and structural study of parts of Al-Jazira Area by using seismic and well data. His study was extended to cover larger parts of the region as well as parts of eastern Syria covered by Nasir (2001).

The present study aims to represent a comprehensive tectonic, tectonostratigraphic and structural study that may contribute to a better understanding of the region and eventually the tectonic evolution of Iraq.

STRATIGRAPHY

Sediments of Late Oligocene to Late Miocene age are exposed in the Jazira Area. Late Oligocene marine carbonates of Anah Formation are exposed in a very narrow strip along the Euphrates River near Rawa. Early Miocene marine carbonates of the Euphrates Formation are exposed as a narrow strip along the northern bank of the Euphrates River with maximum exposed thickness of about 110 m. Fat'ha Formation represents the Middle Miocene sediments, it consists of cyclic alternations of claystones, carbonates and evaporites. The evaporites dominate the lower part, whereas the claystones dominate the upper part of the formation. The maximum exposed thickness of the formation is about 175 m. The Late Miocene sediments are represented by Injana Formation, which consists of cyclic alternations of sandstones, siltstones and claystones, with a maximum exposed thickness of about 200 m.

Khleissia-1 oil well is the only deep exploration well in Al-Jazira Area. The well is 3791 m deep, penetrating rock units as far as Paleozoic in age. The penetrated 2098 m of the Paleozoic sequence is represented by the Ordovician – Carboniferous Khabour, Pirispiki, Ora and Harur formations. It is dominated by siliciclastic sediments deposited in shallow stable epicontinental sea. A case reflected by almost all of the Paleozoic sediments in northern Arabia (Beydoun, 1991 and Alsharhan and Nairn, 1997). The Mesozoic sequence consists of 747 m thick clastics and carbonates assigned to Triassic Beduh (23 m), Gelikhana (108 m) Kurra Chine (357 m), Early Jurassic Butmah (163 m), and Late Cretaceous Hartha – Shiranish formations (96 m).

The Cenozoic sequence consists of 908 m thick marine carbonates grading upwards into evaporites then to continental clastics. It is represented by Eocene Jaddala (118 m), Oligocene Tarjil (42 m) and Palani (41 m), Early Miocene Euphrates (31 m), Serikagni (43 m) and Middle and Late Miocene Dhiban (64 m) and Jeribe (47 m), and Fat'ha and Injana (522 m) formations.

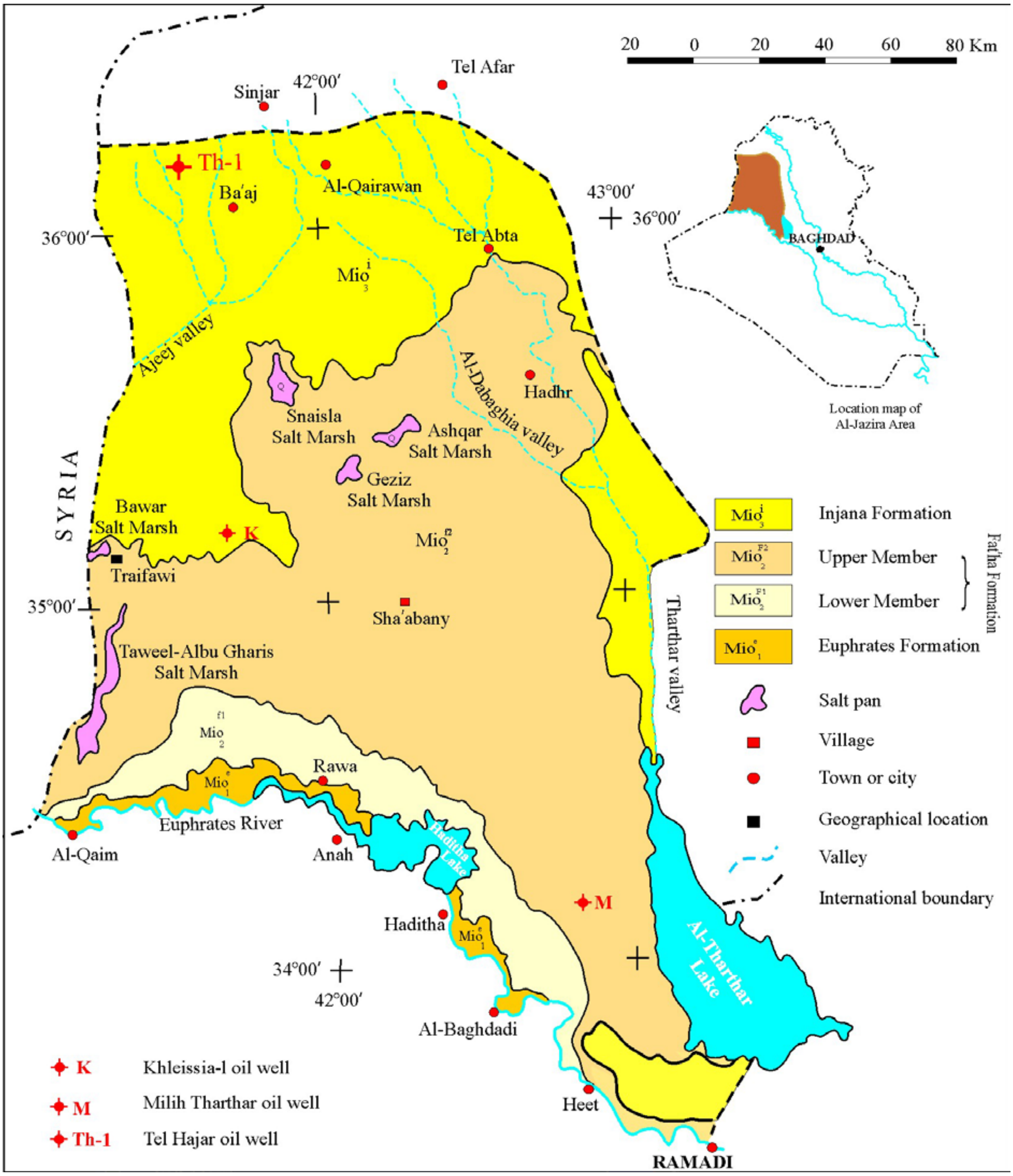


Fig.1: Location and geological map of Al-Jazira Area
(Anah Formation is not represented, due to scale limitation)

By correlation with some nearby exploration wells (Fig.2) such as Tel Hajar-1, Milih Tharthar-1, Anah-2, Key hole-12/ 7, it can be readily noted that Khleissia-1 well displays a remarkably reduced and highly punctuated Mesozoic sequence with total absence of Late Jurassic and Early Cretaceous sediments. This phenomenon is rarely observed elsewhere in Iraq, except along Hail – Rutbah Arch (Fouad, 2007). On the other hand, the Paleogene – Neogene rock units exhibit almost a complete and uninterrupted sequence. It is noteworthy to mention that Khleissia-1 well has been drilled in the northern shoulder of Khleissia Graben (Fig.2).

TECTONOSTRATIGHY OF AL-JAZIRA AREA

Al-Jazira Area is dominated by numerous subsurface extensional structures (Fouad, 1997 and 1998 and Nasir, 2001). When viewed in cross sections, extensional structures, or rift basins, are essentially of three types; **symmetrical grabens,** when the basin is bounded by two major normal fault dipping toward the basin with approximately equal displacement; **asymmetrical grabens**, when one boundary fault has much more displacement than the other; or **half-grabens**, when the basin is bounded by one boundary normal fault on one side and by a continuous sequence of dipping beds on the other relatively downthrown side (Anderson *et al.*, 1983; Ramsay and Huber, 1987 and Groshong, 1989).

It is now became evident that the ideal method in determining the onset and cessation of active subsidence, and the structural control on sedimentation, is by examining the stratigraphy and the stratigraphic architecture of the footwall and hangingwall adjacent to the rift boundary fault (Cartwright, 1989 and 1991 and Cooper *et al.*, 1989). Accordingly, rift basins exhibit three distinct tectonostigraphic sequences: prerift, synrift, and postrift sequences. **Prerift** sequences refer to sediments that have been deposited prior to any extensional fault movement and basin development. Therefore, the thickness of the sequence remains unchanged from footwall to hungingwall across the basin boundary fault. If the sediments continue to deposit during extension and rift formation, then the resulting graben or half – graben is progressively filled with **"synrift"** sediments. Therefore, synrift sequences are typically thicker than their equivalents in the footwall. **Postrift** sequence is addressed to the sediments deposited after the cessation of boundary fault active movement and the termination of basin subsidence, and hence maintain unchanged thickness in passing from footwall to hangingwall across the basin (Williams *et al*., 1989; McClay and Buchanan, 1992 and Withjack *et al*., 2002).

Rift basins may be structurally inverted when subjected to latter compression. Structural inversion refers to an initial structural low that subsequently uplifted to form a structural heigh. It may be achieved by the compressional reactivation of the pre-existing bounding normal fault. This imply that during subsequent compressional period, the earlier basin boundary normal faults are reactivated as reverse faults, leading to a partial or total inversion of the basin and the formation of a compressional structure above the former basin (Harding, 1985; Lowell, 1985; McClay and Buchanan, 1992; Mitra, 1993 and Fouad, 1997).

However, the available geological, seismic and well data on Al-Jazira Area (Fouad, 1997 and 1998 and Nasir, 2001) and on the surrounding regions (Lovelock, 1984; Peel and Wright, 1990; de Ruiter *et al*., 1994; Fouad, 1997; Litak *et al*., 1997 and 1998 and Brew, 2001), point out that the Upper Cretaceous rock units represent the synrft sequence. In Al-Jazira Area, the synrift sequence is assigned to Campanian – Maastrichtian Shiranish, Hartha and Tayarat formations. This sequence is bounded by two regional unconformities. The lower one "rift – onset unconformity" separates the prerift and the synrift sequences, and an upper "postrift unconformity" separates the synrift and the postrift sequences. The prerift sequence is represented by the pre – Late Cretaceous rock units, whilst the postrift sequence is represented by the Paleogene – Neogene rock units.

Based on Fyodorov (1981 and 1982), OEC (1980) and Fouad (1997 and 1998), several seismic markers were identified within the area. In the present study area, however, seismic marker $\mathbf{R_1}$ is a marker within the postrift sequence, $\mathbf{R_2}$ denote the top of the synrift sequence, $\mathbf{R_3}$ denote the top of prerift sequence and $\mathbf{R_4}$ and $\mathbf{R_5}$ are within the prerift sequence.

STRUCTURE OF AL-JAZIRA AREA

Though it lacks significant surface structures, Al-Jazira Area is dominated by a network of subsurface extensional structures. These structures are mainly ENE – WSW and NW – SE trending grabens and normal faults (Fig.2).

▪ The ENE – WSW Fault System

It is the major and well developed fault system with larger extension and displacements. The system dominates the western part of the area (Fig.2) and consists of five major basins. They are (from south to north), the eastern extension of Anah, Tayarat South, Tayarat North, Khleissia and Tel Hajar Structures.

Anah Graben is a 250 Km long and (7 – 15) Km wide subsurface graben that exhibits different structural styles along the strike. However, only 100 Km of its eastern part extends through Al-Jazira area. Near its eastern termination, Anah trough appears as simple symmetrical graben bounded by a pair of high angle normal faults (Fig.3). The maximum structural relief between the centre of the graben and its shoulders measured at the top of the prerift sequence is about (0.2) seconds. The upper part of the prerift sequence doesn’t appear to be displaced by the boundary faults, instead it appears to be draped over the tip of the faults and symmetrically sagged into the basin forming a pair of folds on the shoulders of the graben. Such folds are known as extensional fault-propagation folds (Suppe, 1985; Mitra, 1993: Schlishe, 1995 and Fouad, 1997). The synrift sequence displays clear thickness change, with maximum development at the centre of the graben and symmetrically thins towards the shoulders. The postrift sequence which is seen to pass across the graben horizontally shows parallel reflection signature and uniform thickness indicating a period of quite and uninterrupted deposition across the entire region at the time of their deposition.

It is noteworthy to mention that near the eastern termination of Anah Graben, a small graben branches from the main one (Fig.2). This small graben, which is addressed here as Tayarat East Graben has smaller displacement in comparison with Anah Graben. The displacement decreases gradually northwestwards as it dies out in that direction.

Tayarat South and North Grabens are relatively smaller troughs and are roughly parallel to Anah Graben (Fig.2). Figure (4) is a seismic section passing through Tayarat South Graben, it appears as a simple symmetrical graben bounded by a pair of high angle normal faults with maximum structural relief of about (0.25) seconds, measured at the centre of the graben. The boundary faults do not displace the upper units of the prerift sequence, which appears to be draped over the tip of the boundary faults and symmetrically sagged into the basin, indicating that they underwent an extensional fault-propagation folding.

The synrift sequence shows maximum development at the centre of the graben, and symmetrically thins toward the shoulders with an onlapping stratal pattern. The postrift sequence appears uniform with horizontal unit that maintain their thicknesses across the graben.

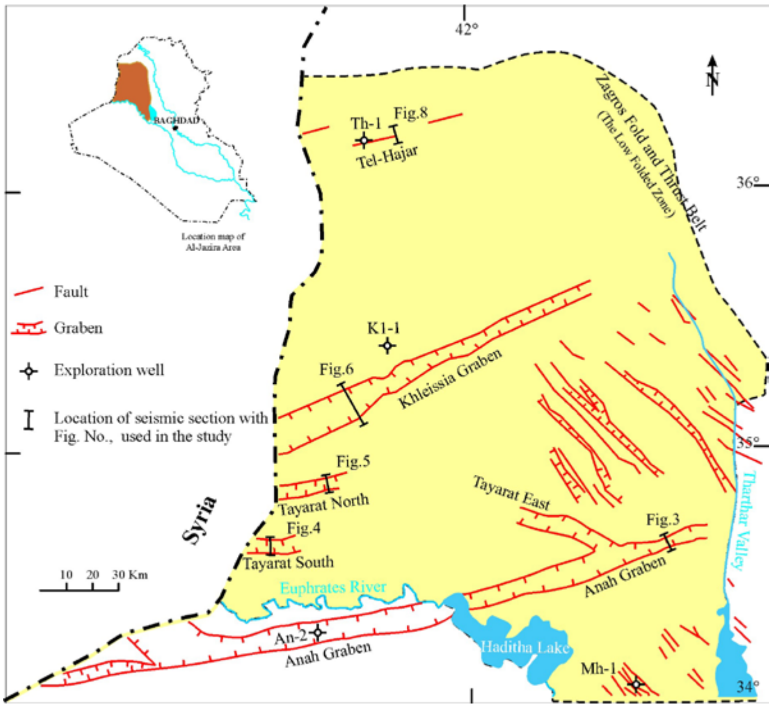


Fig.2: Structural map showing the subsurface extensional structures of Al-Jazira Area

Tayarat North is another ENE – WSW trending trough, which appears as a broad half-graben bounded by one master boundary fault (Fig.5). The prerift sequence in down thrown hanging wall displays gradual inclination towards the basin boundary fault. Also it shows an extensive fault dragging and development of anticlinal fold on the footwall.

The synrift sequence exhibits a huge thickness increase in the immediate vicinity of the boundary fault and decreases gradually away towards the hinged margin. The synrift sequence displays an onlapping pattern on the hinged margin, indicating contemporaneous subsidence and sedimentation. The post rift sequence maintains unchanged thickness from the hangingwall to footwall across the basin.

Khleissia Graben, which is 130 Km long and (5 – 10) Km wide, is the second largest ENE – WSW trending graben in Al-Jazira Area. It is a symmetrical graben, bounded by two major boundary normal faults (Fig.6). The upper part of the prerift sequence is not involved by faulting, but appears to be draped over the tips of the boundary faults to form a pair of extensional fault-propagation folds. The sequence exhibits maximum thickness development in the centre of the graben and decreases towards the shoulders with onlapping stratal pattern. The displacement on the boundary faults decreases as the graben extends eastwards. This is also reflected by the slight thickness increase of the synrift sequence within the graben in that direction.

Of particular interest is that the postrift sequence exhibits sagging within the fault bounded trough without visible thickness change. The subsidence of the postrift sequence, however, seems to be followed by generation of relatively smaller normal faults. The faults dislocate the upper most part of the synrift sequence as well as postrift sequence (Fig.6). Some of these faults have reached the surface; forming two parallel ENE – WSE trending fault scarps (Fig.7). The scarps formed (5 – 12) m height straight escarpments extending for about (100) Km inclosing (5 – 10) Km wide depression in between (Sissakian and Abdul Jabbar, 2009). Extensive karstification took place along the depression, and ultimately many salt pans have developed within the fault bounded depression (Fig.7).

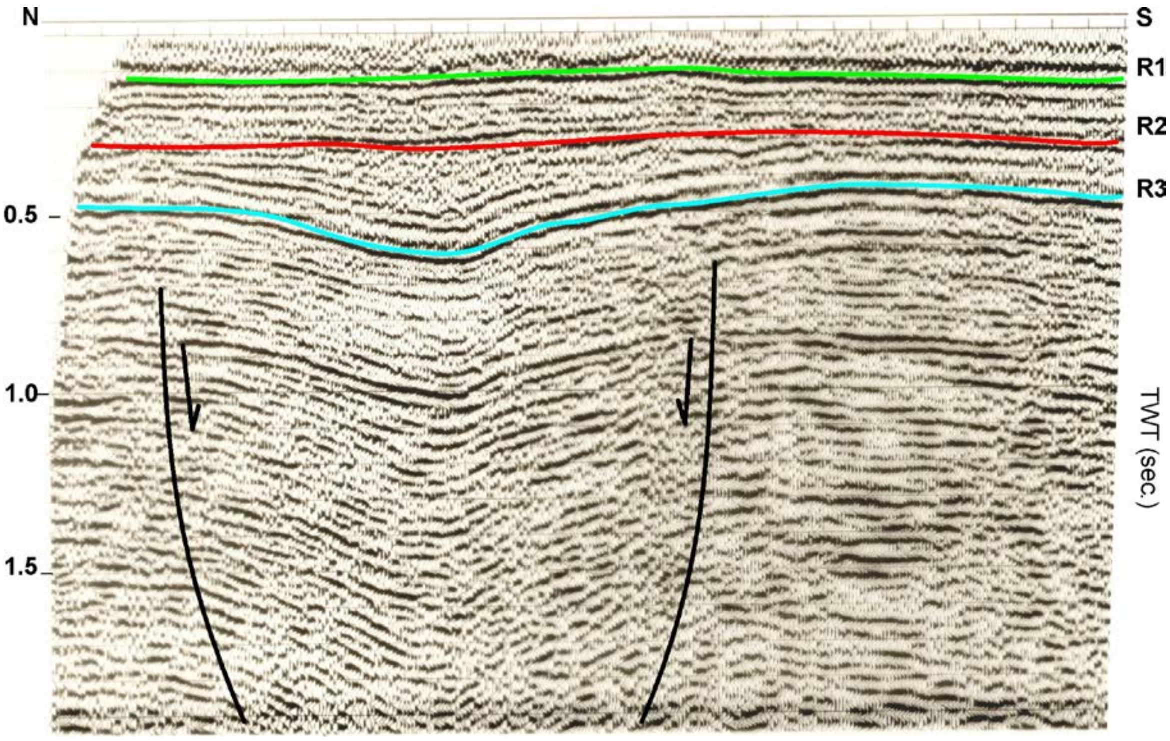


Fig.3: Seismic reflection profile across the eastern part of Anah Graben
(For location, refer to Fig. 2)

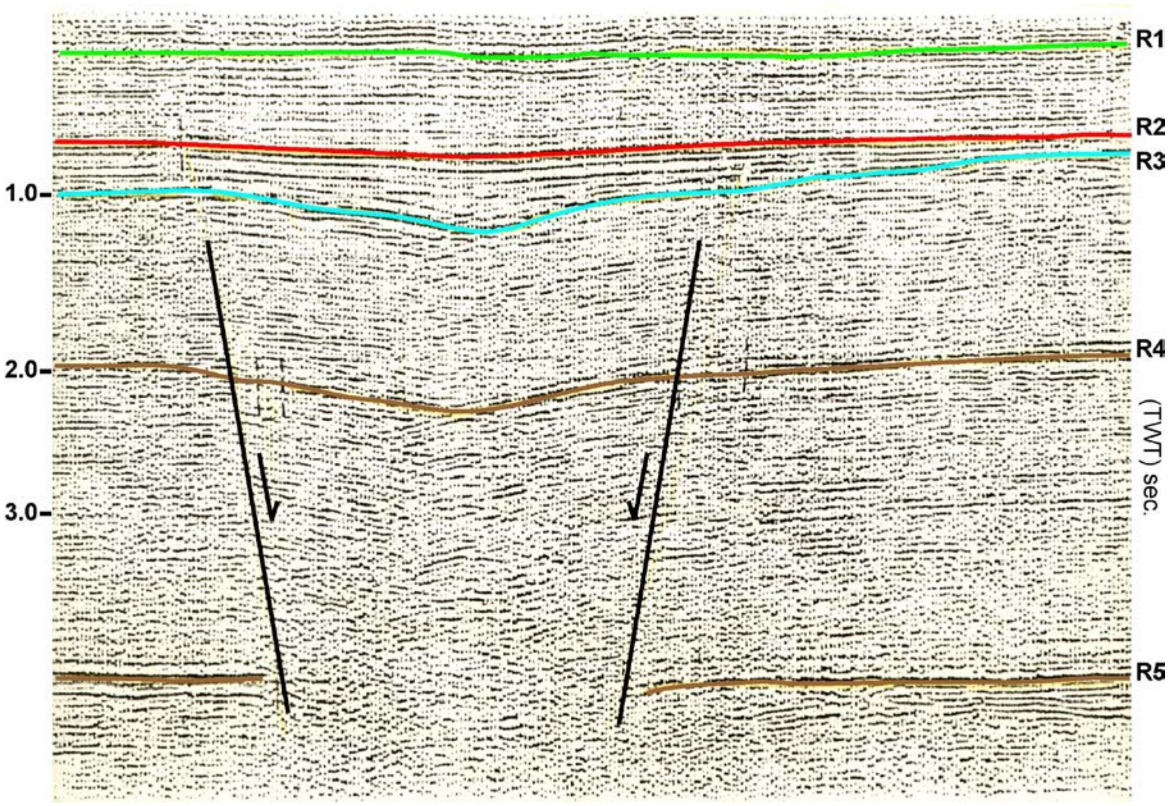


Fig.4: Seismic reflection profile across Tayarat South Graben
(For location, refer to Fig. 2)

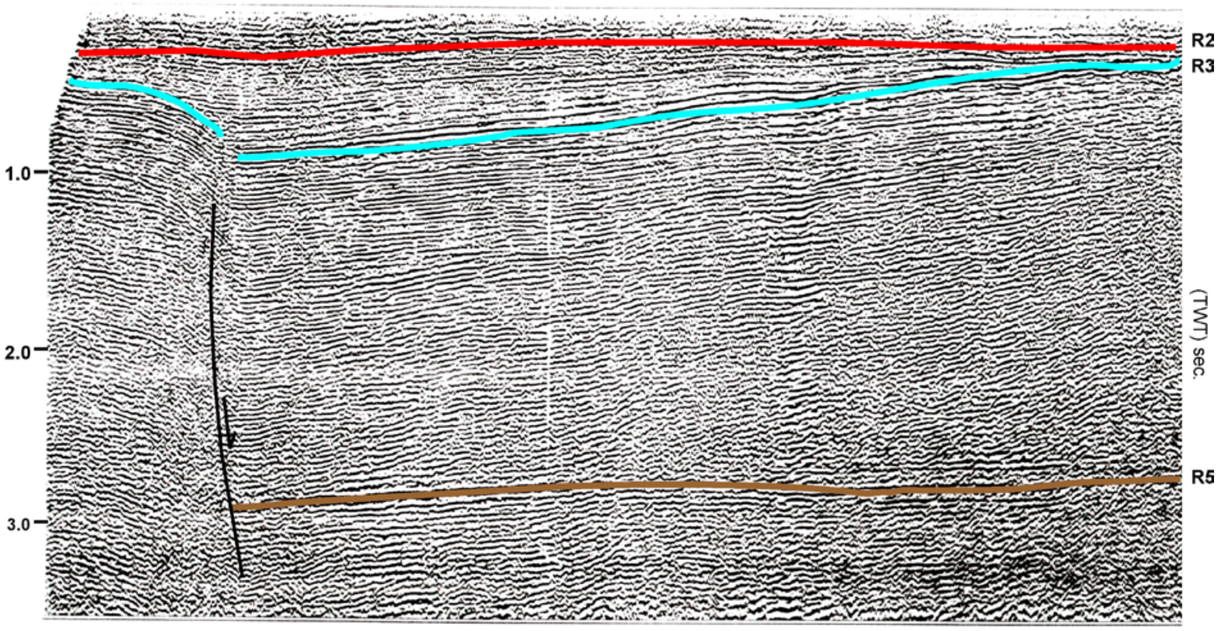


Fig.5: Seismic reflection profile across Tayarat North half-Graben
(For location, refer to Fig. 2)

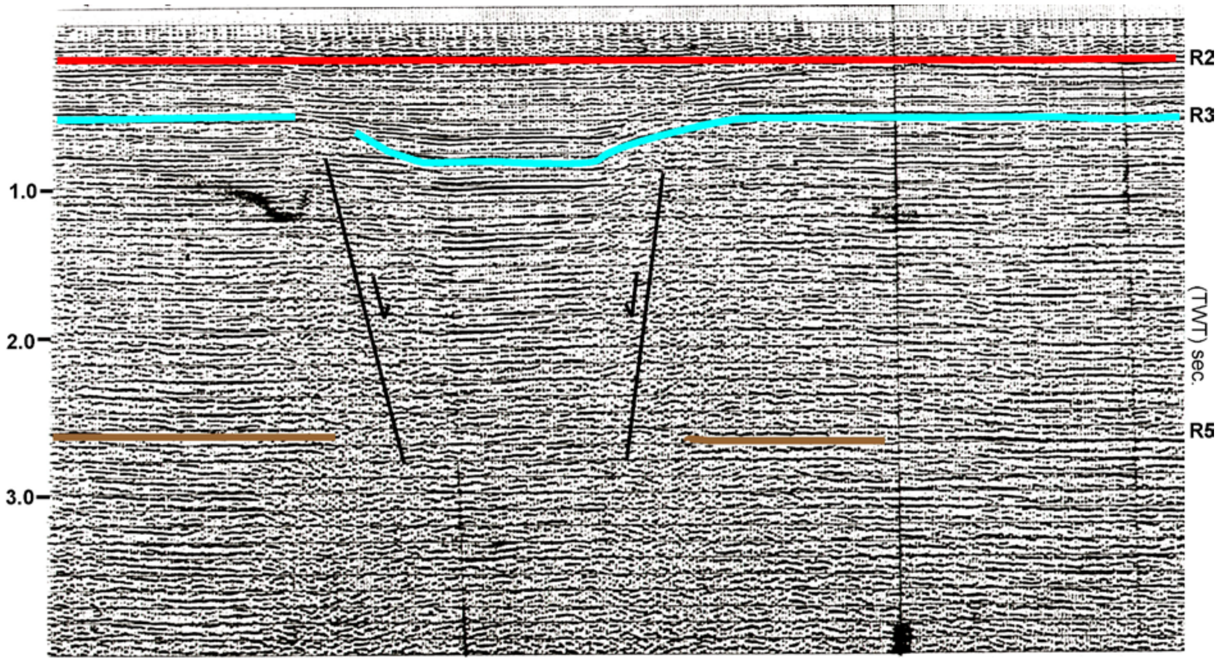


Fig.6: Seismic reflection profile through Khleissia Graben
(For location, refer to Fig. 2)

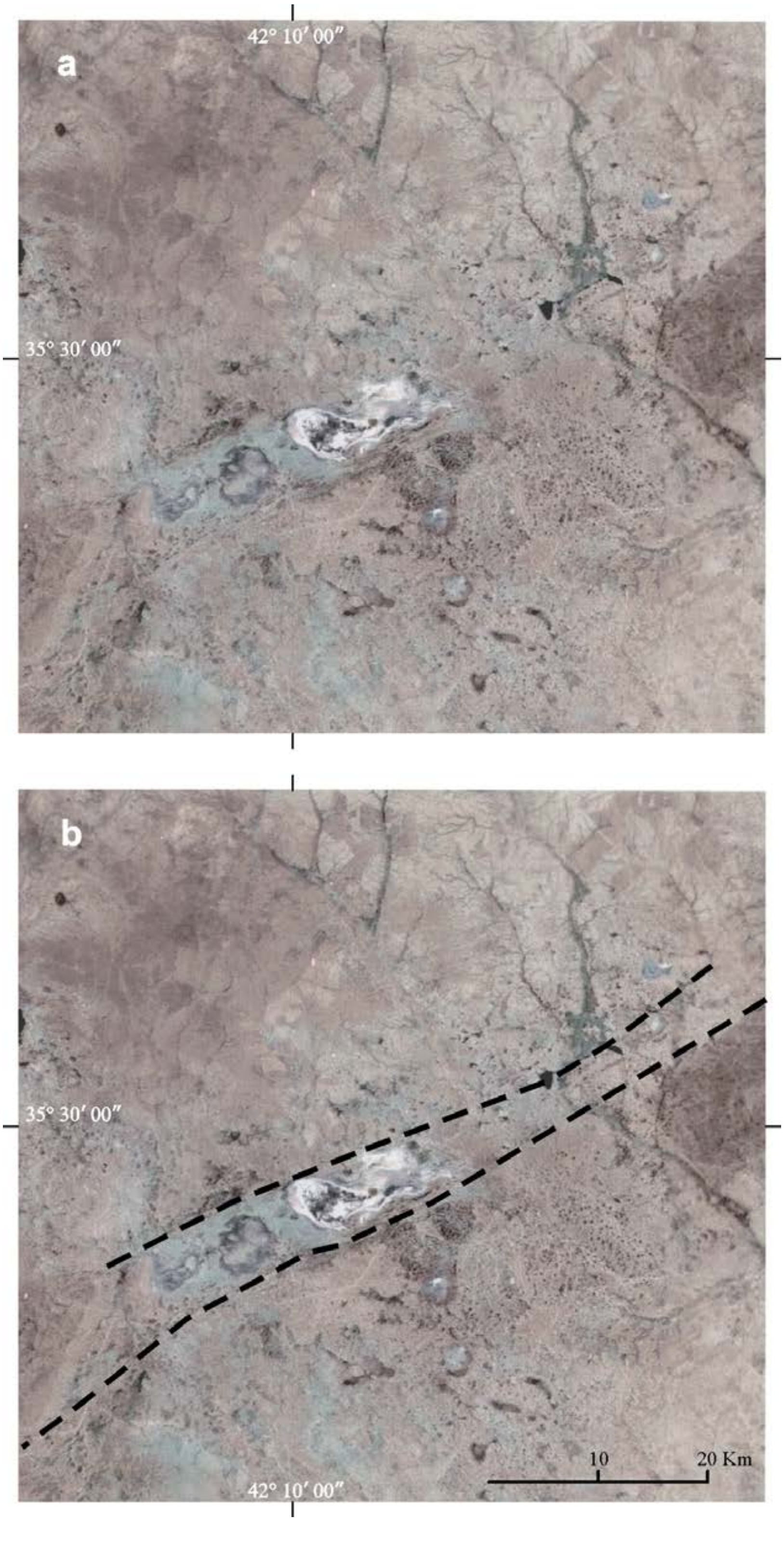


Fig.7: Google earth image showing (**a**) fault traces of Khleissia Graben. Note the salt pans and the evolving karstification along the graben (**b**).

Several geological evidences including recent subsidence, changing drainage patterns, active karstification (Fig.7) indicate that Khleissia Graben has reactivated after its initial formation and still active currently. Further details on this subject will be discussed in a following research.

At the extreme northern part of Al-Jazira Area, Tel-Hajar structure has developed. The available seismic data revealed that it is an inverted half-graben bounded by one major boundary fault (Fig.8). The prerfit sequence appears normally faulted with about (0.5) sec structural relief. The synrift sequence display huge thickness increase on the downthrown side of the boundary fault. The lower part of the sequence seems to be involved by normal faulting, whereas its upper part has been draped over the tip of the fault, forming a pronounced fault-propagation fold without visible faulting. Consequently, the lower part of the sequence exhibits negative structural relief, whilst its upper part displays positive structural relief. The postrift sequence, which passes across the basin without any disturbance, has intensely folded above the tip of the basin boundary fault. The generated compressional fault-propagation fold is sharply asymmetrical with steep southern vergence.

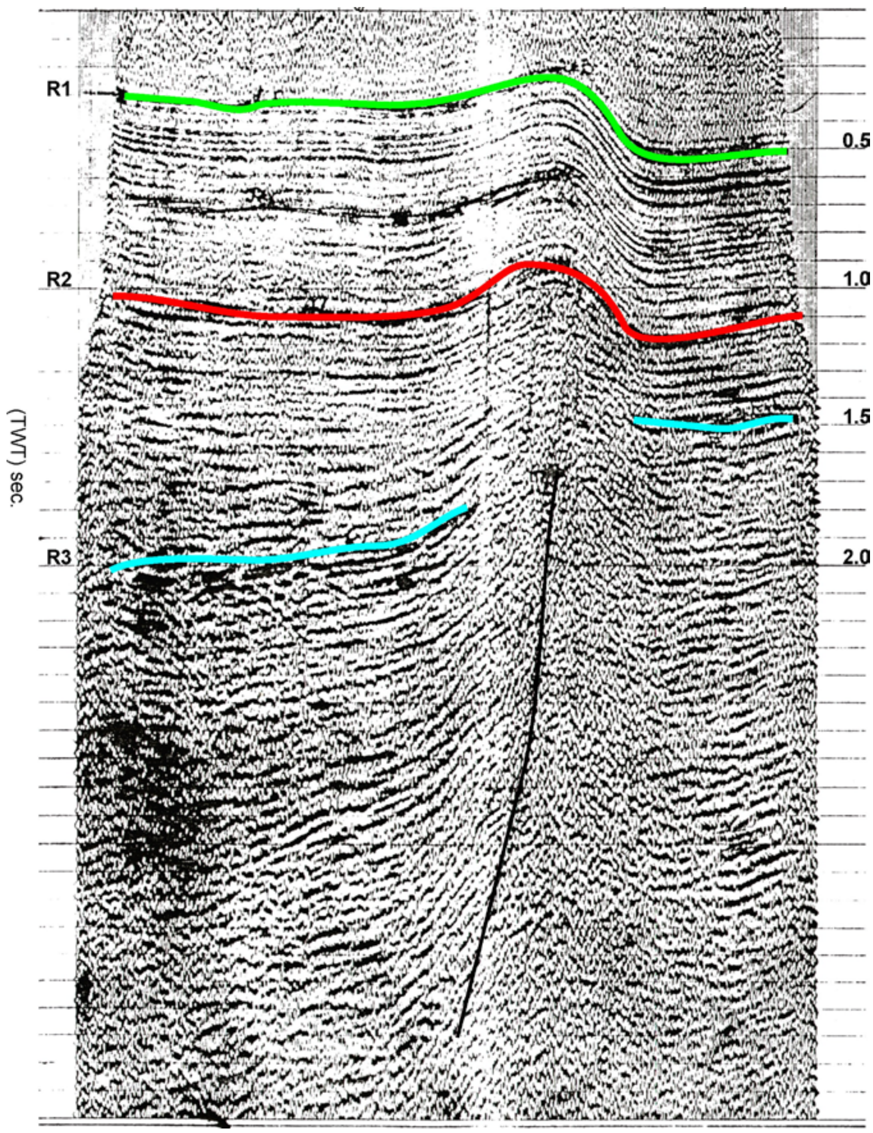


Fig.8: Seismic reflection profile through Tel Hajar Structure
(For location, refer to Fig. 2)

▪ **The NW – SE Fault System**

The system consists of grabens and normal faults. This system, which is strikingly parallel to the Zagros mountain front, is well developed in the eastern part of Al-Jazira Area (Fig.2). However, it is less extensive, shorter, narrower, and with lesser displacements in comparison with the ENE – WSE trending system.

Unfortunately, seismic data are not available to be introduced here. Nevertheless, there is no evidence that these basin bounding faults had suffered structural inversion within Al-Jazira Area, although they did in other nearby provinces such as Sammara and Tikret.

TECTONIC AND STRUCTURAL EVOLUTION

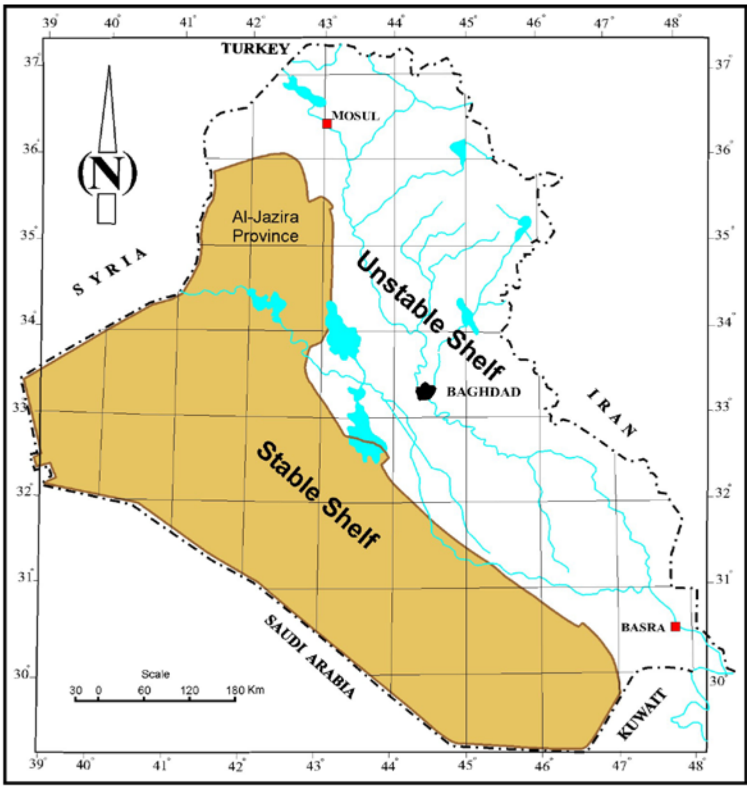
The geological setting of Al-Jazira Area, which is also known as "Khleissia Heigh" is one of the most controversial subjects in the geology of Iraq. It has traditionally being considered as the northern extension of a regional upwarp known as Hail – Rutbah Arch that extends from Saudi Arabia to northern Iraq (Buday, 1973).

Buday and Jassim (1984 and 1987) considered Al-Jazira Area as a portion of the Stable Shelf of the Arabian Platform, and consist of two parts: The western part called Rutba – Jazira Subzone, and eastern part called Salman Zone. Later on, Jassim and Goff (2006) modified the original definition by considering Rutba – Jazira Subzone as two separate subzones, and by changing the geological and the structural position of the boundary between Jazira and Salman Subzone of the province. On the other hand, the boundary between Al-Jazira Area, as a part of the Stable Shelf with the adjacent Mesopotamia Zone, as a part of the Unstable Shelf was taken along Al-Tharthar Fault line (Buday and Jassim, 1984). This boundary has also been modified by Jassim and Goff (2006) by considering the Mesopotamian Zone as a part of the Stable Shelf.

Taking these geological facts and controversies in account, it can be really noted that there is no general agreement on the internal (Rutba, Jazira, and Salman) and the external (Stable and Unstable) structural boundaries of the area, and that the boundaries are usually poorly defined, loosely delineated and has no proven geological signature and impact on the geology of the region.

Fouad (1997, 2004 and 2007), using reflection seismic data proved that there is no so called Al-Tharthar Fault line, and that Abu Jir Fault system terminates against Anah Graben and does not continue northwards. Therefore, the boundary between the stable part of the Arabian Platform must be taken along Abu Jir – Anah Fault system (Fig.9). Accordingly, Al-Jazira (or Khleissia) Area can no longer be regarded as a part of the Stable Shelf; instead it represents part of the Mesopotamia Foredeep. The Paleogene – Neogene subsidence history of the area provides another evidence to this conclusion as will be shown later.

For most of its Mesozoic history Al-Jazira Area was the northern extension of Hail – Rutba Arch. The arch was a broad upwarp extending from the northern margin of the Arabian Shield to northwest Iraq (Alsharhan and Nairn, 1997; Beydoun, 1991). Geological evidences point out that the arch was lest effective during the Paleozoic, but was most active during the Mesozoic and Cenozoic (Al-Bassam *et al.*, 2004 and Fouad, 2007). Khleissia-1 oil well revealed a much reduced Jurassic and Cretaceous sequence that is highly punctuated by unconformities, with total absences of Late Jurassic and Early Cretaceous sediments. This implies that Khleissia has been frequently uplifted above sea level and eventually was subject to erosion at that time span. However, by the Late Cretaceous, the area regained its normal condition and subsided below sea level and marine carbonates started to deposit above the former eroded uplift.



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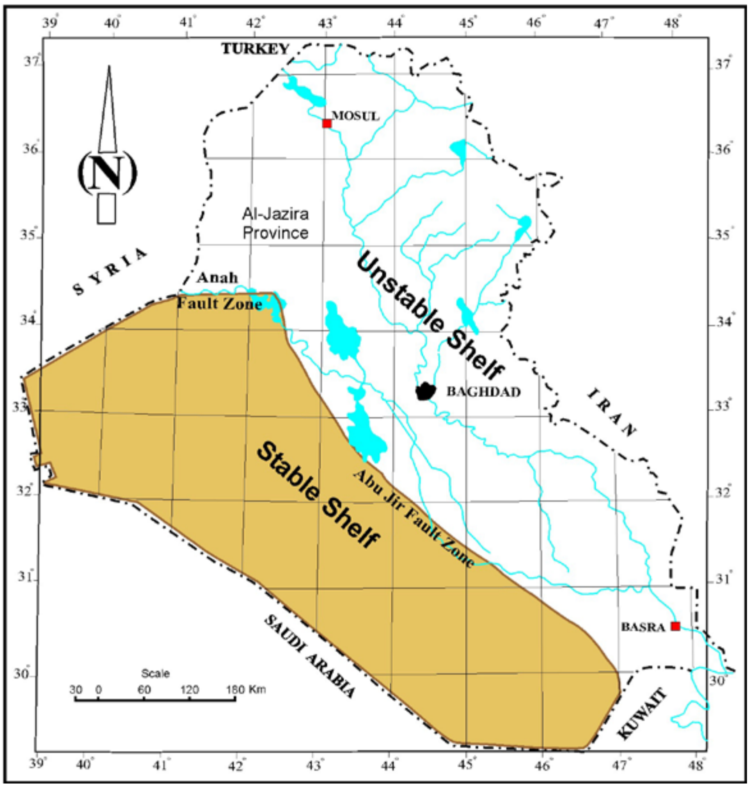

b

Fig.9: The tectonic position of Al-Jazira Area with respect to the Stable – Unstable Shelves of the northern Arabian Platform.
a) after Buday and Jassim (1987)
b) after Fouad (2007) and the present study

The subsidence of Al-Jazira Area or "Khleissia Heigh" was the result of the Late Cretaceous stretching of the Arabian Platform. The stretching was enough to generate systems of intercontinental elongated graben and half-graben rift basins in northern Arabia (Peel and Wright, 1990). The rift system occurred in two trends: ENE – WSW and NW – SE. The first system prevailed in the western part, whereas the second prevailed in the eastern part of Al-Jazira Area (Fouad, 1997 and 1998). Lovelock (1984) and Ruiter *et al.* (1994) considered the distribution and geometries of the rift system were largely controlled by failure along pre-existing lines of structural weakness in the body of the Arabian Plate. The lines of weakness are considered to be linked to the initiation and opening of the Neo-Tethys in the Mesozoic Era. Foaud (1997) and evidence of the present study support this consideration, because: First, the rifts are strikingly parallel to the trend of the mountain front of the Arabian Foreland and hence, following boundaries of the older plate margin. Second, there is no evidence of prerift doming, thermal activity and volcanism, which point out that the rifts were of the passive type. Passive rifting, as known in many areas such as the Baikal and Rhine rifts is strongly governed by inherited zones of weakness (Kazmin, 1987and Park, 1988). Late Cretaceous stretching of the Arabian Platform was most probably the result of the slab-pull force that was associated with the subduction of the Arabian Plate under the Central Iranian and South Anatolian Microplates (Lovelock, 1984; Daly, 1990 and Ruiter *et al*., 1994).

As the rift basins of Al-Jazira Area have formed, Campanian – Maastrichtian synrift sediments started to fill these basins. The synrift sequence, which is represented by Shiranish, Hartha and Tayarat formations, exhibits a remarkable thickness increase within the fault bounded basins in comparison with their counterparts on the shoulders. Basin subsidence and sedimentation conditions lasted for about (15 – 20) Ma until the end of the Maastrichtian (65 Ma), when the active graben subsidence terminated. Cessation of active subsidence was followed by regional uplifting and total emergence of the area and development of region-wide unconformity (i.e. the postrift unconformity). Denudational condition has lasted for about 10 Ma as indicated by the total absence of the Paleocene sediments.

It is important to mention that the Late Cretaceous formation of the deep basement involved Anah Graben in the southern part of Al-Jazira Area, resulted in the separation of Khleissia Heigh from the rest of Hail – Rutba Arch. The later Paleogene – Neogene development is therefore completely independent on that of its former southern Hail – Rutba extension. The uninterrupted and almost complete Paleogene – Neogene sequence of Al-Jazira Area in correlation with their highly interrupted and reduced counterpart along the extension of Hail – Rutba Arch provides decisive evidence to this conclusion.

Gradual sea-level rise took place at the beginning of the Eocene (~ 48 Ma), leading to the deposition of the open marine carbonates of Jaddala Formation as the early postrift units over the eroded Late Cretaceous synrift sequence. Marine conditions continued throughout the Paleogene, though a sharp sea-level fall took place during the Oligocene. The regional eustatic sea-level fall was not enough to put Al-Jazira Area under subaerial exposure, though it has affected vast regions in Iraq. That intern points out that the area was one of the lowest regions during that period of time, in contrast to Hail – Rutba Arch, its former southern extension, which was a positive area and under extensive erosion.

By the end of the Middle Miocene (~11Ma), however, a transition from marine to continental condition start taking place. As the collision between Arabia and Iranian – Anatolian portions of Eurasia started to culminate through the Late Miocene onwards, the marine conditions terminated and were replaced by continental condition. The huge deltaic and fluvial clastics of the Late Miocene invaded Al-Jazira Area causing the gradual southeast wads retreat of the sea.

When the compressional phase reached its climax during the Plio – Pleistocene, extensive folding and faulting occurred along the former Arabian Plate margin. The deformational wave soon started to propagate south and southwest ward, to involve gradually the proximal parts of the Mesopotamia Foreland basin by folding and faulting. However, Al-Jazira Area, as the distal part of the Mesopotamia Foredeep basin, was too remote to be involved by folding, except its northern most part, where Tel Hajar Graben had suffered positive structural inversion. The inversion occurred by compressional reverse reactivation of the former basin bounding normal fault (Fig.8). The boundary fault shows normal stratigraphic separation at depth, but gradually decreases up section through a nil point to change to a reverse stratigraphic separation upwards. The uppermost part of the synrift units as well as the entire postrift units have draped over the tip of the fault to form an extensive compressional fault-propagation fold.

It is interesting to note that, except Tel Hajar, all of the rift basins within Al-Jazira Area have not being involved by structural inversion phenomena, although the entire province is bounded by two of the major inverted basins of the north Arabian Platform; Sinjar and Anah from north and south, respectively. More details on this subject matter are found in Fouad (1997).

However, Khleissia Graben exhibits a distinguished structural feature. As shown in Fig.6, the Paleogene – Neogene postrift units display a uniform thickness across the graben, but also show some subsidence (sagging) toward the centre. Moreover, few small normal faults have developed, truncating the postrift sequence and have propagated to the surface (Fig.7), indicating a second stage of recent activity. The sequence of development and the details of the structural evolution will be discussed separately in a following work.

CONCLUSIONS

- Though it lacks significant surface structures, Al-Jazira Area, which is also known as "Khleissia Heigh", is dominated by a network of subsurface intracontinental rift basins. The extensional structures form two systems of ENE – WSW and NW – SE trending grabens and half grabens. The first dominates the western part, whereas the second dominates the eastern part of the area.
- Khleissia-1 oil well, which penetrated sediments as far as Paleozoic in age revealed a much reduced, least complete and highly punctuated Mesozoic sequence and almost complete Paleogene – Neogene one. This intern reflects, on one hand that the area was most active and frequently being uplifted above sea-level to be under subaerial erosion during the Mesozoic, and that it was of inactive nature and underwent steady subsidence during most of the Paleogene – Neogene, on the other.
- The sedimentary sequence in Al-Jazira Area has been divided into three genetically distinct tectonostratigraphic sequences. A Paleozoic – late Early Cretaceous prerift sequence, which deposited prior to rift basin formation; Campanian – Maastrichtian synrift sequence deposited during basin subsidence in response to extensional fault movement; and Paleogene – Neogene postrift sequence deposited after the cessation of active basin subsidence. These sequences are separated from each other by "rift-onset" and "postrift" unconformities.
- Former thoughts have had traditionally regarded Al-Jazira Area (or Khleissia Heigh) as the northern extension of the regional Hail – Rutba Arch throughout all of its geological history. However, evidences presented in this study including the involvement of the province in the Late Cretaceous rifting as well as its steady subsidence during the Paleogene to Middle Neogene, indicate that Al-Jazira Area has acted as separate entity independent and unlike its

southern extension. Therefore, the area can no longer be regarded as the northern extension of Hail – Rutba Arch from the Late Cretaceous onwards.

- The Late Cretaceous rift systems in Al-Jazira Area (and other parts of northern and central Iraq) are most probably of the passive type and following earlier lines of structural weakness in northern Arabian Platform established during the Tethys opening of the Neo-Tethys Ocean in the Mesozoic Era. Lack of evidences on prerift doming, thermal activity and volcanism as well as being strikingly parallel to the Zagros Fold and Thrust Belt are an additional support to this preposition.
- The compressive phase of the late Alpine Orogeny, which culminated during the Plio – Pleistocene has resulted in structural inversion of many early formed rift basins in northern and central Iraq. Nevertheless, the majority of the rift basins in Al-Jazira (except Tel Hajar) remained tectonically inactive without inversion although they are surrounded by the strongly inverted Sinjar and Anah basins from the north and south, respectively.
- Al-Jazira Area has been regarded earlier as a part of the Stable Shelf of the Arabian Platform by many workers. However, by adapting the persistent geological aspects of the new proposed boundaries between the stable and unstable parts of the northern Arabian Platform (Fouad, 1997 and 2002) and by considering its Late Cretaceous and Paleogene – Neogene stratigraphic and structural evolution, the area is regarded here as the northwestern extension of the Unstable Mesopotamia Fordeep.
- Several geological and morphotectonic evidences including recent faulting, subsidence, intensive karstification and changing pattern of the drainage systems, indicate that Khleissia Graben is Neotectonically active as a fault bounded trough. Its activity is regained after a considerable period of quiescence.

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