TECTONIC AND STRUCTURAL EVOLUTION

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ABSTRACT

The available geological information including stratigraphic sequence, unconformities pattern, drill-hole data, structural elements have been integrated to infer the tectonic and structural evolution of the Iraqi Southern Desert.

The Southern Desert is a part of the northern Arabian Platform, where relatively thin Phanerozoic sediments cover the Precambrian NW – SE and NE – SW fractured continental basement complex. The platform itself is divided into two parts, a stable one to the west (Southern Desert) and unstable one to the east. The boundary between the two parts of the platform is taken along Euphrates Fault Zone (extension of Abu Jir Fault Zone).

The Paleozoic sequence is reduced in the Southern Desert. Its composition and development is still unknown. The Mesozoic cover characterized by significant carbonate deposition with interspersed clastic episodes and is marked by few gaps in Campanian – Maastrichtian. However, the Cenozoic sequence displays gradual retreat of the sea and final transition to the continental conditions.

The main structural element is Safawi Arch, which initiated in Late Triassic – Early Jurassic. The sedimentation pattern through the most of the Mesozoic era was a reflection to a fluctuating sea level and periodical movements of Safawi Arch. In the Tertiary, the main tectonic activities were periodical uplift and downwarp along the southeastern slope of Safawi Arch during Late Oligocene and Miocene periods which reactivated of Al-Batin fracture system, as well are contributed to formation of the Dibdibba basin and terminated by a limited right lateral strike – slip movement on Euphrates Fault Zone in Pliocene – Pleistocene period. Finally, conclusive evidences on the nature of Al-Batin fracture system were introduced.

النشأة التكتونية والتركيبية

خلدون عباس معلة

المستخلص

استخدمت المعطيات الجيولوجية المتوفرة بما فيها التتابعات الطباقية وسطوح عدم التوافق وتوزيعها ومعلومات الآبار والعناصر التركيبية لاستنتاج النشأة التركيبية والتطور التكتوني لمنطقة الصحراء الجنوبية العراقية. إن الصحراء الجنوبية جزء من المسطبة العربية، حيث تغطي رسوبيات نحيفة نسبياً من الحقبة الفانيروزوية صخور القاعدة القارية المتصدعة باتجاهات شمال غرب – جنوب شرق وشمال شرق – جنوب غرب. وإن المسطبة العربية في العراق مقسمة الى جزئين، جزء مستقر الى الغرب والجنوب (حيث تتواجد الصحراء الجنوبية) وآخر غير مستقر الى الشرق. وإن الحد الفاصل بين هذين الجزئين هو نطاق تصدع الفرات (امتداد نطاق تصدع أبو جير).

إن تتابعات الدهر القديم (الباليوزوي) الصخرية تعتبر مختزلة (فقيرة) في الصحراء الجنوبية العراقية، وإن مكوناتها وتطورها مازال غير معروف. أما تتابعات الدهر الوسيط (الميسوزوي) الصخرية تمتاز برسوبيات بحرية ضحلة تسودها الصخور الكلسية مع رسوبيات فتاتية بينية، موسومة ببضع الثغرات في عصر الكامبانيان – مسترختيان. كما أن تتابعات الدهر الحديث (السينوزوي) الصخرية تعكس تراجع تدريجي للبحر ثم التحول الى بيئة قارية في عصر المايوسين المبكر.

أمكن الاستدلال على قوس صفاوي كظاهرة تركيبية، بدأ في عصر الترياسي المتأخر– الجوراسي المبكر. إن نظام الترسيب لمعظم فترة الدهر الوسيط (الميسوزوي) قد عكس تأثره بتذبذب مستوى سطح البحر إضافة للحركات

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المتكررة لقوس صفاوي. وفي العصر الثلاثي حصلت فعاليات تكتونية بدأت بحركات نهوض وهبوط متكررة على طول المنحدر الجنوبي الشرقي لقوس صفاوي في عصري الاوليكوسين والمايوسين وكذلك تكوين حوض دبدبة وانتهت بحركة مضربية-يمينية محدودة على طول نطاق تصدع الفرات في عصر البلايوسين – بلايستوسين. أخيراً تم تبيان شواهد حاسمة عن طبيعة نظام كسور الباطن.

INTRODUCTION

The region, which lies to the west of the Euphrates River, is assigned to the Western and Southern Deserts; the boundary between them is geographic feature (Wadi Al-Khir). The present study focuses on the Southern Desert; it occupies about 76 000 Km^2 and is located in the southern part of Iraq and bordered by Euphrates River from NE and Wadi Al-Khir from NW. From the SW and SE is bordered by Saudi Arabia and Kuwait, respectively (Fig.1).

Morphologically, the area is relatively flat terrain, slopping gently towards E and NE. The elevated part (300 – 400 m, a.s.l.) exists along the Iraqi – Saudi Arabian border (Ansab – Ma'aniya), while the northeastern part (20 – 150 m, a.s.l.) is along the Euphrates River. The northeastern area includes morphologic features, such as Bahr Al-Najaf, Hor Al-Milh, Sawa Lake, Samawa Saline and Slaibat Depressions (Fig.1).

Structurally, the Arabian Plate is divided (from southwest to the northeast) into: Arabian Shield, Arabian Platform (with its stable and unstable parts) and the Zagros Thrust Belt (Fouad, 2007). The Iraqi Southern Desert lies within the stable part of the Arabian Platform, where Cenozoic rock units are exposed and slopping gently east and southeast, towards the unstable part of the Arabian Platform.

The present study is a review to the regional structure of the Southern Desert, as a part of the Arabian Platform and to comprehend the area in terms of stratigraphic sequence, unconformities and structural elements. The best available materials are used in this study.

PREVIOUS STUDIES

There are many geological studies, concerning the regional structure of the Southern Desert. Most of the workers like Ditmar *et al*. (1972); CGG (1974); Al-Amiri (1979); Al-Ani and Ma'ala (1983 a and b); Al-Hadithi and Al-Mehaidi (1983); Al-Mubarak and Amin (1983); Al-Sharbatti and Ma'ala (1983a); Buday and Jassim (1987); Sissakian *et al*. (1994); Hassan *et al*. (1995); Al-Kadhimi *et al*. (1996); Al-Shamma'a (2000) and Jassim and Goff (2006) believed that the Euphrates Fault Zone has step-like character, excluding Barazanji and Al-Yasi (1987) and Fouad (2004), they revealed that the fault zone exhibits horizontal displacement. Al-Ethawi (2000) postulated that Salman – Samawa Fault is a tectonic line between Western and Southern Deserts. Henson (1951) in Al-Mubarak and Amin (1983) and Roychoudhury and Nahar (1980) believed that Safawi Arch of NE – SW trend is an important structural element, in the Southern Desert, which extends from Hail in the Saudi Arabia. Al-Mubarak and Amin (1983) postulated that the folding is related to movements of basement blocks. They recognized two kinds of folds: horst anticlines over horst blocks and minor folds parallel to major fault system. Al-Hadithi and Al-Mehaidi (1983) and Al-Sharbatti and Ma'ala (1983) displayed that Al-Batin Fault has horizontal displacement, according to the geological map of the Saudi Arabia.

Buday and Jassim (1987) pointed out that the Salman Zone is characterized, besides the fold structures, by a relatively dense net of faults. Moreover, the southeastern border of the Stable Shelf (Euphrates Fault Zone) runs along a system of step faults up to Iraqi – Kuwait borders. As well, they believed that NE of Shbicha area comprised relatively of dense net of anticlines, some of them over (25 – 50) Km long, with trends mostly ENE and NE. For these reasons, the structural setting of the northern part of the Arabian Platform requires reviewing, concerning the regional structural setting, as the recent comprehension is considered.

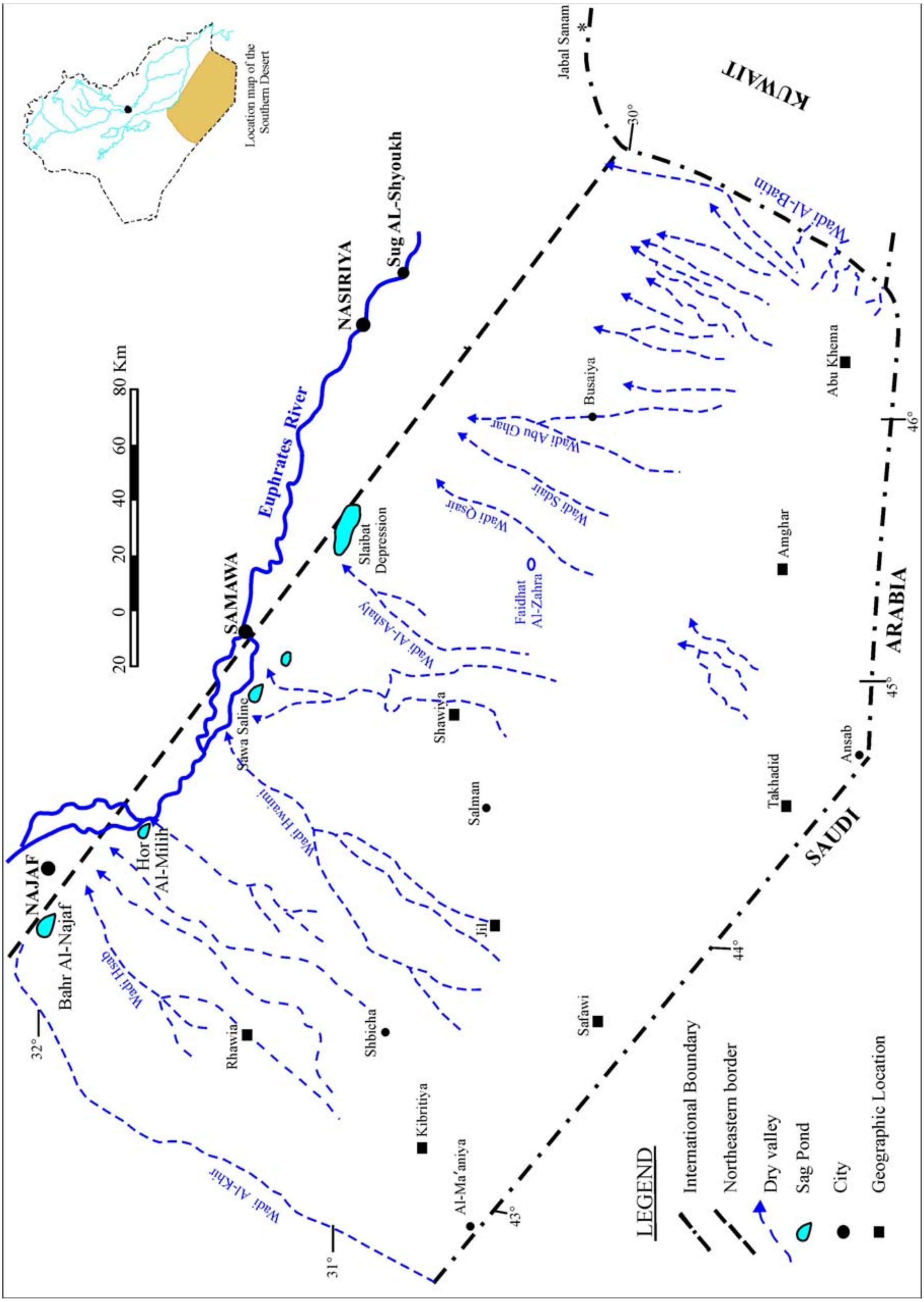

Fig.1: Location map of the Iraqi Southern Desert

STRATIGRAPHY OF THE IRAQI SOUTHERN DESERT

The exposed sedimentary sequence in the Southern Desert ranges from Paleocene to Pleistocene in age with two regional unconformities, which interrupted the stratigraphic sequence. The stratigraphic sequence provides significant tectonic and structural information, as it records the activities that have been prevailing at the time of deposition. The following is a brief review to the stratigraphic column of the involved area, including the basement.

- **The Basement**

Basement outcrops are completely absent in Iraqi territory, as well, no boreholes were penetrated the basement. Therefore, the basement characteristics and depths are estimated indirectly from geophysical data. The Arabian Shield formed as a result of a Proterozoic amalgamation of island arcs and micro plates against northeast Africa as part of the Pan African orogenic system, most probably occurred between (~ 950 – 640) Ma (Stoesser and Camp, 1985; Beydoun, 1991 and Alsharhan and Nairn, 1997 in Fouad, 2007). The convergence of these fragments occurred in a general east – west direction and eventually left north – south trending lines of weakness (Fouad, 2007) known as Najd Fault System. Moreover, Fouad (2007) mentioned that strike-slip movement on NW – SE trending faults took place as, Najd Fault System imposed significant NW – SE trending lines of weakness. These inherited lines of weakness played an important role in the style and location of the later formed structure and sedimentation pattern. The estimated depth of the basement within the Southern Desert, based on CGG (1974) aeromagnetic interpretation, ranges (5 – 8) Km; mainly (6 – 7) Km towards east.

- **The Paleozoic (570 – 245) Ma**

The Paleozoic section is neither exposed nor penetrated by any borehole in the Iraqi Southern Desert. Buday (1980) showed that the area characterized by thin or absence of Paleozoic sequence.

- **The Mesozoic (245 – 65) Ma**

The Mesozoic section is not exposed in the Iraqi Southern Desert, but penetrated by boreholes. Boreholes were drilled until the Jurassic rocks, but almost none of them penetrated full Jurassic succession. Abu Khema borehole (Fig.2) penetrated the Late Jurassic rocks; therefore, the data concerning the Stratigraphy of the Southern Desert is limited to the Late Jurassic on wards.

The Mesozoic succession, in the Abu Khema borehole (2680 m deep) is represented by eighteen formations. The formations are assigned to the Late Jurassic Najmah and Gotnia, which consist of carbonate in the lower part and gypsum in the upper part.

The Cretaceous sequence, which is conformably overlying the older rock units, is represented by sixteen formations: Sulaiy, Yamama, Ratawi, Zubair, Shu'aiba, Nahr Umr, Mauddud, Ahmadi, Rumaila, Mishrif, Khasib, Tanuma, Sa'di, Hartha, Qurna and Tayarat. All these formations consist of carbonate with interspersed clastics. Each formation has a conformable contact, except Sa'di and Hartha formations, which are separated by unconformable contacts.

The Mesozoic sequence is terminated by shallow marine sediments, in Abu Khema borehole (Roychoudhury and Handoo, 1980), while in the Salman area, the Late Cretaceous sequence is terminated by regional unconformity that extends almost along the entire Arabian Platform (Tamar-Agha, 1984).

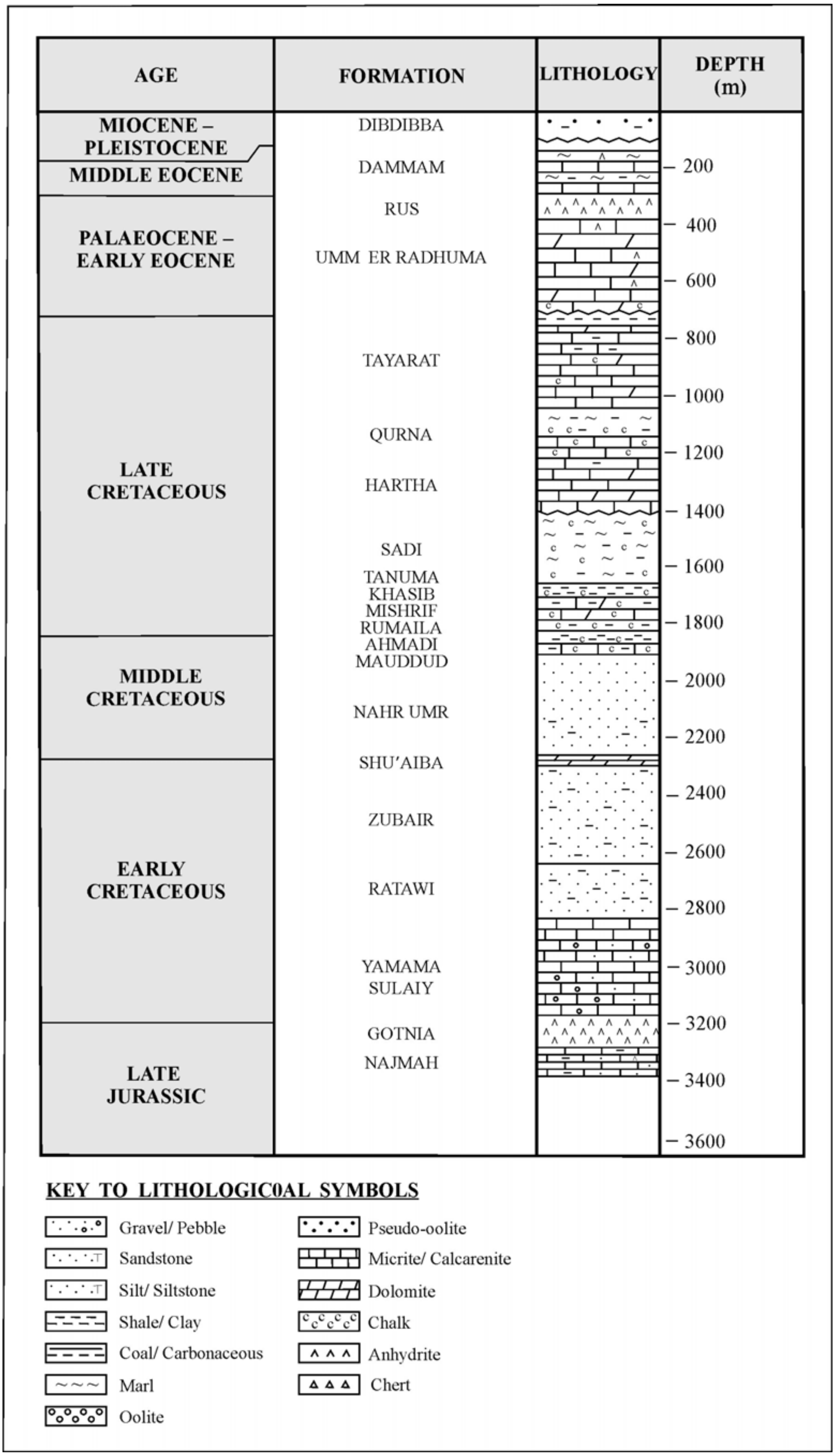

Fig.2: Stratigraphic column, Abu Khema borehole (Roychoudhary and Nahar, 1980)

▪ The Cenozoic (65 Ma – Present)

The Cenozoic sequence overlies unconformably the Mesozoic rock units, in the Salman area (Tamar-Agha, 1984), but conformably in the Abu Khema area (Roychoudhury and Handoo, 1980). The sequence is represented by the Paleocene Umm Er Radhuma, Early Eocene Rus, Eocene Dammam, Early Miocene, Euphrates and Ghar, Middle Miocene Nfayil and the Pliocene – Pleistocene Zahra and Dibdibba formations (Fig.3). The shallow carbonate of the older formation denoted first marine transgression, in the area, after an extensive erosional period. It is followed unconformably by the carbonate facies of Umm Er Rhadhuma Formation, which passes laterally to anhydrite facies of the Rus Formation, along NW alignment (Al-Hashimi, 1973). A gap exists between the Eocene and the second marine transgression, in the area due to extensive erosional period (Al-Naqib, 1967; Al-Hashimi, 1973; Al-Ani and Ma'ala, 1983a and b and Tamar-Agha, 1984). Another gap exists between the Middle Miocene and Pliocene – Pleistocene, due to the last marine regression cycle in the area (Al-Ani and Ma'ala, 1983b). It is worth to mention that the continental clastic sediments and fresh water limestone of the Zahra Formation had filled old collapse dolines and passed laterally to the Dibdibba Formation along NE lineament (Ansab – Sdair) in the eastern part of the area (Al-Ani and Ma'ala, 1983 and Jassim and Goff, 2006).

STRUCTURAL GEOLOGY OF THE SOUTHERN DESERT

The Southern Desert is a part of the Arabian Platform, where a relatively thin Phanerozoic sequence covers the Precambrian basement complex. Generally, the area lacks expressive Alpine related compressional structures. The exposed Cenozoic rock units have east and northeast regional dip that does not exceed 2° (Al-Mubarak and Amin, 1983; Sissakian *et al*., 1994 and Hassan *et al*., 1995).

▪ The Boundaries

The Arabian platform within the Iraqi territory has been divided, by different authors, into two main structural domains, the Stable Shelf to the west and the Unstable Shelf to the east (Fouad, 2007). The eastern boundary of the Southern Desert coincides with the stable and unstable parts of the platform. Several workers tried to delineate this boundary by considering different geological aspects. Buday (1973) and Buday and Jassim (1987) subdivided the Stable Shelf, into two main parts, the western Rutba – Jezira Zone and eastern Salman Zone. Then, they considered the Southern Desert as part of the Salman Zone and placed the Euphrates Fault Zone as a transition part between the Stable and Unstable parts of the Shelf.

All previous authors considered the Euphrates Fault Zone as step-faults, indicated by well-marked gravity gradient. The main objection to this division is that it relies on physiographic and gravity data and disregarded the proper structural and seismic data; besides the main tectonic framework of the Middle East. Fouad (2007) showed that Abu Jir Fault Zone extends from east of Anah city for about 600 Km across the Iraqi territory towards Al-Batin lineament along Iraqi – Kuwait borders.

– Northeastern Boundary; Euphrates Fault Zone

The northeastern boundary of the Southern Desert and also the boundary of the stable part of the platform are considered to be the Euphrates Fault Zone. The zone, which is running along the western side of the Euphrates River, through Najaf and Samawa cities to meet Al-Batin lineament consists of two parallel faults (Fig.4). Several workers tried to delineate this zone by various methods including field investigations (Al-Ani and Ma'ala, 1983 and Al-Mubarak and Amin, 1983), landsat images (Al-Amiri, 1978 and Al-Hadithi and Al-Mehaidi, 1983), geophysical (Al-Kadhimi *et al*., 1997), aeromagnetic interpretation (CGG, 1974) and by regional compilation (Buday and Jassim, 1987 and Al-Kadhimi *et al*., 1996).

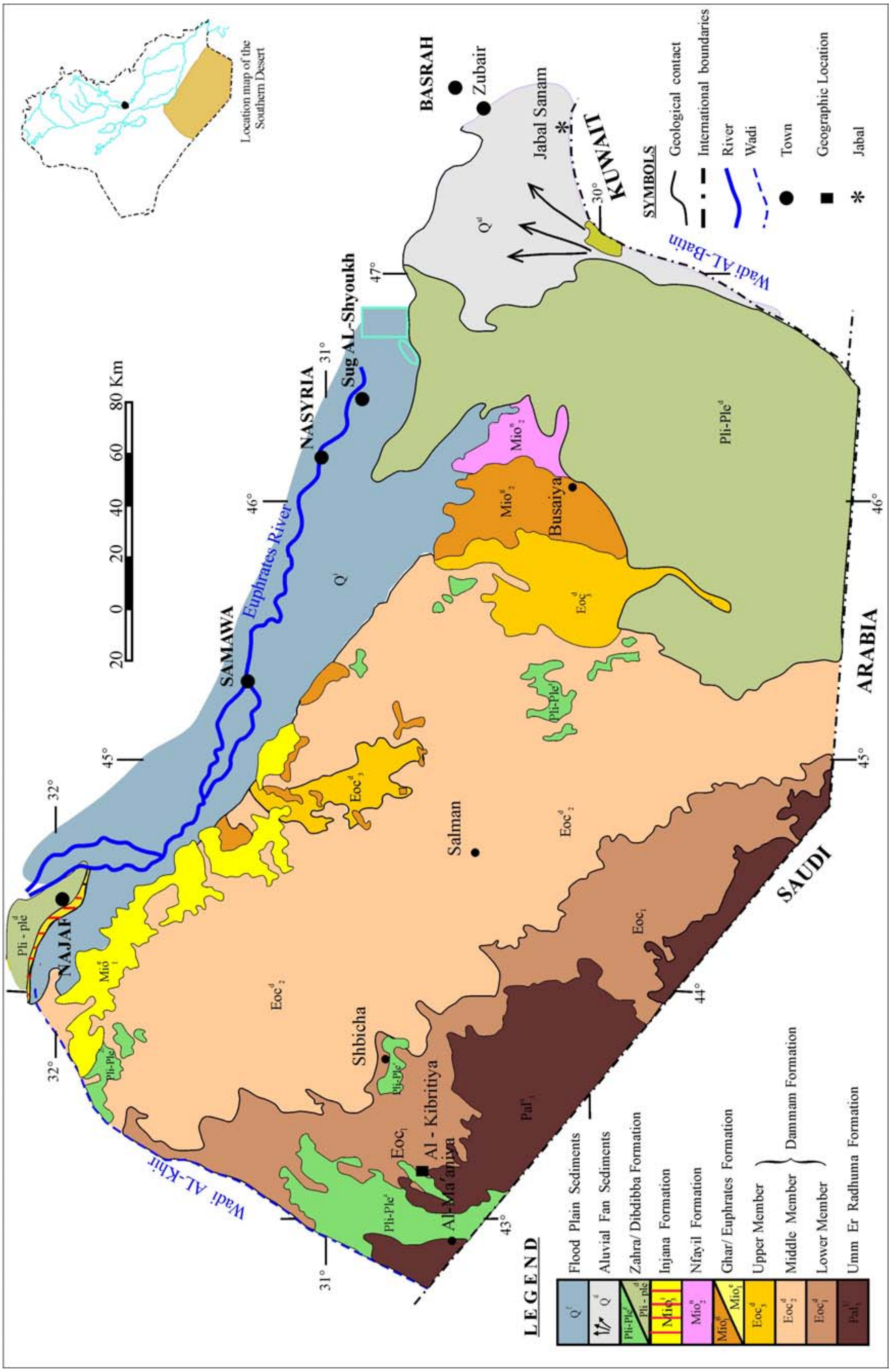

Fig.3: Geological Map of the Iraqi Southern Desert (after Sissakian, 2000)

Almost all previous authors had thought that the fault zone has step-fault pattern with down thrown side facing towards the Mesopotamian Plain. Deikran (1995) referred the Euphrates Fault of unknown character. Fouad (2007) believed that Abu Jir Fault Zone extends to the Euphrates Fault Zone along western side of the Euphrates River, through Najaf and Samawa cities to meet Al-Batin lineament, west Basrah and north Kuwait; it forms an expressive linear feature across the Iraqi territory for about 600 Km, that is clearly visible from satellite images. Moreover, Barazanji and Al-Yasi (1987) supported this opinion. Fouad (2002) pointed out that Abu Jir Fault Zone exhibits some geomorphological features that are directly related to the lateral movement of the zone, such as pressure ridge and sag ponds.

The view of the Euphrates Fault Zone includes many elliptical topographic depressions, such as Bahr Al-Najaf, Hor Al-Milih, Sawa Lake, Samawa Saline and Slaibat (Fig.1). These features might be related to lateral movement along the Euphrates Fault Zone. Therefore, the author believes that Euphrates Fault Zone is coincides with extension of Abu Jir Fault Zone.

- **The Intra-Stable Platform Fault System**

Several faults were inferred by various methods including field observation (Al-Ani and Ma'ala, 1983a; Al-Mubarak and Amin, 1983 and Al-Sharbatti and Ma'ala, 1983), landsat images (Al-Amiri, 1978 and Al-Hadithi and Al-Mehaidi, 1983), and geophysical method (Ditmar *et al*., 1972; CGG, 1974 and Al-Ethawi, 2000) and by regional compilation (Buday and Jassim, 1987; Sissakian *et al*., 1994; Deikran, 1994a; Hassan *et al*., 1995 and Al-Kadhimi *et al.*, 1996). Many of these faults are speculative and subjected to debate. In this study the author will focus on the geologically proven faults only.

– NE – SW Trending Lineaments, Al-Batin Lineament System

The Land sat image (Fig.4) shows several fracture traces of NE – SW in the southeastern part of the Southern Desert. They are:

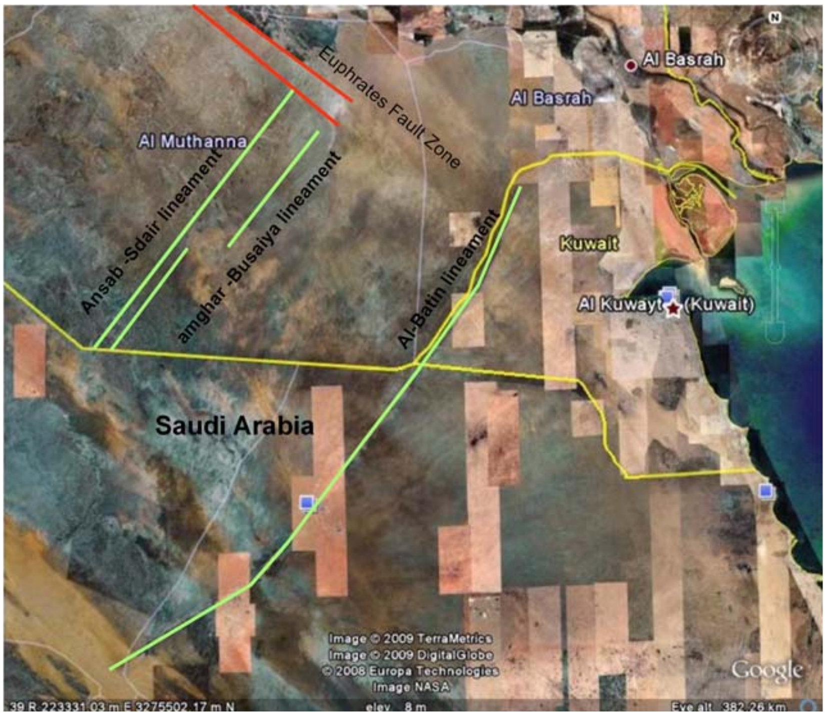

Fig.4: Landsat Image showing Al-Batin lineament system and Euphrates Fault Zone in the Iraqi Southern Desert

- Al-Batin lineament, which extends 150 Km along the Iraqi – Kuwait borders, is expressed by isolated and nearly straight valley with course of NE – SW direction, known as Wadi Al-Batin. On landsat image, the lineament is long and straight topographic feature, which extends for more than 250 Km in Saudi Arabia territory (Fig.5). Jassim and Buday in Jassim and Goff (2006) showed that Al-Batin lineament is connected with Arabian Shield. According to the Geological map of the Saudi Arabia, Al-Batin lineament dissects the Mesozoic and Tertiary rock units with horizontal offset on both sides of the valley. For this reason, Al-Hadithi and Al-Mehaidi (1983) considered it as a probable fault of horizontal displacement. The tectonic map, compiled by Ditmar *et al*. (1972) shows Wadi Al-Batin as a major fault of NE – SW trend.

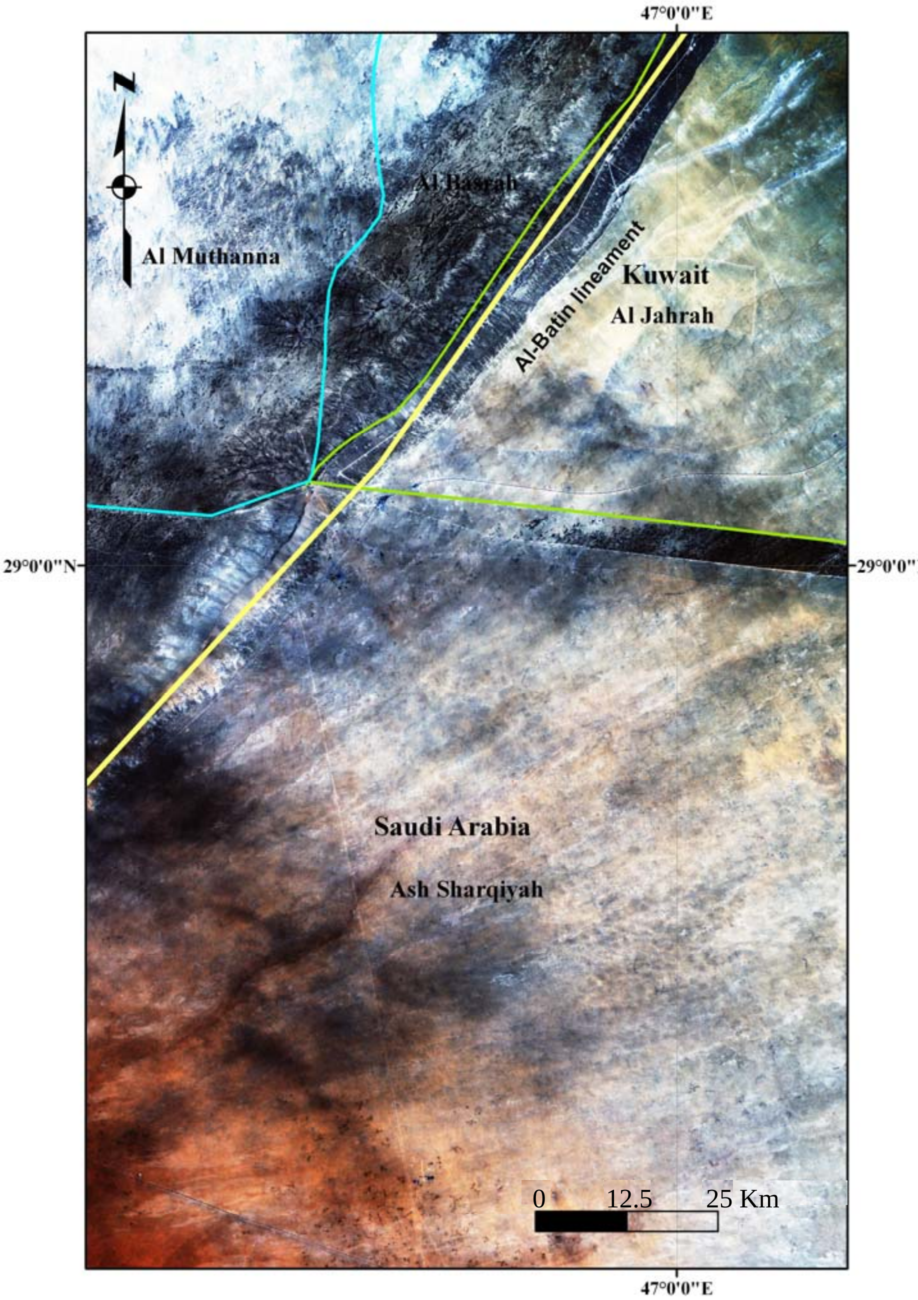

Fig.5: Landsat, ETM+321 RGB, showing Al-Batin lineament in the Iraqi Southern Desert (prepared by Arsalan A. Al-Jaf)

- Ansab – Sdair and Amghar – Busaiya linea, are restricted to the southern part of the Southern Desert. Al-Amiri, 1978; Al-Ani and Ma'ala (1983) and Al-Hadithi and Al-Mehaidi (1983) described them as a set of normal faults of NE – SW trend, with traces having length of (55 – 195) Km. Moreover, Al-Ani and Ma'ala (1983a) showed that Ansab – Sdair lineament has been observed as a border of well relatively abrupt facial changes, periodically in Early Miocene (Euphrates – Ghar formations) and Pliocene – Pleistocene (Dibdibba – Zahra formations).

Remarks:

- The aforementioned lineaments are well visible in Land sat ETM + 321 RGB (Fig.6), according to the lithological variations, alignment of sinkholes, stream alignments and linear topographic features.
- Huntington (1969) stated that a long fracture indicates a deep zone of failure. Therefore, Al-Batin and Ansab – Sdair lineaments could be attributed to deep structures.

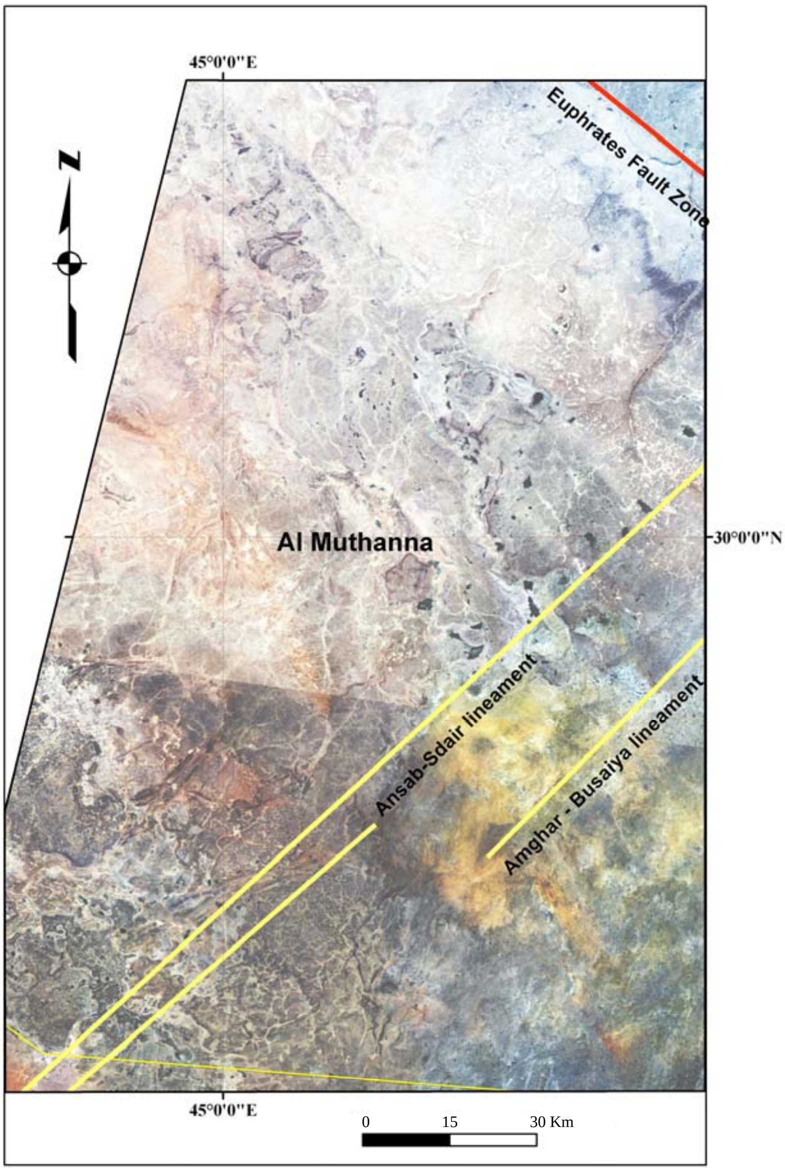

Fig.6: Landsat ETM+321 RGB, showing Ansab – Sdair and Amghar – Busaiya lineaments in the Iraqi Southern Desert (prepared by Arsalan A. Al-Jaf)

▪ **Arches**

Several major arches dominated the structural part of the basement, originated from Hail region of Saudi Arabia, and extends to south of Iraq. Among them is Safawi Arch. This arch is trending northeast through Safawi locality towards Samawa town, within Iraqi territory (Fig.7) (Henson, 1951 and Roychoudhury and Nahar, 1980). Its nature, position and periodic activity remained unknown, due to lack of deep wells and seismic data. Nevertheless, the available data show that Safawi Arch is a basement swell with down warping on both flanks, which created basins (Roychoudhury and Nahar, 1980).

Safawi Arch is marked by prominent positive gravity anomaly indicating the presence of basement at a relatively shallow depth. The shallowest locality is in Salman Depression (Sallomy and Al-Khatib, 1981 and Al-Ethawi, 2002). Moreover, Ditmar *et al*. (1972) showed that the zone, which situated along Safawi lineament, is very specific structural element of the platform; it represents a system of large local uplift of ellipsoidal forms, usually bordered by faults mainly of N – S trend.

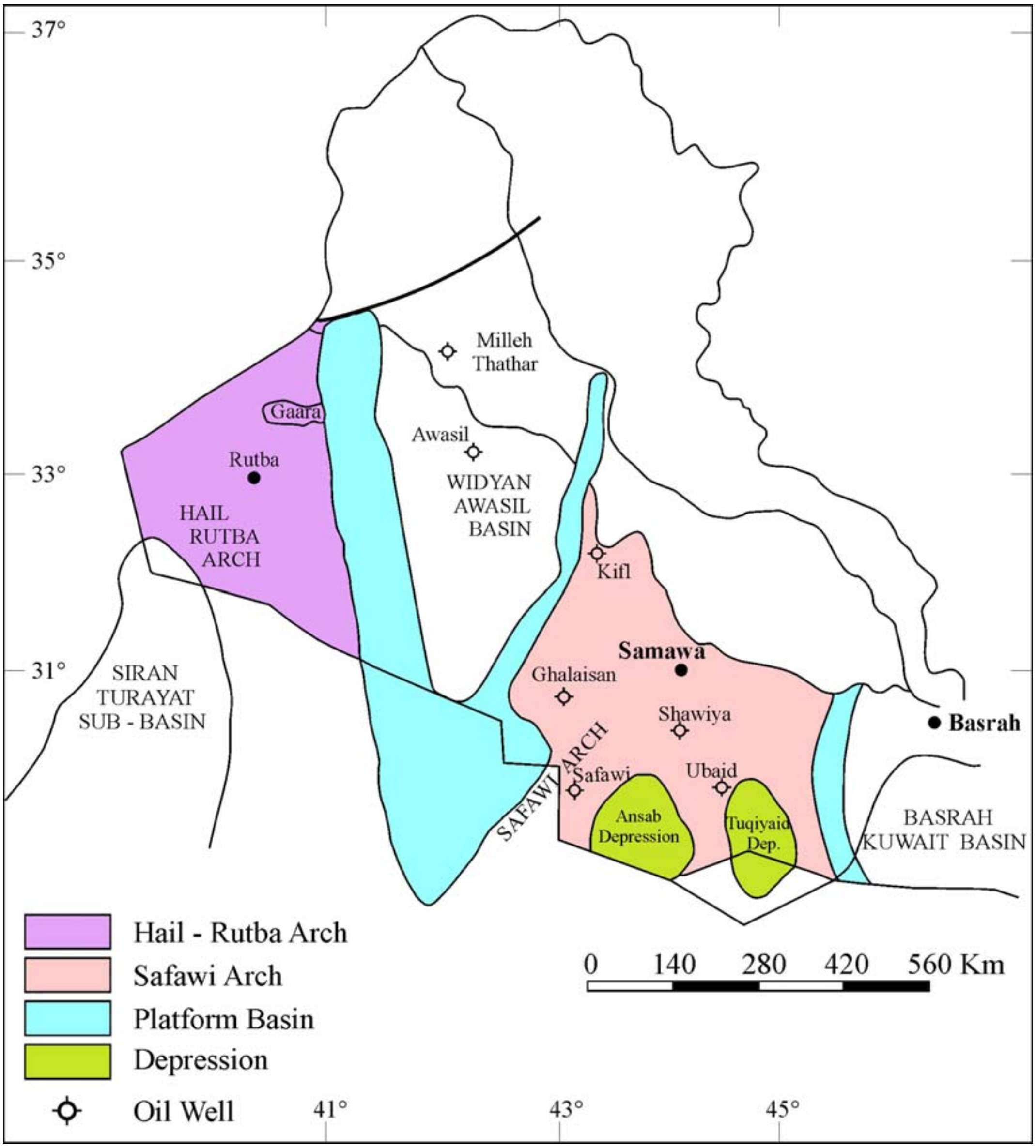

Fig.7: Structural pattern of the basement, showing Safawi Arch (Henson, 1951)

TECTONIC EVOLUTION

By integrating the data already displayed, the tectonic and structural evolution of the Southern Desert, as a part of the Stable Platform of the Arabian Plate, can be broadly outlined. Geological, geophysical and deep drilling data have shown that the Stable Platform is divided up into local basins and highs controlled by deep seated block faulting in the basement. The suggested tectonic pattern is a complex one, resulting from interplay of differential movement on the fault systems, which are oriented predominately in NW – SE, NE – SW and N – S trends.

The accretion and cretonization of Arabia Peninsula throughout the Proterozoic (950 – 640 Ma) and the following Latest Proterozoic – Earliest Paleozoic (620 – 550 Ma) intercontinental failure and strike-slip faulting of Najd printed two main trends of weakness within the body of the continental basement. These are: N – S and NW – SE trending lines of weakness (Fouad, 2007). These lines of weakness controlled the location and the style of some of the later Phanerozoic deformations. Buday and Jassim (1987) showed that the Southern Desert is characterized by a relatively thick Mesozoic – Tertiary cover and the thickness of Infracambrian – Paleozoic sequence is strongly reduced.

According to the available data, the structural framework of the Southern Desert could be recognized as follow:

- **The Mesozoic Evolution (245 – 65 Ma)**

The Mesozoic witnessed the birth and development of the Atlantic-type Arabian passive margin that bordered the western shore of the Neo-Tethys Ocean. An extraordinarily wide, shallow marine epeiric shelf developed on this ENE-dipping platform (Beydon, 1991).

The contact between Triassic and Jurassic (Rhaetic and Middle Liassic) is represented by erosion gap in the Southern Desert. At Samawa borehole, equivalent of Butmah Formation contains thin section of clastics. Al-Bassam *et al*. (2004) showed that the Early Kimmerian movements resulted in the uplift of the area and evidenced by the absence of the Early Triassic sediments.

The first tectonic event of the Jurassic was the closure of the Paleo – Tethys Ocean by the collision of central Iran with the mass of Laurasia. At that time, the Neo-Tethys ocean reach its maximum width, which was (2000 – 4000) Km (Dercourt *et al*., 1986). This event was too far to be felt on the platform. Nevertheless, on the Southern Desert region of the Stable Platform, it was also evident that up warping along Safawi Arch became clearly active. Roychoudhury and Nahar (1980) showed that the sections of the Late Jurassic sequence (Najmah and Gotnia formations) has been noted to be developed in three facies**: plat forma**l, consisting of thick detrital carbonate and thin anhydrite; **basinal**, consisting of thin detrital carbonate and thick anhydrite and **transitional**, consisting detrital carbonate interbedded with anhydrite). The Late Jurassic sequence in Safawi area represents platform facies, whereas in Abu Khema area indicates transitional facies. Thus, the plat formal facies covers the surface of the highest area of the pre – Mesozoic basement structure, which may refer to the activity of Safawi Arch. Hassan (1984) believed that the Jurassic Sea was shallow at all times in the Western Iraq. In Abu Khema borehole, the record of the penetrated sequence, from Late Jurassic to Early Cretaceous, reflects no interruption (Roychoudhury and Nahar, 1980).

During the Cretaceous Period (145 – 60 Ma) three obvious phases of evolution appeared. The **first phase** one was through out the Early Cretaceous to Turonian – Coniacian, where the marginal part of the Arabian Plate was continuously consumed by subduction beneath Iranian Plate. The subduction event was not induced the Arabian Platform. Thus, during that period, the depositional environment of shallow carbonate shelf with clastic influxes was over the region, which followed the pattern established during the Jurassic. Therefore,

sedimentational facies reflect global sea level fluctuation with minor upwarpping along Safawi Arch. The Arabian Shield, in the south, was a source area for the clastics in the Early Cretaceous (Buday, 1980). Huge clastic sediments were transported at that time from the Arabian Shield, as evidenced by Zubair Formation. Two transgressive cycles of the Shu'aiba and Nahr Umr – Mauddud formations are well defined in the Abu Khema area. Therefore, sedimentation pattern and facies reflect global sea level fluctuation and minor upwarpping along Safawi Arch.

The **second phase** of the Cretaceous evolution was remarkable and sharp. During the Campanian – Maastrichtian, the Arabian Plate underwent stretching (Fouad, 2004 and 2007). The stretching was enough to generate systems of intracontinental rift basins in the northern Arabia Platform (Fouad, 1997 and 2007). The extensional phase produced numerous E – W and NW – SE trending faults, which were developed along pre-existing lines of weakness that are related to the Neo-Tethys rifting and development. In the Southern Desert, the Sa'di – Hartha break, which is associated with Campanian – Maastrichtian, is short erosional cutout period due to uplifting in Abu Khema Area.

Abu Jir Fault Zone formed during this extensional period (Fouad, 2007). This time span was associated with a major global sea level rise. The marine transgression was extensive, covering almost the entire Southern Desert, including Safawi Arch.

The **third phase** of the Cretaceous evolution occurred in the latest Maastrichtian, when the Arabian passive margin was under compression for the first time, as a consequence of the first phase of the Alpine Orogeny. The compressive phase is related to the ophiolites obduction and emplacement along the Arabian Plate margin (Kazmin *et al*., 1986 and Fouad, 1997). Away from the compressed and destroyed margin, however, within the interior of the Arabian Plate, the compression caused the emergence the entire Stable Shelf of the platform, except the down warping area of Abu Khema (due to uplifting of Safawi Arch), which was covered by shallow water, as indicated by the conformable contact between Tayarat and Umm Er Radhuma formations.

- **The Cenozoic Evolution (65 Ma – Present)**

The Cenozoic Era started with a large scale transgression covering the entire platform. The Paleocene – Eocene (65 – 35 Ma) was largely a time of quiescence in the northern Arabian Platform and deposition of significant open marine sediments. Safawi Arch was submerged. The anhydrite facies (Rus Formation), which is defined in very restricted area in Iraq, is developed in local basin, fringing the Stable Shelf (along the boundary from Kifl area in the northeast until the Iraqi – Kuwait border, in the southeast). The stratigraphic position of the anhydrite facies is somehow obscures (Buday, 1980). The Eocene Sea was the last sea that covered the Southern Desert.

Middle Eocene was the time for early collision of the Arabian Plate with Bitlis fragments of the Turkish Plate (Yalmaz, 1993 in Fouad, 2007). This event was too remote to leave any effect on the interior of the Arabian Plate. Safawi Arch was submerged by marine sediments.

The Oligocene (35 – 35 Ma) started with sharp global sea level fall exposing the Southern Desert to erosion, including Safawi Arch and its eastern slope .

The Early Miocene (25 – 17 Ma) witnessed the final marine transgression on the northern and southern parts of the Southern Desert. Different Early Miocene sedimentary facies were deposited on both sides of Ansab – Sdair lineament. The Ghar Formation marked the formation of a new basin in the Southern Iraq named Dibdibba Basin (Powers *et al.*, 1966). As well; the same basin was occupied by Middle Miocene marine facies. Buday (1980) pointed that the Early – Middle Miocene cycle, in the southern area of Iraq, is more basinal (started with sandy – littoral facies and ended by a marine episode). It is clear that the cycle is

marked by structural down warping along the Ansab – Sdair and Busaiya – Amghar fractures (eastern slope of Safawi Arch).

The Late Miocene (~11 Ma) was the time of the final transition to continental condition, which is marked as a time of compression increasing, as collision along the northern and eastern boundaries of the Arabian Plate with Iran/ Anatolia portions of Eurasia proceeded, then culminated through the Pliocene (5.3 Ma). The compression, in late Tertiary, imposed lateral movement along the NW – SE trending faults, such as the Abu Jir and Euphrates Fault Zones. Moreover, the collision caused uplifting of the Stable Shelf area, including Safawi Arch and Dibdibba Basin, which is indicated by the lack of the Late Miocene terrestrial sediments (Injana Formation) in the Southern Desert. The influx of ancient rivers from the rising Zagros Mountains has been rapidly arrested along the limits of the Euphrates Fault Zone, which might be associated with initial upheaval of the Stable Shelf. Sallomy and Al-Khatib (1981) displayed that the uplifting of Salman region (Safawi Arch) is related to the basement uplift. Moreover, Sissakian and Deikran (1998) showed that the Southern Desert was uplifted since the Late Miocene with amount of (50 – 350) m; and exhibits clear bulging with the same trend of aforementioned lineaments (Ansab – Sdair, Amghar – Busaiya and Al-Batin) (Fig.8). They also deduced that the rate of regional uplift is about (0.1 – 0.2) cm/ 100 year, in the area involved.

The Pliocene – Pleistocene (5.3 – 1.8 Ma) was the time of strong influx of terrigenous debris, from the Arabian Shield, due to the climatic changes. The sediments filled the aforementioned structural down warped area (Abu Khema Area), which was later on named as Dibdibba Basin, by Powers *et al.* (1962).

Al-Batin fracture system imposed borders of the Miocene – Pleistocene rock units inside Dibdibba Basin (along eastern slope of Safawi Arch).

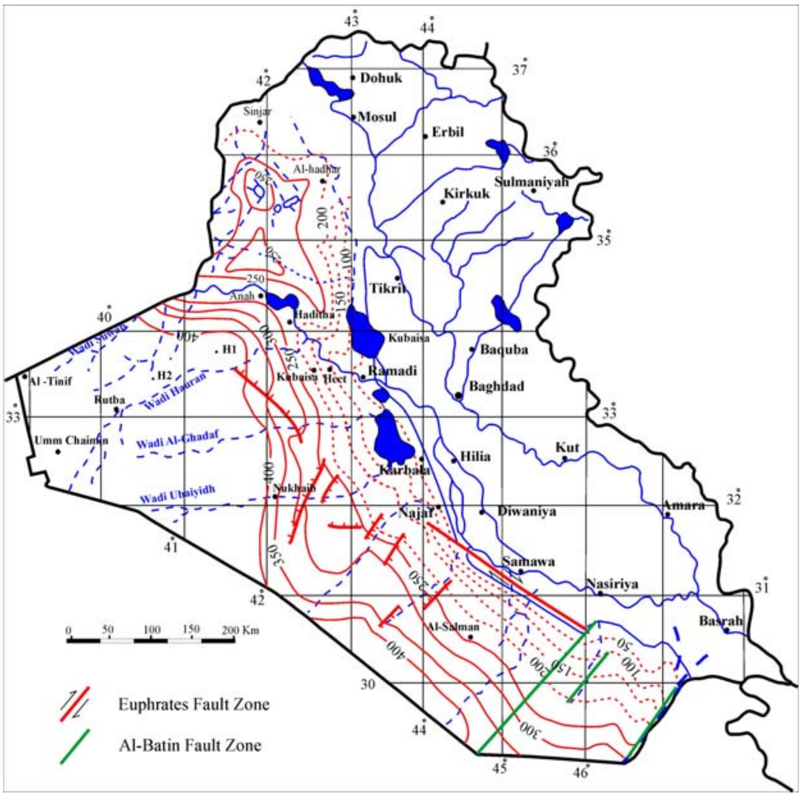

Fig.8: Neotectonic Map of the Western Iraq Exhibit trends of lineaments (fracture traces) in the Southern Desert (modified from Sissakian and Deikran, 2009)

CONCLUSIONS

- The Iraqi Southern Desert is a part of the Northern Arabian Platform, where relatively thin Phanerozoic sediments cover the Pre-Cambrian continental basement complex. The area lacks expressive Alpine related compressional structures.
- The basement itself contains two printed fracture traces of NE – SW and NW – SE trends, which grossly controlled the location and style of some later Phanerozoic deformation.
- The Arabian Platform, within the Iraqi Southern Desert, has been divided into two parts, a stable one to the west and an unstable one to the east along Euphrates Fault Zone, based on more reliable geological criteria.
- The Triassic and Jurassic Periods (245 – 145 Ma) reflected fluctuating sea level and a periodic movement of Safawi Arch.
- Al-Batin fracture system (NE – SW fracture traces) dated from (at least) the Triassic – Jurassic and continued intermittently up to Pliocene – Pleistocene.
- The Cretaceous Period (145 – 65 Ma) exhibits three distinct evolutionary episodes. The first one, which persisted through the Early Cretaceous to Turonian – Coniacian (145 – 84 Ma), was the continuation of the sedimentation pattern, established during the Jurassic. The second one reflected two transgressive cycles in the Abu Khema Area (Dibdibba Basin), which reflects global sea level fluctuations and minor upwarpping along Safawi Arch. The third evolutionary episode established during the latest Maastrichtian, when a regional emergence of the entire stable platform occurred, excluding Dibdibba Basin and development of an extensive regional unconformity.
- The Cenozoic Era started with an extensive sea transgression that covered the entire platform. The Paleocene – Eocene (65 – 35 Ma) was a time of quiescence and deposition of significant open marine carbonates. Gradual retreatment of the sea took place by the end of the Eocene. The regression continued through the Oligocene to Early Miocene, with some limited transgression until the final transition to continental condition by Late Miocene (~11 Ma). Safawi Arch was active in Late Oligocene and Miocene Periods formed the Dibdibba Basin, due to down warping, and terminated by limited right lateral strike-slip movement on Euphrates Fault Zone, during Pliocene – Pleistocene.

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REFERENCES

Al-Amiri, H., 1979. Structural Interpretation of the Landsat Satellite Imagery for the Southern Desert of Iraq. GEOSURV, int. rep. no. 988.

Al-Ani, M.Q. and Ma'ala, K.A., 1983a. The Regional Geological Mapping of South Samawa Area. GEOSURV, int. rep. no. 1348.

Al-Ani, M.Q. and Ma'ala, K.A., 1983b. The Regional Geological Mapping of North Busaiya Area. GEOSURV, int. rep. no. 1349.

Al-Bassam, K.S., Al-Azzawi, A.M., Dawood, R.M. and Al-Bedawi, J.A., 2004. Subsurface study of the pre – Cretaceous regional unconformity in the Western Desert of Iraq. Iraqi Geol. Jour., Vol. 32/ 33, p. 1 – 25.

Al-Ethawi, A.M., 2002. Tectonic Boundary Evolution of the Southern Part of Al-Salman Zone by Analysis of Geophysical data. Unpub. Ph.D. Thesis, College of Science, University of Baghdad.

Al-Hadithi, T.M.S. and Al-Mehaidi, H.M., 1982. Photogeological – Hydrogeological Survey of the Southern Desert (Blocks 1, 2 and 3). GEOSURV, int. rep. no. 1251.

Al-Hashimi, H.A.J. 1973. The Sedimentary Facies and Depositional Environments of Eocene Dammam and Rus Formations. Jour. Geol. Soci. Iraq, Vol. VI (Al-Naqib Volume), p. 1 – 18.

Al-Kadhimi, J.A.M., Sissakian, V.K., Fattah, A.S. and Deikran, D.B., 1996. Tectonic Map of Iraq, scale 1: 1000 000, 2nd edit., GEOSURV, Baghdad, Iraq.

Al-Mubrak, M.M. and Amin, R.M., 1983b. Report on the Regional Geological Mapping of the Western Desert and the Western Part of the Southern Desert. GEOSURV, int. rep. no. 1380.

Al-Naqib, K.M., 1967. Geology of the Arabian Peninsula, Southwestern Iraq. United States Government Printing Office, Washington.

Al-Shamma'a, A.M., 2000. The Source of Water Springs along the Fault Zone of Southern Euphrates River. Iraqi Geol. Jour., Vol. 32 – 33 (1999 – 2000), p. 29 – 145.

Al-Sharbatti, F. and Ma'ala, K.A. 1983b. The Regional Geological Mapping of South West of Busaiya Area. GEOSURV, int. rep. no. 1346.

Al-Sharbatti, F. and Ma'ala, K.A. 1983a. The Regional Geological Mapping of South of Busaiya Area. GEOSURV, int. rep. no. 1347.

Barazanji, M.A. and Al-Yasi, A., 1987. Geophysical study of Habbania – Razzaza Area. Jour. Water Resour., Vol. 6, No. 2.

Beydoun, Z.R, 1991. Arabian Plate Hydrocarbon Geology and Potential. A Plate Tectonic Approach. The American Assoc. of Petrol. Geol, Tulsa, Oklahoma, USA, 77pp.

Buday, T., 1973. The Regional Geology of Iraq. GEOSURV, manuscript report.

Buday, T., 1980. The Regional Geology of Iraq, Vol. 1, Stratigraphy and Paleogeography. Kassab, I.I. and Jassim, S.Z. (Eds.). GEOSURV, Baghdad, 445pp.

Buday, T. and Jassim, S.Z., 1987. The Regional Geology of Iraq, Vol. 2, Tectonism, Magmatism and Metamorphis. Abbas, M.J. and Kassab, I.I. (Eds). GEOSURV, Baghdad, 352pp.

Compani General De Geophysique (CGG), 1974. Aeromagnetometric and Aerospectometric Survey of Iraq, Massy, France, GEOSURV, int. rep. no. 2642.

Deikran, D.B., 1994a. Geological Report on Ar-Rukhaimiya and Kuwait Quadrangles, sheets NH-38-11and NH-38-12, scale 1: 250 000. GEOSURV, Baghdad, Iraq.

Deikran. D.B., 1994b. The Geology of Ansab Quadrangle, sheet NH-38-10, scale 1: 250 000. GEOSURV, Baghdad, Iraq.

Deikran, D.B., 1995. The Geology of Suq Al-Shyukh Quadrangle, sheet NH-38-7, scale 1: 250 000. GEOSURV, Baghdad, Iraq.

Ditamr, V. and others, 1971 – 1972. Geological conditions and Hydrocarbon Prospects of the Republic of Iraq (Northern and Central parts). Tecno-Export, INOC Lib. Baghdad.

Fouad, S.F.A., 1997. Tectonic and structural evolution of Anah Region, West Iraq. Unpub. Ph.D. Thesis, University of Baghdad.

Fouad, S.F.A., 2004. Contribution to the Structure of Abu Jir Fault Zone, West Iraq. Iraqi Geol. Jour., Vol. 32 – 33 (1999 – 2000), p. 63 – 73.

Fouad, S.F.A., 2007. Tectonic and Structural Evolution of the Iraqi Western Desert. Iraqi Bull. Geol. Min., Special Issue: Geology of Iraqi Western Desert. p. 29 – 50.

Hassan, K. M., Yacoub, S. Y. and Amir, E. A., 1995. The Geology of Al-Salman Quadrangle, sheet NH-38-6, scale 1: 250 000. GEOSURV, Baghdad, Iraq.

Hassan, K.M., 1984. Jurassic Moluska from Western Iraq. Unpub. M.Sc. Thesis, Hall University, 210pp.

Henson, F.B.S., 1951. Observations on geology and petroleum occurrences of the Middle East. Proc. 3rd World Pet. Cong. The Hague, I, p. 113 – 140.

Huntington, J.F., 1969. Method and Application of Fracture Trace Analysis in Quantification of Structural Geology. Geol. Mag., Vol. 106. No. 5.

Jassim, S.Z. and Goff, J. C., 2006. Geology of Iraq. Dolin, Prague, 341pp.

Kazmin, V., Rico, L.E., and Sbortshikov, I.M., 1986. Structure and Evolution of the passive margin of the eastern Tethys.

Ma'ala, K.A., 2008. Geomorphology of the Iraqi Southern Desert. Iraq Bull. Geol. and Mine. Special Issue, Geology of the Iraqi Southern Desert. p. 7 – 33.

Powers, R.W., Ramirez, L.F., Bedmond, C.D. and Alberge, E.L., 1966. Sedimentary geology of Saudi Arabia, in: Geology of Arabian Peninsula. U.S.G.S. Profess, paper 560 – D, p. 1 – 141.

Roychoudhury, S.C. and Handoo, A.K. 1980. Stratigraphy and Geology of Oil Bearing Horizons in the Area around Iraq-Kuwait-Neutral Zone (between Iraq and Saudi Arabia). Trijunction oil and natural Gas Commission, India. Jour. Geol. Soci. of Iraq, Special Issue, 5th Iraqi Geological Conference, p.187 – 266.

Roychoudhury, S.C. and Nahar, K.S., 1980. Jurassic oil prospects in south and west Iraq. Jour. Geol. Soc. of Iraq, Special Issue, 5th Iraqi Geological Conference, p.199 – 204.

Sallomy, J.T. and Al-Khatib, H. H., 1981. Basement Tectonics in Al-Salman Area, Southwestern Desert, Iraq. Proceedings of the 6th Iraqi Geol. Cong.

Sissakian, V.K., Youkhana, R.Y., and Zainal E.M., 1994. The Geology of Al-Birreet Quadrangle, sheet NH-38-1, scale 1: 250 000. GEOSURV, Baghdad, Iraq.

Sissakian, V.K. and Deikran, D.B., 1998. Neotectonic Map of Iraq, scale 1: 1000 000. GEOSURV, Baghdad, Iraq.
Sissakian, V.K., 2000. Geological Map of Iraq, scale 1: 1000 000, 3rd edit., GEOSURV, Baghdad, Iraq.
Sissakian, V.K. and Deikran, D.B., 2009. Neotectonic movements in West of Iraq. Iraq Bull. Geol. and Mine, Vol.5, No.2, (In press).
Tamar-Agha, M.Y., 1983. Hydrogeological and Hydrochemical Exploration in Blocks 1, 2 and 3. Final report on geology of the Southern Desert. GEOSURV, int. rep. no. 1424.