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Shedding Further Light on Upper Cretaceous – Neogene Subsurface Lithostratigraphy of Southwestern Iraq

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Abstract

Exploratory activities carried out by oil companies in the latter half of the past century proved the existence of voluminous reserve of oil and gas in the southwestern area of Iraq. In view of this, it seemed more than prudent to add a new knowledge to that currently existing about the subsurface lithostratigraphy of this area. As a first step in fulfilling this mission, this paper will attempt to do so by covering the time interval from the Upper Cretaceous to the Neogene. In turn, this effort had entailed both the description of about 4707 metres of fully recovered cores, plus the subjection of more than 4000 samples to existing petrologic analyses. Findings worth mentioning does include the observation that with the exception of the Paleogene sequence, the Upper Cretaceous and Neogene sequences are no different from those found in other parts of southern Iraq. For instance, the Upper Cretaceous sequence is found to be consisted of the common Hartha, Qurna, and Tayarat Formations. The same could be said about the Neogene sequence which is found to be again made of the common Ghar, Euphrates, Fatha, and Zahra Formations. In contrast, the Paleocene – Lower Eocene sequence lithology is found a bit different from those commonly encountered in other parts of southern Iraq. This difference emanates from the intense sulphidzation as manifested in the common occurrence of anhydrite, gypsum, and vanished evaporite being observed through the lower Paleogene sediments of south west, Iraq. Because this phenomena exhibits strong vertical as well as lateral variation, this sequence is divided into an intensely evaporitic portion, which is introduced in this article under the name of the Jerishan Group (Paleocene - Lower Eocene), inclusive of Umm Er Radhuma, Rus, Jil/Rus, and Jil Formations. The latter formation is recently introduced stratigraphic rock unit representing the non-evaporitic equivalent for the Rus Formation. The less evaporitic portion (the Dammam Formation) of the Paleogene was found to be the same as the ones found in other parts of the south Iraq, Kuwait and Saudi Arabia.

Keywords: Stratigraphy, Southern Iraq, Upper Cretaceous, Paleogene, Neogene.

القاء المزيد من الضوء على طباقية و صخارية تحت السطح للكريتاسي الأعلى–النيوجين في جنوب غرب العراق

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الخلاصة

بينت التحريات و الأستكشافات النفطية التي قامت بها الشركات النفطية في النصف الثاني من القرن الماضي وجود كميات كبيرة من احتياطيات النفط و الغاز في جنوب غرب العراق مما يبرر الأستزادة من

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البحث و الأستقصاء عن الطباقية الصخارية تحت السطحية في منطقة الدراسة، و كانت الخطوة الأولى في هذا البحث هو دراسة تعاقب الكريتاسي الأعلى الى النيوجين و شملت دراسة ما يقارب ٤٧٠٧ مترا من اللباب و حوالي ٤٠٠٠ شريحة للأغراض البتروغرافية. بينت الدراسة تشابه تعاقب الصخور الكريتاسية و النيوجين مع بقية المنطقة من جنوب العراق و اختلافها لتعاقب عصر النيوجين. يشمل تعاقب الكريتاسي الأعلى تكوينات الهارثة و القرنة و الطيارات و يشمل النيوجين تكوينات الغار و الفرات و الفتحة و الزهرة.
وعلى النقيض من ذلك تبين ان صخارية تعاقب الباليوسين – الأيوسين الأسفل تختلف عن بقية المناطق في جنوب العراق اذ تميزت صخور الباليوجين الآسفل بشيوع المتبخرات متمثلة بالأنهايدريت و الجبسوم و المتبخرات المختفية مما شجع على جمعها ضمن مجموعة طباقية جديدة و اطلاق تسمية مجموعة جريشان باليوسين – أيوسين أسفل) عليها، و نتيجة لأختلاف الصخارية أفقيا و عموديا ضمن هذه المجموعة تم تقسيمها الى وحدات اصغر، و تضم المجموعة تكوينات ام الرضومة و الرص و الجل/الرص و الجل. و مما يذكر أن تكوين الجل هو المكافيء لتكوين الرص الخالي من المتبخرات. اما تكوين الدمام الذي يمثل الجزء شبه الخالي من المتبخرات يشابه من الناحية الصخارية بقية امتداداته في جنوب العراق و الكويت و المملكة العربية السعودية.

Introduction

According to the many references Iraq's proven reserve amounts to 113 billion barrels of oil, and 100 trillion cubic feet of gas [1-4]. On the global scale, these numbers places Iraq's proven hydrocarbon reserve second only to Saudi Arabia. Now, much of Iraq's production pumped out of oilfields is located in this country southern sector. Because these oilfields had reached their production capacity, Iraqi Oil Ministry had turned its attention to the less well developed Iraq's southwestern area.

Though oil companies had drilled in this area during the latter half of the past century, these efforts were neither geographically wide not deep enough. Currently the Iraqi Oil Ministry spearheaded efforts to lure oil companies to initiate new exploratory endeavors in Iraq's southwestern corner. As a predisposed step to these efforts, this paper attempt to present an amalgamated point of view about the subsurface lithostratigraphy of Southwestern Iraq Figure- 1. As a first step in this direction, emphasis will be placed on rock units deposited during the time interval from the Upper Cretaceous to the Neogene. Issues to touch on will include the following: to divide the rock sequence into appropriate lithostratigraphic units, and if necessity requires it, these units are to be divided in their turn into smaller units such as formations, member, and beds; characterize the lithology of each unit; and establish these units spatial geometry, and document their relationship with their underlying, overlying, and time equivalent rock units.

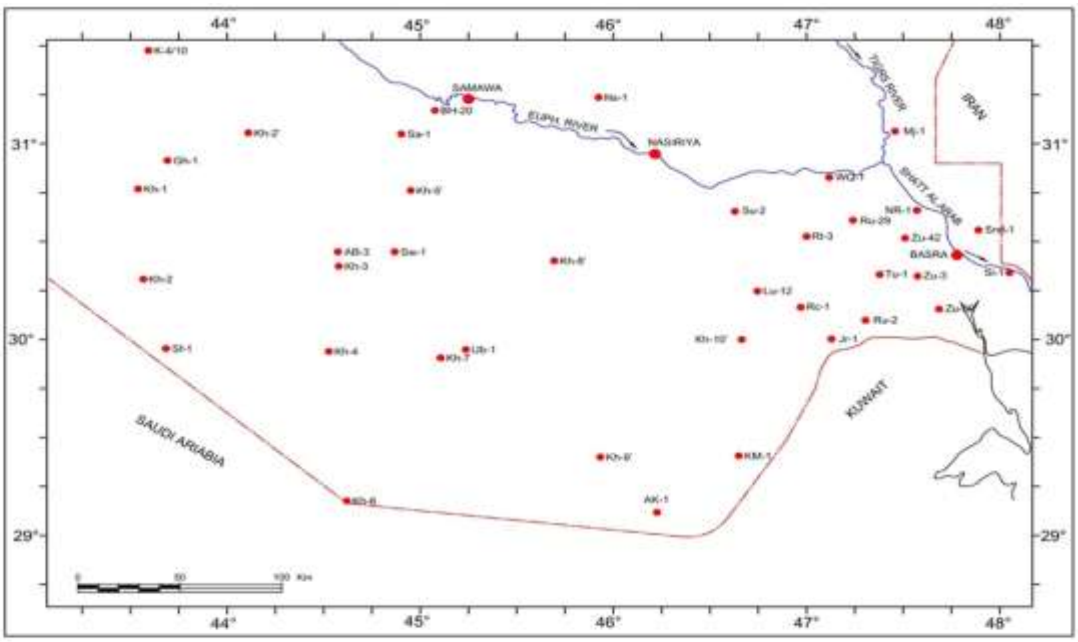


Figure ۱ - A blow up for the study area giving the locations of the wells mentioned in the text.

Previous Work

Macfadyen worked in southern Iraq in 1938 looking for groundwater resources and is the first to describe the Dibdibba Formation [5]. Subsequently, Williamson in 1941 described the Zahra Formation and Ramsden in 1945 divided the Dammam Formation into ten informal and mapable units to facilitate geological mapping [6]. The latter added to the original Dammam Formation (Middle – Upper Eocene) another five units of Lower Eocene age. The newly added part is separated from the overlying (proper Dammam Formation) an unconformity.

Husdon in 1951, in an unpublished report, made much contribution, perhaps the most outstanding is his paleontological study of the Dammam Formation [6]. He also emphasized the occurrence of *Ostera* in the Shawiya Beds. Ramsden and Andre in1953 reduced the Dammam informal units in to four only by combining some units together [7]. Mithchell in1956 summarized the geology of the Iraqi desert and made many valuable comments on many of the observed rock units [8]. At the same time, deep drilling in search of the area hydrocarbon fortunes commenced. These wells reports contain valuable information on the stratigraphy of the drilled area.

The benchmark works produced in those decades appeared in the late fifties of the past century [9]. They laid down for the first time a regional stratigraphic framework for southern Iraq. Subsequently, Bellen in 1959 summarized the knowledge available then about Iraq's stratigraphy including its southern region and presented a schematic diagram on his own views of the stratigraphic setting Figure- 3 [6]. Other salient works must be mentioned here in this regard the works of Al-Naqib in 1967 [10] and Al-Hashimi in1972, 1973, and 1980 [11-13]. Al-Naqib reviewed the previous works, and compiled a geological map for the studied area [10]. Al-Hashimi concentrated on biostratigraphy and depositional environment of the area most widely exposed rock unit [11-13]. Since then, many contributions are made covering the various aspects of geology of the studied area. Among them is that of Al-Siddiki in1978 as he constructed isopach maps for the various formations encountered in southern Iraq from the Yamama to the Fatha (previously named Lower Fars) Formation [14]. Subsequent to this work, the amount of works on the area increased during the mid-seventies to the early eighties of the last Century by the Iraq Geological Survey and in this regard a reference must be made about the works of Tamar-Agha in 1983 [15], Al-Mubarak and Amin in 1983 [16], Al-Ani and Ma'ala in 1983 [17 and 18] and Al-Sharbatti and Ma,ala in 1983 [19 and 20] as they produced maps accompanied with unpublished reports.

It might be unfair to close here without saying a couple of words about the milestone paper of Tamar-Agha and co-workers in 1997[21]. They solved a decade longstanding issue related to the stratigraphic status of the lower part of the Dammam Formation exposed in south and south western Iraq (the study area), which was previously contested by Bellen [6, pp. 244 redrawn here in Figure-۲]. In the ensuing years since then surface and subsurface geological investigation compiled with Bellen's proposal led to the separation of the lower part of the Dammam Formation, and its establishment as a new rock unit, and is given tentatively the name of Jil Formation.

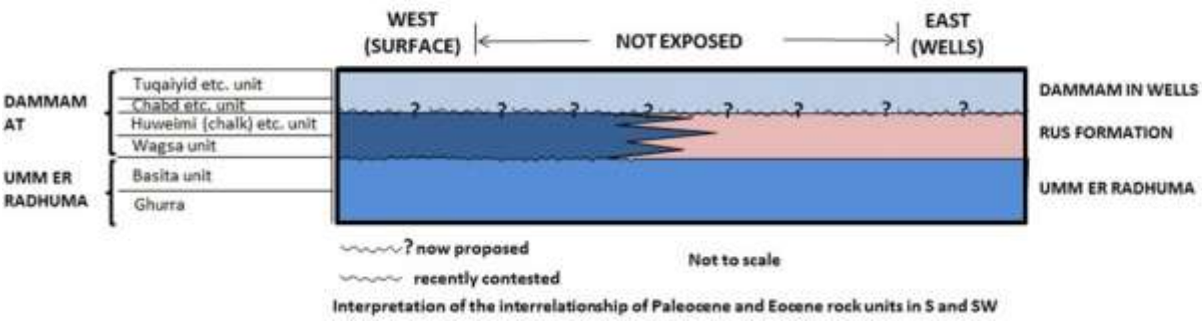
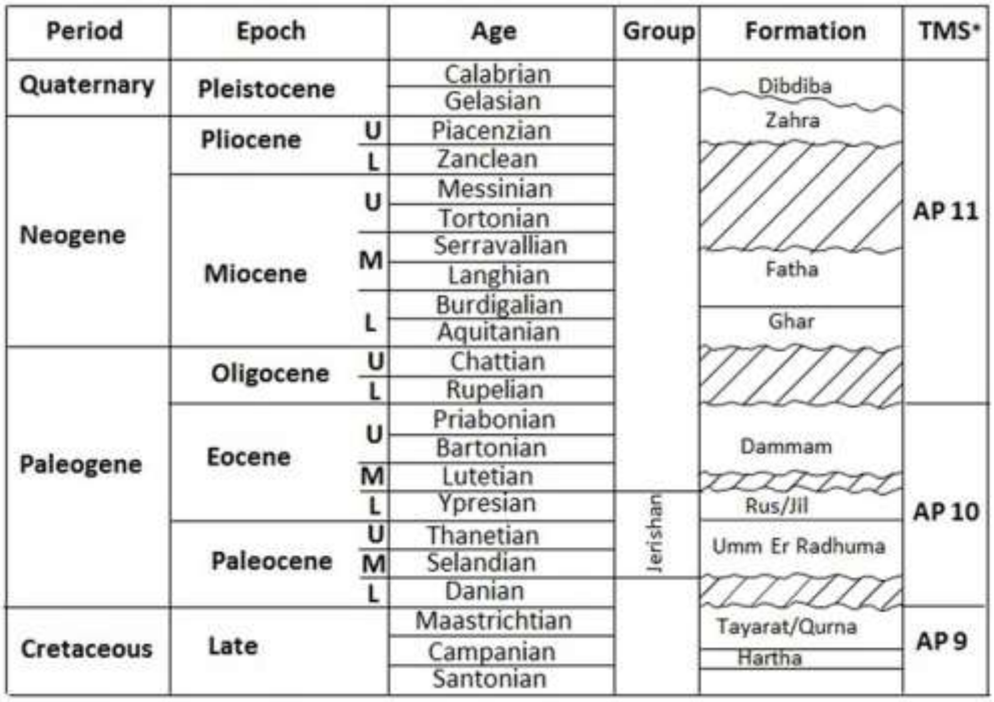


Figure ۲ - Bellen's proposal for the Paleocene-Eocene stratigraphy in the southern desert of Iraq (redrawn from Bellen et al., 1959).

Geographic and Geologic Setting

The surface area of the study area comes to be about 60,000 square kilometres. The study area is bounded to the north by latitude 31° 30´ Figure- 1. The Mesopotamian fluvial plain is its eastern boundary. Iraqi-Saudi boundary is the western outlier whereas Iraqi-Saudi and Iraqi-Kuwaiti borders is the southern off-limits. Stratigraphy of the Upper Cretaceous - Tertiary sequence in the studied area is summarized in Figure-3. The study area is formed of a very gently lying sedimentary strata composed mostly of carbonates, mudrock and sandstone sequences, with a prevalent evaporitic influence. These sequences constitute a cover over part of the Stable Shelf of the Arabian Shield, which laps over into the Tethys southern margin to the north and east [15-20].



*TMS - Tectonostratigraphic megasequence

Figure 3- Stratigraphy of the southern desert of Iraq.

The general direction of the Tethys seaway in Iraq is generally northeast-southwest, which reverse its direction in part of north Iraq along the Taurides into east-west direction. In the rest of the country, the Tethys runs in a northwest-southeast direction in accordance with the Zagros trend. The extension of this trend passes through the eastern margin of the study area [21].

The strata of the study possess very gentle gradient (a fraction of the degree) towards the Mesopotamian Alluvial plain. The regional strikes of these strata run in a northwest-southeast direction being sub-parallel to the Euphrates River. In the south of the area, it swings southwards to become in a north-south direction i.e. sub-parallel to Shaat Al-Arab waterway [16-20].

It must be mentioned that the area of concern with its adjacent territories has suffered remarkably little deformation. The structural history in general is almost restricted to gentle dipping and some minor and gentle undulation. Faults are not infrequent, some trends northeast-southwest, others trends northwest-southeast and towards the south trend in a north-south direction. In general the faults and other lineaments have some genetic relationships with the deep configuration of the basement beneath the sedimentary cover [15-20].

Some folding is also noticeable in the southern area. Their origin in some cases could be attributed to the tectonic activities whereas most of them are thought to be of secondary structural origin. They owe their origin to the solution collapse initiated by tectonic movements such as faulting and major fractures as well. The lineaments are tracts for the activity of percolating solutions. The rocks were then bent by flexuring and by subsequent differential settlement and adjustment [15].

Materials and Methods

Eleven keyholes and two subsidiary boreholes are drilled by Iraq Geological Survey for the Desert Development Consortium during the early eighties as well as those drilled by other authorities such as oil companies Figure- 1. With the exceptions of the latter ones, the total depth for the other well varied between 120 to 600 metres deep. A total 4707 metres of recovered cores are retrieved. They are described and sampled (about 4000 samples) for petrographic and paleontological studies. The current study focuses on the lithostratigraphy of the Upper Cretaceous – Neogene sequence. Petrology, paleontology and geochemistry of the collected samples are studied by the staff of the Iraq Geological Survey and reported in unpublished reports which are deposited in their library. These studies are summarized in unpublished report by the senior author of this paper [15]. This paper represents the lithostratigraphy part only.

Results and Discussion

The results of this study are graphically portrayed in Appendices I and II and supporting figures. Inhereafter an attempt will be made to give a concise summary for the general lithostratigraphic characters for each formation encountered. In addition, formation relationships with the underlying and overlying formations are to be alluded too. Nonetheless, some alterations are suggested in this paper, especially regarding the Paleogene Sequence. The suggested new units are restricted to the study area. These units are thought to be drawn here while they are in their utmost conditions and presented in Appendices I and II.

Upper Cretaceous Sequence

The studied succession of the Upper Cretaceous is equivalent to the upper part of Sharland et al.'s in 2001 Tectonostratigraphic megasequence AP 9 (TMS AP9) [22]. The stratigraphy of the upper Campainan-Maastrichition cycle in Iraq is still confusing [22]. Numerous divisions are presented by Bellen in 1959 [6] and an oversimplified version is subsequently presented by Chatton and Hart in 1961 [24]. Buday gave an account for these divisions and suggested another scheme [23]. Unraveling and deciphering the stratigraphy of this cycle is beyond the scope of this work because only one borehole has penetrated the Upper Cretaceous sequence. Since the major work in the area is carried out by the geologists of the oil companies, their scheme of stratigraphic subdivision is adopted here. Correlation diagrams are given in Figure-5.

<u>Hartha Formation (Maastrichtian-Upper Campanian)</u> - It is the oldest unit encountered in the present work and is reached in one borehole only (Kh-6 in the Ansab area). The formation is first described by Rabaint, 1952 [6] and later Owen and Nasr in 1958 selected an interval in the B.P.C well Zu-3 as its type section [9]. In this section, the Hartha Formation is made out of about 128 metres of organic detrital glauconitic limestone with grey marls and green shale. The limestone is strongly dolomitized in places.

Hartha Formation overlies Sa'adi Formation in the type locality conformably and underlies the Qurna Formation disconformably Figure- 4 [9]. Al-Siddiki in1978 stated that "it is overlain by the Shiransih Formation as evidenced by the sudden change from shallow water, lagoonal facies (Hartha) to basinal facies (Qurna)" [14]. The Hartha Formation changes towards the west into dolomite and anhydrite [14]. The evaporite nodules and beds are noticed at the top of the sequence in Kh-6 Figure-5 and Sf-1. Further details are not given here because of the limited depth penetration of this lithostrigraphic unit.

The thickness of the penetrated part is about 16.4 metres. It is distinguished by alternation of evaporatic layers with creamy organodetrital dolostones and grey dolomitic marl. Claystones are presented at many intervals (drilling depths 580.0, 582.0, and 589.0 metres). Bioturbations and algal laminations are noticed in the dolostones. Tiny gastropods are not uncommon. The porosity is low and increases downwards. Pores are in the form of biomolds and vugs. Figure-7 is an adaptation from Al-Siddiki in 1978, which is an isopach map for the Hartha Formation [14].

<u>Tayarat/Qurna Formation (Maastrichtian)</u> – The Tayarat Formation is introduced by Henson in 1940 in an unpublished report for about 30 metres rubbley, porous, white, buff and pink, rather chalky, fossiliferous, recyrstallized, locally sandy limestone about 37 km south of Rutbah town [6]. The Qurna Formation is introduced by Rabanit in 1952 in an unpublished report [6]. Later Owen and Nasr selected an interval in the B.P.C well Zu-3 as its type section [9]. In this section the Qurna Formation is about 112 metres of "buff or ash grey globigerinal marl, sometimes dolomitic, and occasional marly limestone beds with rich microfauna". Similar globigerinal marls of the same age make up part of the much thicker Shiranish Formation.

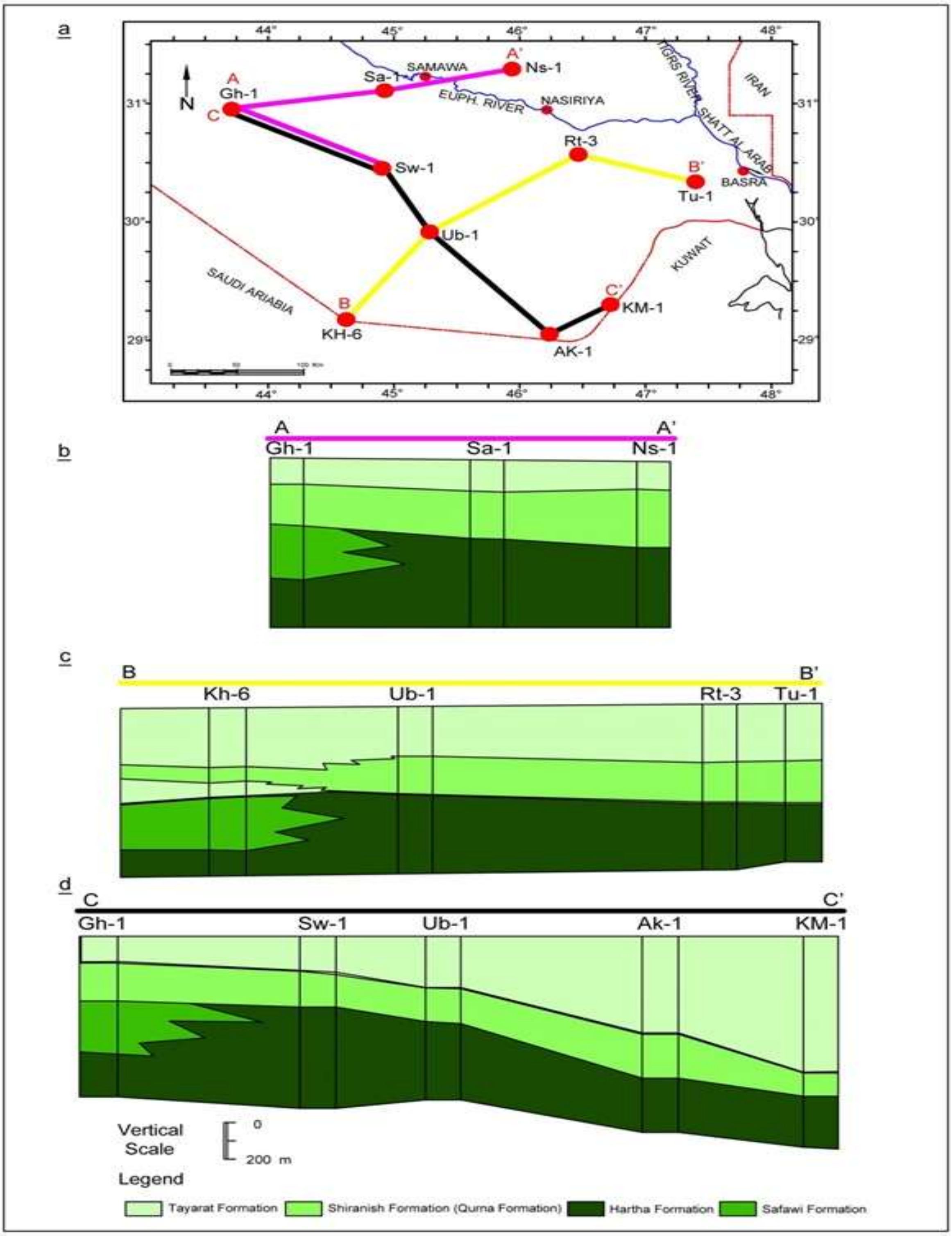


Figure 4 - a) Map showing the cross section lines along which Upper Cretaceous formations are correlated. b) Correlation along section line A-A′. c) Correlation along section line B-B'. d) Correlation along section line C-C′.

Figure 5-Nodular gypsum in the Hartha Formation from KH-6 at Ansab (drilling depth 584.0 metres), showing chicken-wire texture. Gypsum nodules are circumscribed by thin filaments of carbonate/clay rim which represent the original sediments.

The Tayarat/Qurna Formation in the studied area is found in subsurface sections only. This unit was reached in five keyholes namely, Kh-3, at Al-Salman depression, Kh-4 at Takhadid, Kh-5 at Salhobiya village, Kh-7 at Abu Radham, and Kh-6 at Ansab. In the Kh-5 at Salhobiya the penetration took place using rock-bit (cuttings). Only at Kh-6 the whole sequence is penetrated Figure-4.

In KH-6, the Tayarat deposits comprise a lens of Qurna. In the other boreholes, only the uppermost few metres are penetrated. Considering the recent results and the previous works of the oil companies, it is concluded that the Tayarat Formation interfingers with the Qurna Formation especially in the western part of the study area. Figure-6 is isopach maps for the Tayarat/Qurna Formations, which had been modified, after its adaptation from Al-Siddiki in 1978 [14].

In the studied area, however, its lithology is not fully established because the drilling has yielded insufficient information. Most of the documentation comes from Kh-6 at Ansab area. The characters of the rock in that area are not necessarily representative for the whole area. Nonetheless the lithology of the formation is distinct, and can be easily demarcated from the other lithostragraphic units. It comprised of ash grey, tough fossiliferous limestone Figure- 7. This limestone is partially or completely dolomitized, frequently giving rise to sugary dolostone. The carbonates are interbedded with grey mudstone layers and/or wisps. The carbonates are sometimes nodular. The nodules are formed either owing to differential dolomitization or sometimes they are boulders surrounded by clay matrix Figure- 7. The carbonates in general are porous, vuggy Figure- 7 or biomoldic Figure- 7. The size of the vugs is variable ranging in sizes from microscopic to large megascopic cavities, few centimetres in diameters. The fauna are rich in population and invariably diversified. The biota range in size from macro-fossils, in the form of corals, rudists, bryozoans, loftusia Figure- 7 etc., to tiny other microfossils. Evaporite nodules are infrequent and sparsely scattered throughout the formation. They are formed of gypsum and/or anhydrite and less frequently celestite rosettes Figure- 7. The core of the nodules is commonly anhydritic, whereas the surrounding rim is made of gypsum. The Qurna Formation is formed dominantly of marl and marly limestone, generally rich in fauna with incipient dolomite rhombs Figure- 8.

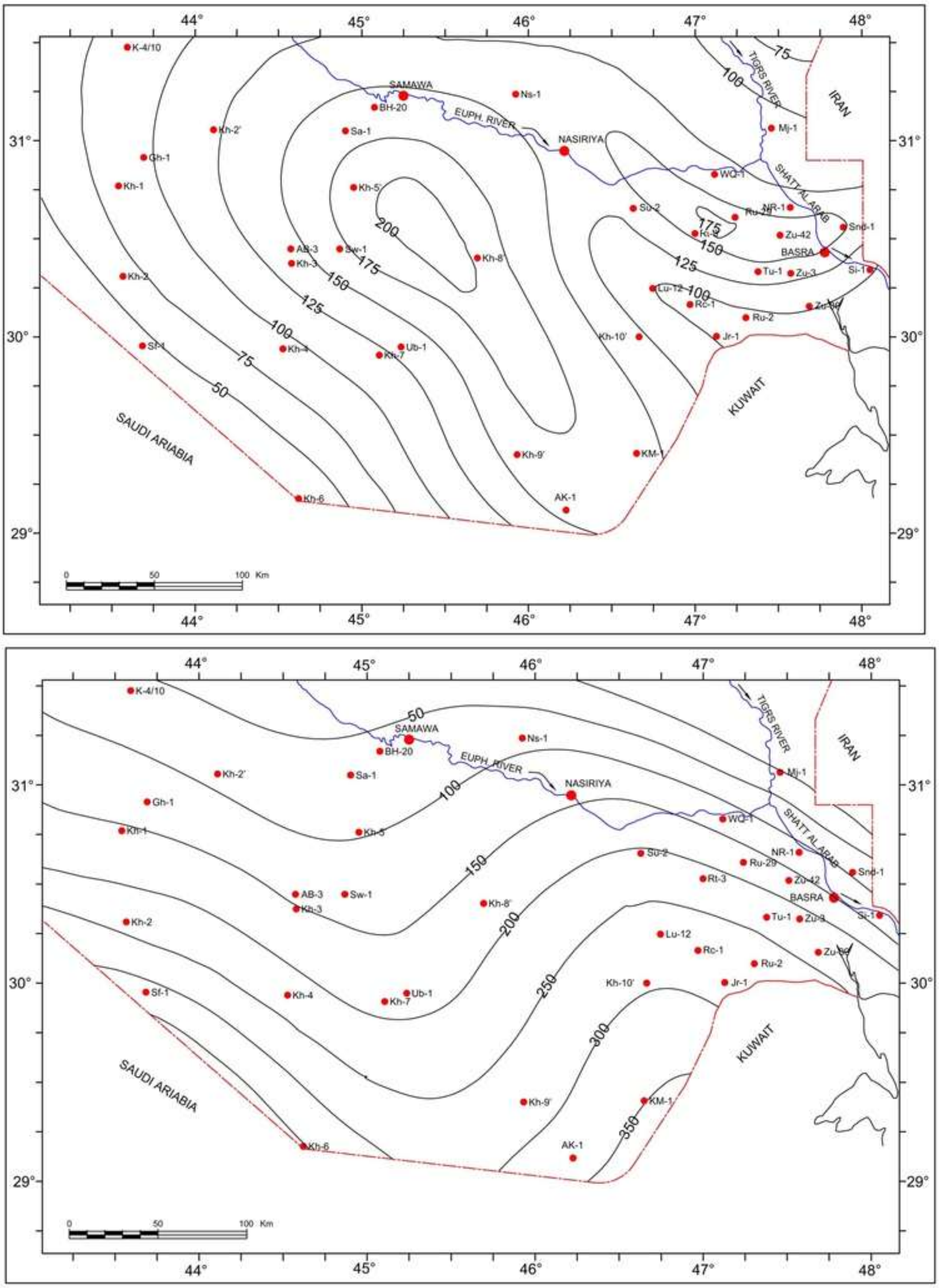


Figure 6 – The upper diagram is isopach map of the Qurna (Shiranish) Formation (adapted from Al-Siddiki, 1978. Contours are in metres, and their intervals are 25). The lower diagram is isopach map of the Tayarat Formation. This map was again adapted from Al-Siddiki, 1978. Contours are in metres, and their intervals are 50.

In the present work, the contact with the underlying formation is observed in one locality only i.e. Kh-6 at Ansab. The details of this contact are given earlier in the text. The contact with the overlying Umm Er Radhuma Formation presents an interesting problem. The contact is usually taken at the top of black bituminous shale immediately above the topmost appearance of the Loftusia Figure- 7. This contact is generally followed as emphasized by Bellen and co-workers in 1959 [6]. The contact seems abrupt and unconformable.

Palynological studies carried out by Konzalova in1982 shows the presence of hydrocarbon-producing alga insinuate that this bituminous material is primary, and its presence covering a large area makes it a suitable marker horizon [25]. Nevertheless some difficulty is faced in placing the contact in Kh-4 and Kh-6. The difficulty is raised owing to the close similarity of the lithology of the basal part of Umm Er Radhuma Formation and the uppermost part of the Tayarat Formation. The contact seems to be gradational but the possibility of some short breaks not to be excluded. Further investigation of this contact is recommended. The black bituminous shale is considerably thick (up to several metres) and repetitive which makes it a good source rock for hydrocarbons.

This work accords with results of the previous studies on the thickness distribution and basin analyses. Figure-6, which is an isopach for the Qurna Formation shows a bifurcating basin trending northwest-southeast (in Shatt Al-Arab area), and north northwest-south southeast (west of Samawah town. The isopach map of the Tayarat Formation Figure- 6 shows general and gradual increases of the thickness of the Tayarat Formation towards the south.

Three stratigraphic correlation sections are constructed here using all the available up to date data Figure-4b, c and d. An east-west section (Section Line A-A′) in the northern part of the area shows a uniform thickness having variations in thickness of the Tayarat Formation, and considerable increases in the thickness of the Qurna Formation towards that east. Another almost east-west section (Section B-B′) in the southern part shows a drastic increase in the thickness of the Qurna Formation toward the east. The latter formation became tongues (about 50 metres) within the Tayarat Formation. A north-south section (Section Line C-C′) in the central part of the area demonstrate an increase in the thickness of the Qurna Formation southward and a drastic increase in the thickness of the Tayarat Formation in the same direction.

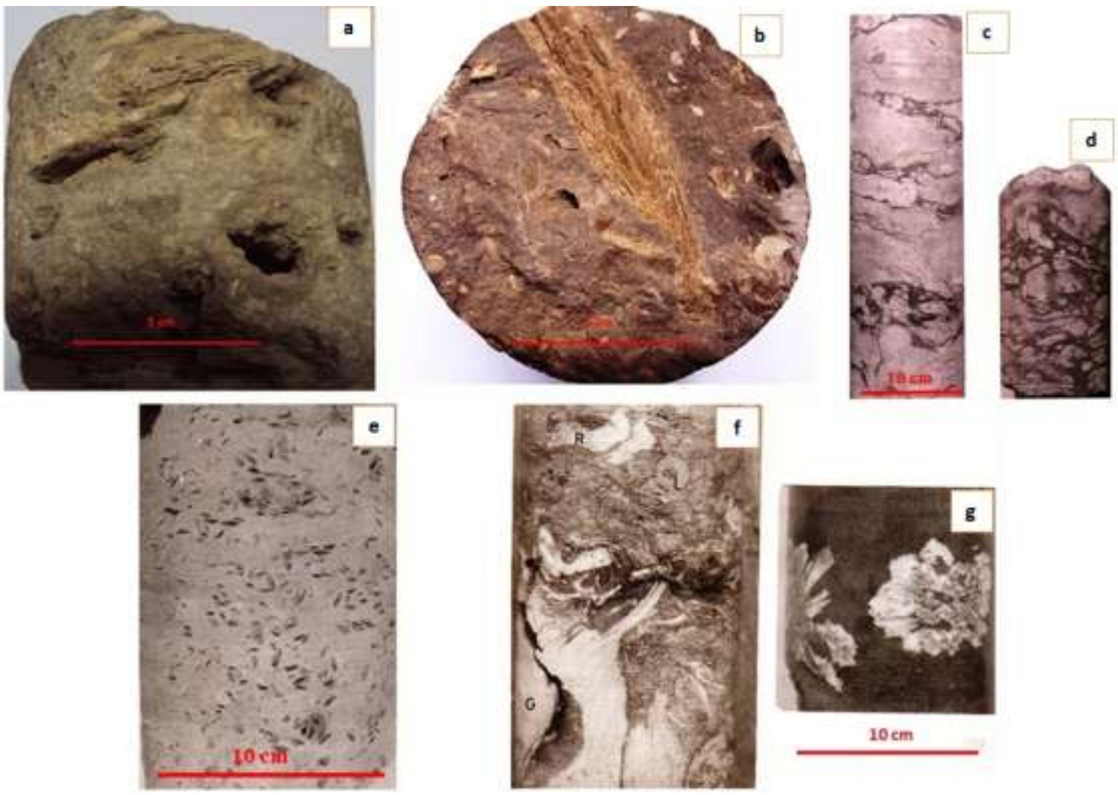


Figure 7 – a) and b) Organodetrital ash grey limestone of the Tayarat Formation with *Loftusia* sp. (same sample). Tayarat Formation at KH-3 at Al-Salman (drilling depth 397.5 metres). c and d) Dolomitic intraclastic limestone from KH-6 at Ansab (drilling depth 355.7 metres). e) Packed biomicrudite from the Tayarat/Qurna Formation from KH-6 at Ansab (drilling depth 494.4 metres). Biomoldic porosity is high. f) Sulphate nodules in the Tayarat/Qurna Formation: a) solitary nodule of gypsum (G) in a rudist shell and anhydrite in an organic dolomitic limestone, calcirudite with rudists (R) and a cross section of Loftusia sp. (L) from KH-6 at Ansab (drilling depth 382.4 metres). g) Rosettes of celestite from KH-6 at Ansab (drilling depth 324.0 metres).

Figure 8 - Sparse and clear dolomite rhombs seems “floating” in a clay/carbonate aphanocrystalline matrix (Plane-polarized light).

Paleogene Succession

The studied succession of the Paleogene is equivalent to the Tectonostratigraphic megasequence AP 10 (TMS AP10) of Sharland and co-workers in 2001 [22]. It comprises two lithostratigraphic units namely the Jerishan Group and the Dammam Formation Figure- 3. In this section, a brief over review for each unit stratigraphic attributes (i.e. thickness, relationship with the overlying and underlying units, and their main lithological character) will be given:

Jerishan Group (Paleocene-lower Eocene) – Jerishan Group is introduced by Tamar-Agha in 1983[15] incorporating three formations namely Umm Er Radhuma, Rus, and Jil Formations. Each of these formations has its own lithological character, easily distinguished in surface and/or subsurface sections, wide geographical distribution, and mapable whether as surface or subsurface unit. At oil well Jr -1, the thickness of this group attains its maximum being 670 metres. Nevertheless, its stratotype is composite taken at the stratototype of the corresponding formation or beds. These formations with its subsidiaries are described hereinafter in ascending order:

Umm Er Radhuma Formation (Paleocene) - The Umm Er Radhuma Formation was named after the Umm Er Radhuma Wells in Saudi Arabia by Henry and Brown in 1935 [25]. Later the name is widespread and adopted by many authors until published by Steineke and co-workers in 1958 [26 and 27]. In Iraq a supplementary type section is chosen by Owen and Nasr in B.P.C. Well Zubair no.3 [9]. The Umm Er Radhuma Formation, in its supplementary type section, is considered of Paleocene and Lower Eocene age overlying the Tayarat Formation unconformably. In order to facilitate mapping, the exposed part of the formation was divided into two mapable and informal units viz. Ghurra and Basita Beds. This subdivision is invalidated in the subsurface work as it is only surface geomorphic reflections and expressions. The lithology of this formation in the supplementary type section is mostly dull, white or buff, anhydritic and dolomitic limestone, microcrystalline and porous. Chert occurs in the upper part of the formation [6].

Umm Er Radhuma Formation is reached in ten keyholes namely, Kh-1 at Shebcha, Kh-2 at Rijm Al-Thaydi, Kh-3 at Al-Salman depression, Kh-4 at Takhadid, Kh-5 at Salhobiya, Kh-6 at Ansab, Kh-7 at Abu Radhum, Kh-8 at Sha’ aib Al-Ghanimi, and Ab-1 and Ab-3 at Abu Allum area. In some of these boreholes, the drilling penetrated the whole sequence whereas in others it was only partially penetrated.

The thickness of this formation in the supplementary type section is about 458 metres. In the studied area, it attained a maximum thickness in Kh-7 at Abu Radhuma (about 476.5 metres). In general, the isopach map Figure- 9 shows that the formation thins towards the west and north of the studied area. It thickens gradually towards the Euphrates/Shatt Al-Arab rivers basin.

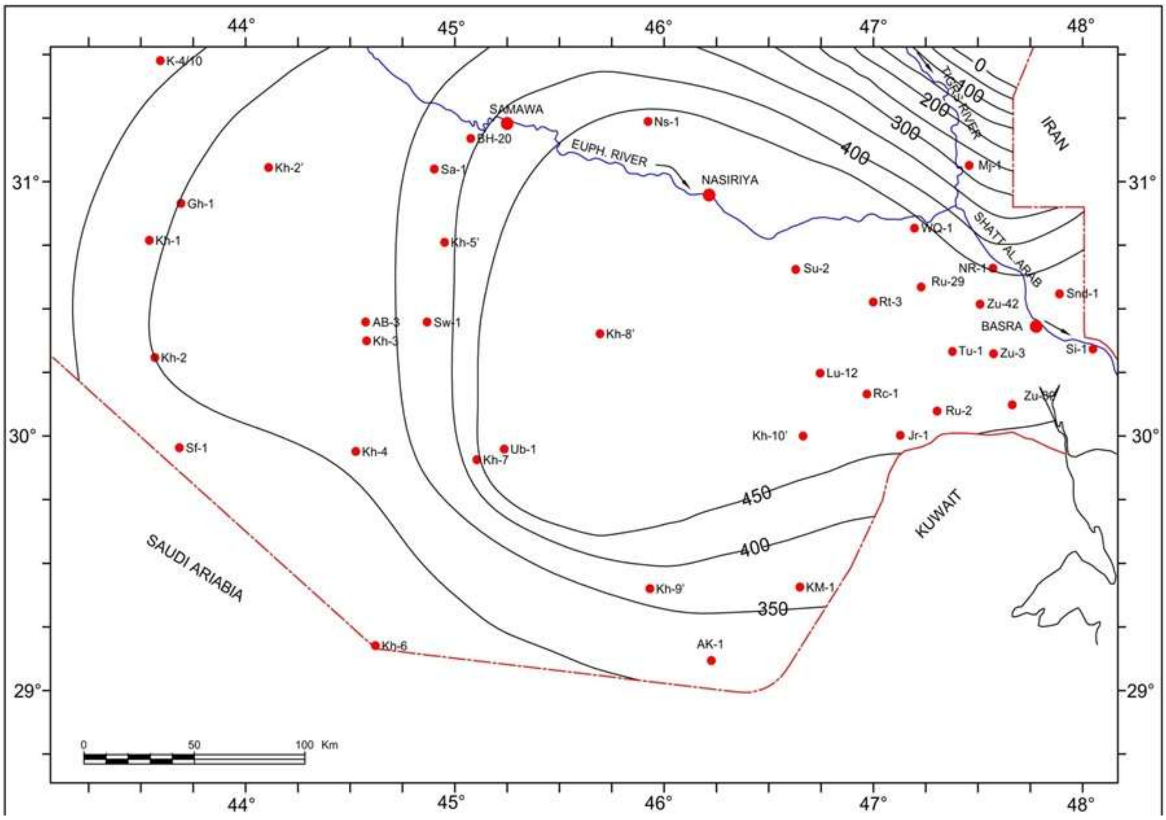


Figure 9 - Isopach map of the Umm Er Radhuma Formation (modified after Al-Siddiki, 1978). Contours are in metres, and their interval is 50.

The contact with the underlying Tayarat/Qurna Formations is variable. In Kh-3, and Kh-7, it seems unconformable. This is indicated by the sharp and drastic change in lithology, and faunal assemblages. The contact is placed at the top of the first bituminous shale overlying the Loftusia-bearing limestone of the Tayarat Formation. In Kh-4, and Kh-6 some difficulty is encountered in placing the contact between the Tayarat/Qurna Formation and the overlying Umm Er Radhuma Formation. The reasons are that the lithology is very slowly gradational and the bituminous shale is repeated at many levels. The contact is conformable with some short and local breaks in the sedimentation.

The upper contact is variable too. In the eastern part, the Rus Formation overlies the Umm Er Radhuma Formation. The contact between the two formations is gradational, and is taken at the base of the last massive and thick anhydrite (and/or gypsum beds) of the Rus Formation. In the western part, the Umm Er Radhuma Formation underlies the Jil Formation. In Kh-3, the sequence shows a special case due to the solution of the evaporite caused by the groundwater activity, and the little core recovery. Hence the contact is not clear. However, in the adjacent area (AB-3), the contact is unconformable with about 90 centimetres of phosphatic arenites at the base of the Jil Formation. The thickness of phosphatic arenties varies as it becomes thin in Kh-1 at Shebcha area. This bed may represent an interrupted or condensed sedimentation.

The lithology of Umm Er Radhuma deposits, as appeared in the studied boreholes, as well as the incorporated Thaydi, Abu Radhuma and Salhobyia Beds are essentially the same. They all show rhythmic nature, i.e. asymmetric alternation of different lithologies. The most ubiquitous difference lies in the variation of beds thickness and clustering of the evaporite nodules. The three evaporitic

Beds differ from the rest of the Umm Er Radhuma Formation by, first having thick evaporite beds and relatively thin carbonates, and second in having the evaporite clusters within relatively short intervals of depth. In the studied area (apart from Kh-3 in Al-Salman depression), the Umm Er Radhuma Formation forms a rhythmic alternations. The complete rhythm is formed of the following attributes: Pale grey, dolomitic marl (bottom); Pale grey, fassiliferous, clayey dolostones; Pale grey, terrigenous carbonate with gypsum nodules; Evaporite bed (top). These rhythms are rarely complete. Many reasons are mingled to cause the missing of one or more of these attributes. Other attributes are also recognized but had very subsidiary status. The status of the complete rhythm is described below outlined as four lithofacies:

Dolomitic Marl Lithofacies (Lithofacies A): It is pale grey, medium tough to tough with occasional fossils. Petrographically they are (using Folk's terminologies) clayey aphancorystalline biogenic and non-biogenic dolomite, which were originally clayey biomicrudite to biomicarenite. Fossils are the main allochems in these sediments. Laminations are not uncommon in this lithofacies. Mottling is present and is attributed mostly to bioturbation.

Clayey Dolostone Lithofacies (Lithofacies B): The colour of this lithofacies is pale grey with brownish tint. It has a lighter colour than the previous lithofacies and is tougher. The population of fauna is generally higher. The basic difference with the previous lithofacies is its lower content of clayey admixtures. Petrographically, these rocks can be described as aphanocrystalline, and fine crystalline biogenic dolomites.

Terrigenous Carbonate with Gypsum Nodules Lithofacies (Lithofacies C): Basically these sediments are similar to Lithofacies A and B. The main difference lies in the presence of gypsum nodules and scarcity of fauna. Gypsum nodules are sub-spherical and range from a pea-size to about 15 centimetres in diameter. The nodules occur as solitary or clusters. Petrographically they are generally formed of albastarine type gypsum.

Evaporite lithofacies (Lithofacies D): This lithofacies is formed mostly from gypsum with some subsidiary anhydrite. Rock salt is not encountered during the drilling. The colour is generally white to grey. The grey is attributed to organic admixture and/or to the carbonate mud and clays in the nodules forming the evaporite beds. The thickness of the evaporite beds range from a fraction of a metre in the Umm Er Radhuma Formation (in general) to about ten metres in Thaydi Beds. The thick beds are especially found in the Thaydi and Abu Radham Beds.

The internal structure of these beds is generally nodular i.e. had a chicken wire texture Figure- 10, but variable ranging from compound mosaic, compound wispy, mosaic, wispy, and structureless (or massive). Some of the evaporite beds are laminated and/or spotted. The laminated gypsum is relatively less common than the other varieties. Though they are referred to as laminated they are in fact formed of nodules aligned parallel to the bedding Figure- 10. The laminae are separated by pale clay carbonate film of sediments with laminae of satin spar. The lamination is either parallel or wavy. Spotted gypsum is also described from this sequence. The evaporite beds are basically massive or laminated gypsum with rosettes of selenetic gypsum. The evaporite nodules seem mostly of replacive origin as shown by their truncation with the original laminated marl Figure- 10.

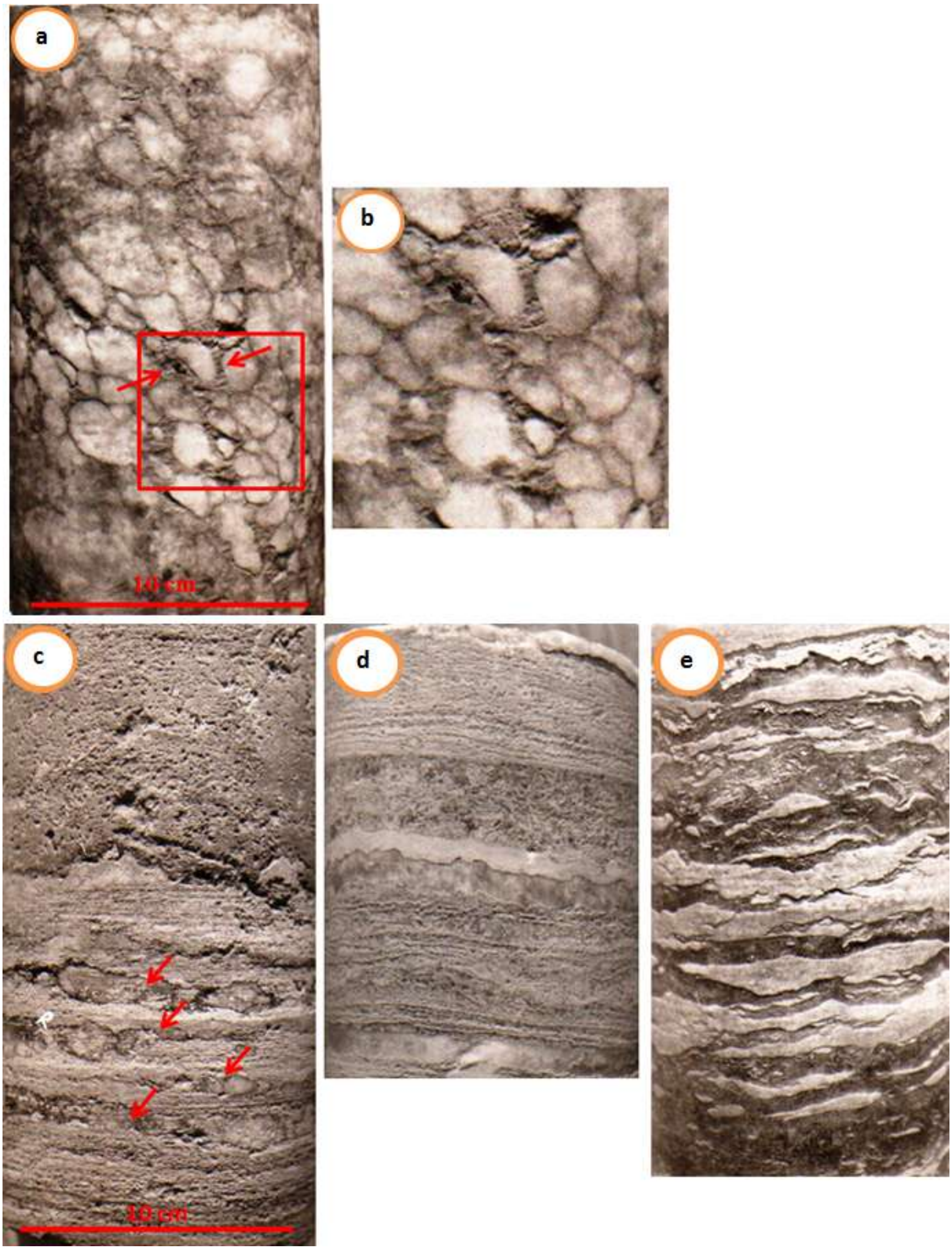


Figure 10 - a) Gypsum and anhydrite from Umm Er Radhuma Formatiom at KH-6 at Ansab (drilling depth 217.2 metres). It is showing chicken-wire texture with clay-carbonate filaments surrounding the nodules. The nodules are formed by replacement and the arrows indicate truncation of the nodules with laminations of the original lithology. b) Enlargement to illustrate the laminations truncated by the growth of nodules. c) Alternating biomoldic carbonates and gypsum nodules embedded in the carbonates. The nodules are aligned along bedding planes though some are solitary. They are of replacive nature too. Umm Er Radhuma Formation at KH-6 at Ansab (drilling depth 270.0 metres); d) Laminated gypsum from the Umm Er Radhuma Formation at Ansab (drilling depth 260.4 metres). The gypsum laminae are made of coalesced gypsum nodules. The carbonate layers are mixed with gypsum too; e) Laminated anhydrite and gypsum from Umm Er Radhuma Formation at KH-6 at Ansab (drilling depth 262.3 metres). The dark laminae are gypsum whereas the white wisps are anhydrite.

In Kh-3 at Al-Salman depression, the evaporite beds are missing, but few gypsum nodules are present and others are represented by vanished evaporite. Large cavities are found at several levels. A reduction in the total thickness of Umm Er Radhuma Formation is expected. The Salman depression, where the borehole is sunk is most probably a karsts depression. This insinuates that the evaporite beds are dissolved, and leached out. In the vicinity of this borehole, outside the depression area, gypsum nodules and beds are encountered.

Thaydi Beds - These beds occupy the second level of evaporites (from top) in the Jerishan Group (i.e. the upper) in the Umm Er Radhuma Formation. The Thaydi Beds are encountered in six boreholes namely Kh-1 at Shebcha, Kh-2 at Rijma Al-Thaddi, Kh-4 at Takhadid, Kh-7 at Abu Radham, and Sw-1, and Ub-1 B.P.C wells. They reach up to 147 metres thick in Kh-2 at Rijm Al-Thaydi and their western and southern limits are vague owing to the lack of information. They seem to have a fairly large extension. By virtue of the rules given in the International Stratigraphic Guide, this unit should be referred to at the present as "Beds". Further future investigation might alters its rank in the stratigraphic hierarchy.

The drilling depth interval from 105 to 252 (about 147 metres thick) at Kh-2 at Rijm Al-Thaydi is suggested to be the stratotype (Longitude 43º 47′ 5٩″ and Latitude ٣٠º 19′ 39.6″. This location is suggested because the beds attained their maximum thickness and development at this locality.

Lithologically, Thaydi Beds comprise of alternating thick sulphate (gypsum and anhydrite beds) and dolomites. The number of rhythms counted in this sequence is about 22 rhythms. Each rhythm has a thick evaporite bed ranging from 1 to 15 metres, and organodetrital dolostones of relatively minor thickness. Some of the organodetrital dolostone beds are with nodular gypsum and/or clay admixtures. These carbonate are rarely laminated or fossiliferous.

The evaporites are mostly gypsum rock though some anhydrite is encountered. They are usually referred to as beds though they are formed almost entirely of packed nodules. The nodular nature is distinguished when the carbonate-clay filaments circumscribe the nodules. Occasionally, the nodules are packed to such an extent that the carbonate-clay filaments disappear and the nodules coalesce. The arrangement of the packed nodules in horizontal rows, and sheets with veins of satin spar in between leads to the formation of laminated evaporites. Diagenetic changes have produced spotted sulphate beds. These spots are formed of secondary gypsum grown in radiating accicular habit to form rosettes.

Abu Radham Beds – They are the deepest level of the evaporite beds. During the present study, it was found in Kh-7 at Abu Radham, and Kh-5 at Salhobiya. The extension of these beds is still obscure. Further details of these beds are still demanded. The type section is taken in Kh-7; naturally no other alternative exists so far. The drilling depth interval (about 103 metres spanning the depth interval from 378 to 481 metres) is the stratotype (Longtitude 45º 14′ 54″ and Latitude 30º 14′ 15″).

The lithological characters are similar to the Thaydi Beds or the Rus Formation. The contact is taken at top and the bottom of the first and the last sulphate beds respectively. Figure-11 gives a fair idea about the variation of this formation internal geometry. This was done first by two east- west running cross section lines (D-D', and E-E'). The last one is a north-south cross section line (F-F'). These lines rather portray a complicated spatial and temporal relationship. Because of this, the authors refrain from any further discussion on why the situation was like so.

Rus Formation (Lower Eocene): Rus Formation was formaly introduced by Sander in 1952 from Saudi Arabia and a supplementary section was chosen later by Owen and Nasr in 1958 in B.P.C. Well Zubair No. 3[6]. In the present study the Rus Formation is penetrated in four boreholes namely Kh-2 at Faidhat Umm El-Hashim, Kh-5 at Salhobiya, Kh-8 at Sha'aib Al-Ghanimi, and Kh-9 at Bataya. In all these boreholes drilling has penetrated the whole sequence.

The Rus Formation is the topmost evaporite unit in the Paleogene sequence and is equivalent to the Jil formation which is dominantly carbonates Figure- 12. It is the most salient amongst them being the thickest, widely distributed and best established for its identity since a long time. It is believed that it satisfies the requirements needed by the International Stratigraphic Guide to be called a formation.

The thickness of this formation in the supplementary type section is 94 metres, and attains its maximum in the oil wells Jr-1, and Rc-1 (over 200 metres). In the studied boreholes, it reaches its maximum in Kh-8. In Kh-2′, the Rus Formation interdigitate with the Jil Formation. An isopach map Figure- 13 is constructed based on Al-Siddiki's map of 1978, with some alterations based on the results of the present work. It abundantly shows a narrow basin extending northeast-south-southwest. The basin seems to extend in Iran, Kuwait and Saudi Arabia.

The contact with the underlying Umm Er Radhuma Formation seems conformable in all of the studied boreholes. At times the contact is optional because of some minor evaporite beds are encountered in the section and near the contact.

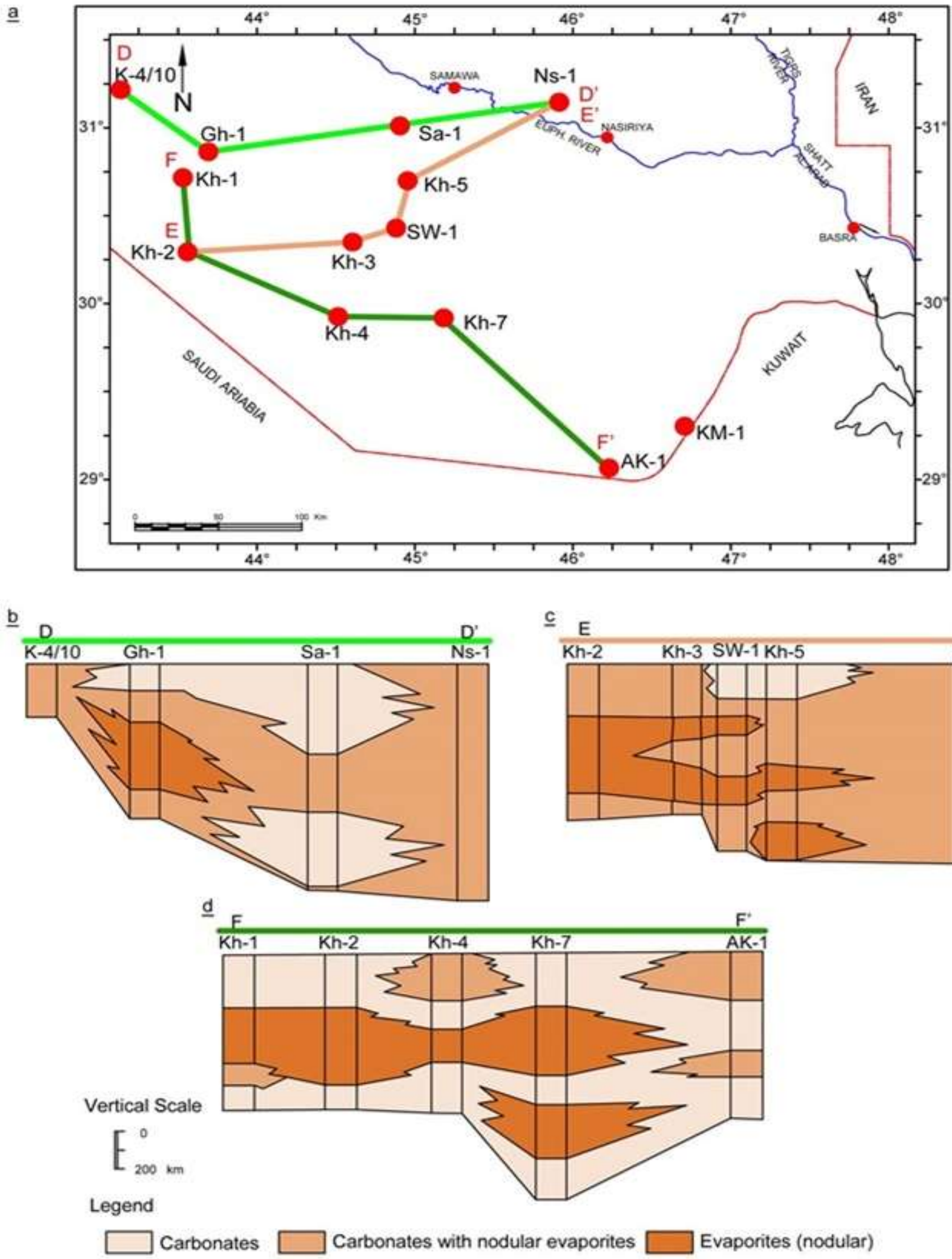


Figure 11 - a) Map showing the section lines along which the internal stratigraphic entities of the Umm Er Radhuma Formation were correlated, b) Correlation along section line D-D′, c) Correlation along section line E-E’, d) Correlation along section line F-F′.

The contact with the overlying Dammam Formation is unconformable and represented in all drilled wells by waxy greenish grey claystone bed with phosphatic gravel near its base. The thickness of this bed varies from 30 centimetres in Kh-5 (at two levels) to four metres in Kh-9. The base of this layer in Kh-9 is sharp and irregular with some pebbles, and phosphatic fragments. Petrographic studies showed dolomite rhombs floating in the claystone groundmass.

The lithology of this formation is basically similar to the Umm Er Radhuma Formation. It also shows a rhythmic pattern as in the other formation (described earlier). The main difference is in the percentage of the carbonate and evaporite beds, and the thickness of the evaporite beds. The evaporite beds in the Rus Formation are usually thick reaching 20 metres as in Kh-5.

Jil Formation (Lower Eocene): The Jil Formation was first informally introduced through unpublished reports of the Iraq Geological Survey such as Tamar-Agha (1982, first under the name Salman Formation and then changed to Jil Formation), Al-Mubarak and Amin (1983, under the name Jil Member) and Jassim and co-workers (1984, under the name Jil Formation) [28]. It was formally published by Tamar-Agha et al. in1997 [21]. The Jil Formation is named after hand-dug water-wells at the Iraqi southern desert named Abar 'l-Jil (Latitude 30º 23′ and Longitude 44º 00′). It is the carbonate equivalent of the Rus Formation. Jil Formation comprises chalky carbonates and marl with coarsely crystalline calcite nodules and beds equivalent to the four upper informal field units of Huber and Ramsden in 1944-1945 [6]. These units are Wagsa, Sharaf, Shabicha and the lower part of Huwemi Beds.

The Jil Formation is reached in seven boreholes namely Kh-1 at Shebcha, Kh-2 at Umm El-Hashim, Kh-3 at Al-Salman depression, Kh-4 at Takhadid, Kh-7 at Abu Radham, and Ab-1 and Ab-3 at Abu Allum area, Kh-2′ demonstrate a case whereby both Rus, and Jil Formation interfinger Figure-12. Figure-12 shows the transition from the Rus Formation to the Jil Formation. Figure-13 is an isopach map for this formation, which clearly demonstrates a north-western tendency for gradual thickness increments.

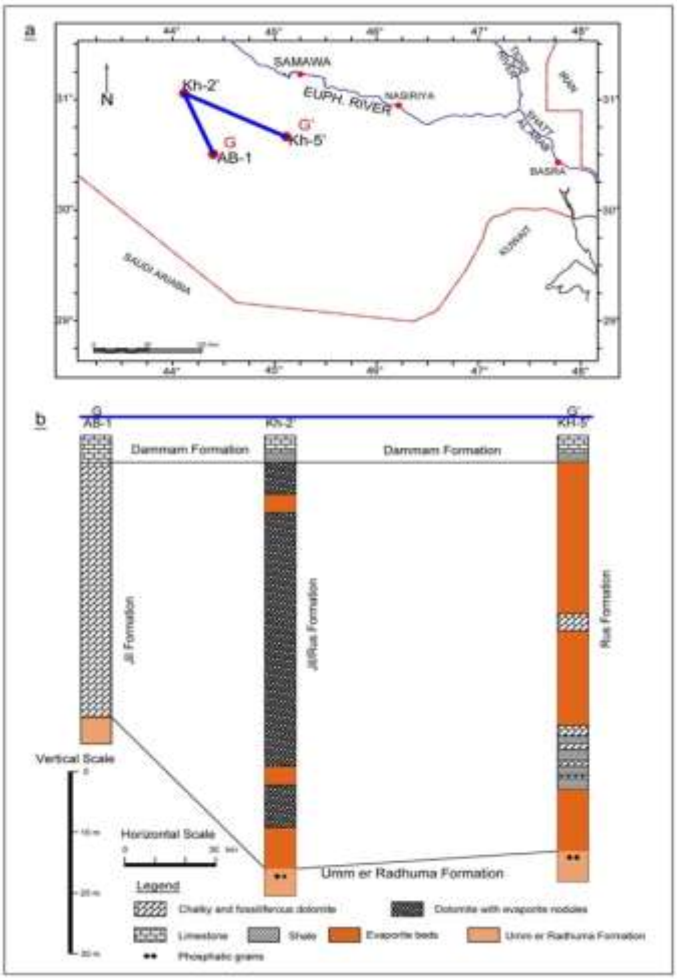


Figure 12 - a) Map showing the section line along which the Rus and Jil Formations is correlated, b) The section line (G-G′) along which the correlation is made.

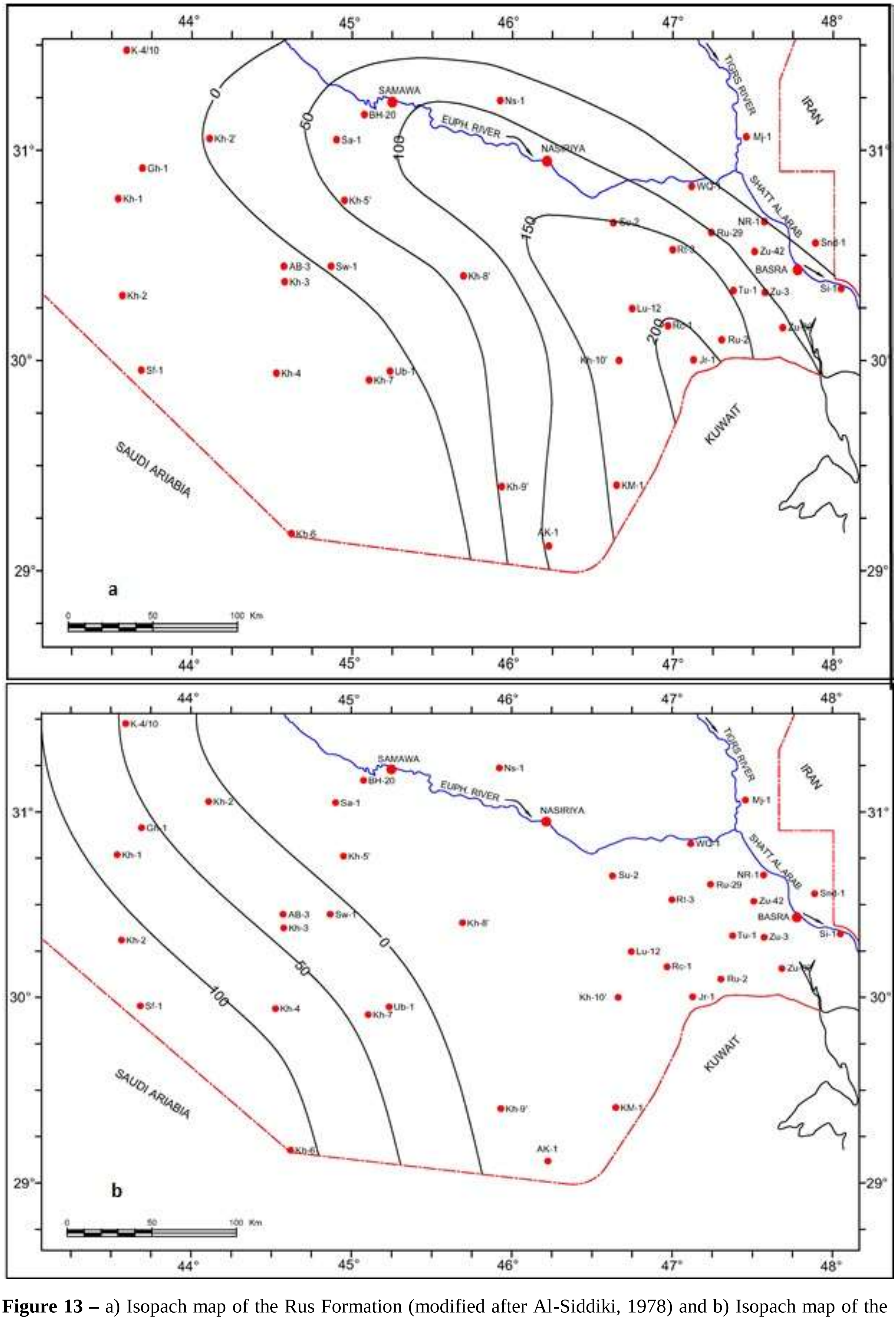


Figure 13 – a) Isopach map of the Rus Formation (modified after Al-Siddiki, 1978) and b) Isopach map of the Jil Formation. Contours are in metres, and their interval is 50.

The Jil Formation is comprised of cream or white, biomoldic (except the middle part), fossiliferous (the middle range almost devoid of fossils), chalky, very friable or friable rarely tough dolostone and dolomitic limestone. Some intercalations of marl are found at various levels. Vanished evaporites characterize the middle and unfossiliferous part. They are represented by calcite microoncretions, calcite noduels and beds of coarsely crystalline limestone.

The calcite crystals are usualy large scalenohedral crystals. Below groundwater level, the lithology of Jil Formation like in KH-1 closely resembles that of the Umm Er Radhuma Formation. It comprises pale grey marl and clayey, organodetrital dolostones and dolomitic limestones with some gysum nodules, and microconcreations.

The part above the water table level, i.e. in the vadose zone, is affected by exogenic processes more than the lower part. Oxidation has played a major role in these processes, and hence it has affected the organic pigments leading to discolouration. In addition to this, leaching led to the removal of gypsum and/ or its replacement by secondary calcite, and henceforth increase of porosity. Below the average groundwater level, in the phreatic, such processes are limited.

In surface sections, the lower contact is represented by a phosphatic arenite layer and red claystone. Angular disturbance is observed between both units possibly attributed to evaporite solution. The upper contact is represented by brecciated carbonate layer. In Shebcha area, this contact is represented by marl and massive discontinuous cavernous limestone.

The contact with the underlying Umm Er Radhuma Formation is unconformable represented in Abu Allum-3 by 90 centimetres of phosphatic arenite at the base of Jil Formation. In Kh-1 at Shebcha, it is represented by brecciated, clayey, pebbly fossiliferous dolostone (with abundant bone fragments and shark teeth). Phosphatic arenite in such case may represents interrupted or condensed sedimentation.

Dammam Formation (Middle-Upper Eocene): Dammam Formation is formally introduced by Sander in 1952 from Saudi Arabia and a supplementary section was chosen later by Owen and Nasr in 1958 in B.P.C. Well Zubair No. 3 [9]. It comprises the upper seven informal field units of Huber and Ramsden in 1944-1945 [6]. These units are the upper part of Huwemi, Shawiya, Chabd, Rudhuma, Barabak, Ghanimi and Tuqaiyid Beds. In the present study this stratigraphic unit is penetrated in nine boreholes. These boreholes are Kh-3 at Faidhat Umm El Hashim, Kh-3 at Al-Salman depression, Kh-5 at Salhobiya village, KH-7 at Abu Radhuma, Kh-8 at Sha'aib Al-Ghanimi, Kh-9 at Batya Police Center, Kh-10 at Ritchi, and Ab1 and Ab3 in Abu Allum area. The Dammam Formation is exposed extensively in the area but only two boreholes showed the complete succession. The top of the succession is eroded in the other boreholes.

The sequence of the Dammam Formation is divisible into two units. The contact between these units is gradual. The thickness of the lower unit varies from 25 to 52 metres. The thickest part form a belt trending southeast, in the wells adjacent to the Euphrates, and thins out sharply towards the west Figure- 14.

The lithology of this unit below groundwater level is characterized by alternating highly fossiliferous clayey limestone, and sparsely fossiliferous clayey limestone and marl. It comprises two lithological packages. The first package is highly fossiliferous greenish grey limestone, mostly nummulitic (large nummulites) with variable amount of groundmass Figure- 15. The groundmass is mostly greenish grey argillaceous carbonates. This package can be generally referred to as calcirudite, or even coquina. The rudite size particles are mostly of bioclastic origin including gastropods, pelecypods, and large forams. The second package is bioturbated and sparsely fossiliferous clayey limestone and marl. The fossils are mostly pelecypods. The amount of groundmass is variable too, but in general it is higher than in the first lithology. The higher amount of groundmass gives this lithology a darker tone than the first package. Possibly the term, calcilutite is the most appropriate for this package. The abovementioned packages alternate in a rhythmic pattern. Cross-bedding is noticed in two boreholes Kh-9 and Kh-8. The cross-bedded horizon encountered at Kh-9 (depth 127 metres) has an upper erosional contact.

Above the average level of groundwater, the lithology is rather different. The two packages can still be distinguished. The first is cream and white, fossiliferous biomoldic vuggy, and tough clayey dolostone and dolomitic limestone (coquina). In brief, they are calcibiourdite. The second lithology is cream and white tough, sparsely fossiliferous clayey dolostone, and dolomitic limestone (dolosiltite and calcisitite).

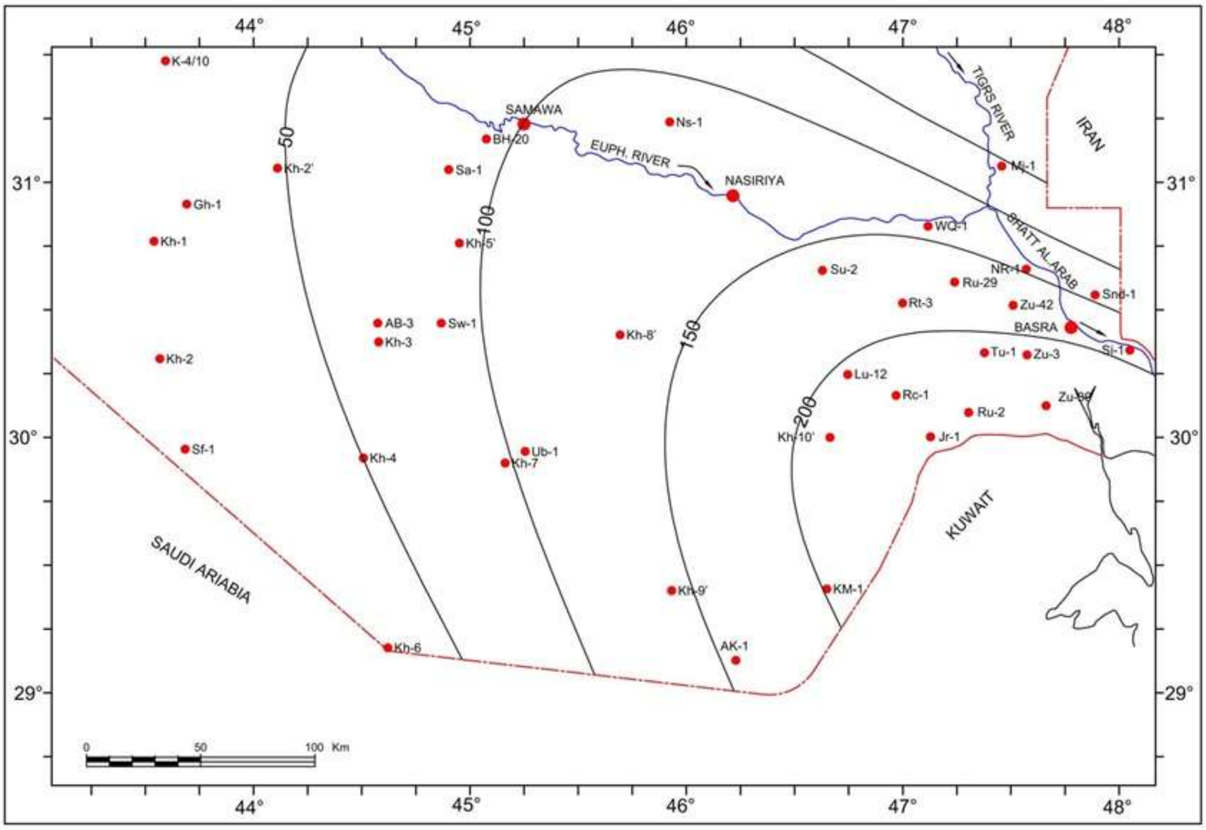


Figure 14-Isopcah map of the Dammam Formation (adapted after Al-Siddiki, 1978. Contours are in metres and their interval is 50).

Figure 15 - a) Highly fossiliferous, greenish grey clayey limestone (calcirudite or coquina). Fossils are mostly nummulitic (large nummulites). b) The lower part of the Dammam Formation at Kh-8 at Sha'aib Al-Ghanimi.

A chert horizon is usually encountered near or at the top of this unit. Such chert horizons also found in the oil wells drilled in the area. Similar phenomenon is also noticed during the course of mapping carried out by the Iraq Geological Survey. It is commonly referred to as chert horizons or silicified beds [16-20]. The lower lithology most probably corresponds to the surface Shawiya Beds. The Shawiya Beds (unit) forms a belt running in northwest-southeast direction and its strike swing southwards in the southern part of the area.

The upper unit ranges from about 150 metres (in Kh-10) to 18 metres in Kh-7. The thickness in Kh-7 however represents only the lower part of this unit as the upper part is eroded. The extensive and comparatively deep erosion in the Eocene deposits, occurred in the western part of our area has hindered the lateral correlation of the thickness. However the whole formation thins out in westerly direction.

This unit comprises alternating fossiliferous dolostone, and clayey dololutite in cyclic pattern. At least five different lithofacies can be distinguished in this unit to make out the cycle. The distinction between the different lithofacies is rather vague because no clear boundary exists between them. The contact between all lithofacies is thus gradual. Thickness of each of these facies and the cycles is variable. The cycle is rarely complete. It represents a shallowing-upwards succession [15]. These lithofacies are (from top to bottom):

Lithofacies A - White to cream, homogeneous, biomoldic, bioclastic, dolostones (dolarenite).

Lithofacies B - White to cream chalky, bioclastic dolostone (dolarenite) with patches of doloutite in some places, which are caused by bioturbation.

Lithofacies C - White to cream chalky dolostone (doloutite) with tubes filled with bicolastic dolostone.

Lithofacies D - White to cream, pseudobrecciated dolomitic limestone. The dolomite patches seems to be cemented by coarsely crystalline calcite. This is formed either by incomplete dolomitisation or by calcification of evaporite.

Lithofacies E - Alternation of mud layers with bioclastic layers. They are occasionally disturbed by fracturing and/or bioturbation.

Each of the abovementioned lithofacies is thicker in the lower part but becomes thinner in the upper part. This unit is more porous than all other units. Most of the pores are in the form of biomolds though some are vugs and cavities do occur. Cross bedding is noticed is also one occasion, at 25 metres depth in Kh-8. Chert horizons are found at different levels.

Neogene Successions

The studied succession of the Neogene is equivalent to the Tectonostratigraphic megasequence AP 11 (TMS AP11) of Sharland and co-workers in 2001 [22]. It comprises here four lithostratigraphic units namely the Ghar, Fatha, Dibdiba and Zahra Formations. In this section, a brief over review for each unit stratigraphic attributes (i.e. thickness, relationship with the overlying and underlying units, and their main lithological character) will be given.

<u>Ghar Formation (Lower Miocene)</u> - Only one of the boreholes had penetrated the Ghar Formation. This borehole is Kh-10 at Ritchi. In addition, it crops out as a discontinuous strip in the eastern of the area concerned.

Owen and Nasr in 1958 [9] are the first to describe Ghar Formation and selected B.P.C well Zu-3 as a type locality. The thickness of the Ghar Formation in the type section is 129 metres. Isopach map Figure-17 shows a sub-oval basin focused around oil well, Jr-1 reaching about 175 metres. The basin extends in Iran, Kuwait, and part of northeast Saudia Arabia. The thickness of the Ghar Formation in KH-10′ is about 206 metres. Accordingly, some alteration is made on the isopach map Figure- 16 constructed by Al-Siddiki in 1978 [14]. The alteration is relatively minor. They are mainly concerned with the shift of the depocenter, and the increase in the asymmetry in the basin.

The Ghar Formation in the type locality is comprised of sands and gravels, rare increments of sandy limestone, clay and anhydrite. Chemical deposits increase slightly in the northeastern and eastern part of the basin [29].

The age of the Ghar Formation, owing to the lack of fauna so far is a matter of controversy. Some suggested upper Oligocene such as Ditmar and others in 1971 [29] others suggested Lower Micoene age [30-32]. The type section is believed to be of Middle Miocene age [6 and 9]. Buday in 1980 forwarded rather firm evidence in favor of Lower Miocene age [23]. However, in Kh-10 the presence of index fauna in the marls, such as *Miogypsina globulina* (MICHELOTTI), *Miogypsina intermidi* (DROOGER) and many others, prove Lower Miocene age.

The sequence in Kh-10 is characterized by alternations of sandstone, mudstones and sandy limestone. The sandstones are white, pale grey, cream, brown, and pink quartzose, friable to tough (loose to well cemented) gravely and/or muddy. Sorting is generally low. The grains are subangular to subrounded. The cement is usually calcareous and white. The mudstones are varicoloured; some are red or greenish grey. Silty and gravelly admixture is found but variable too. The gravels are of various sizes and mostly derived from plutonic and hypabyssal, acidic and intermediate igneous rock with some gneissic rock, i.e. granite and granitoid. They are most probably derived from the Arabian Shields.

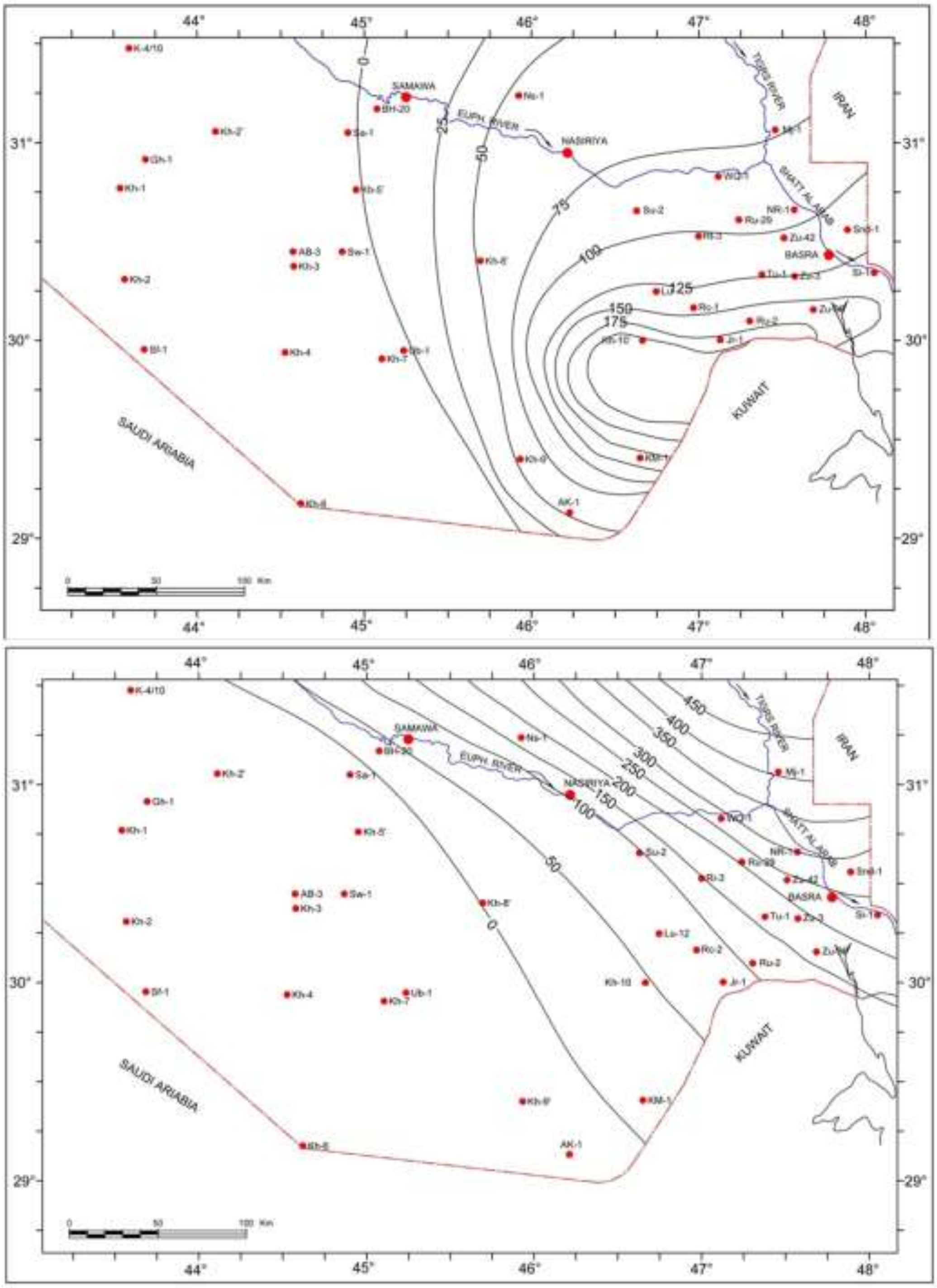


Figure 16 – The upper diagram is isopach map of the Ghar Formation (modified after Siddiki, 1978. Contours are in metres, and their interval is 25). The lower diagram is isopach map of the Fatha Formation (adapted from Al-Siddiki, 1978. Contours are in metres, and their interval is 50).

It is possible to divide the formation into many cycles, but it was not possible to divide it into lithological units. Some coarsening upwards sequences are recognized but further investigations are still needed to establish the depositional environment.

The contact with the underlying Dammam Formation is unconformable. The unconformity surface is marked by coarse grained breccia, sharp and irregular surface with chert pebbles. The contact with the overlying Dibdibba Formation is taken at the top of the topmost marl. This marl bed could belong to the Fatha Formation.

The succession in KH-10′ contains, on one hand a large amount of clastic fraction which usually characterizes the Ghar Formation, on the other hand it contains the fossiliferous marl and faunal assemblage which characterize the Euphrates Formation. In the study area, the Ghar Formation is exposed in eastern part as well. The Euphrates facies are well developed and hence separated during the course of surface mapping [16-20]. The Ghar Formation is divided during the regional geological survey into two units. Each is about 10 metres thick in Busaya area. The Lower unit is characterized by massive, fragmented sandy limestone with chert patches. The upper unit is characterized by greenish grey sandy marly limestone, and whitish grey calcareous sandstones.

The Euphrates Formation is about five metres comprising fossiliferous marl, and limestone. The set of fauna recognized in this formation in this area resembles those reported by other authors for the Euphrates in neighboring areas, which in indicate an Upper Burdigalian age.

<u>Fatha Formation (Middle Micoene):</u> The Fatha Formation formerly known as the Lower and Middle Fars Formations was introduced by Jassim and co-workers in 1984 and later formally published by Al-Rawi and co-workers in 1992 [28 and 33]. Busk and Mayo in 1918 defined the Lower Fars Formation in Iran without giving a specific locality [6]. A references section for southern Iraq is selected by Owen and Nasr in 1958 at B.P.C NR-1 [9]. The Fatha Formation in southern Iraq is formed of rhythms of mudstone, limestone (fossiliferous, sandy and oolitic in parts), and gypsum/anhydrite. The top is taken either at the appearance of prominent evaporite bed or the appearance of first marine mudstone. The Fatha Formation is diachronous and since it is the extension of the Gachsaran basin of Iran the age could be lower Miocene. However the data available in this work does not allow such deduction.

In KH-10′ about eight metres (drilling depth interval 78-86) is expected to belong to the Fatha Formation. Lack of lithological and/or faunal evidence left this problem debatable. However, the oil companies boreholes drilled within and/or in the study area have shown some sequence which were assigned to the Fatha Formation.

An isopach map Figure- 16 constructed by Al-Saddiki in 1978 showed that the thickness of this formation increase sharply towards the northeastern part of the area [14]. It seems that the Fatha succession in southern Iraq forms a small part of very large basin which covers southeast Iran and much of the northeastern coast of the Arabian Peninsula. The thickness of the succession in the reference section in NR-1 is about 306 metres whereas its maximum thickness in southern Iraq is over 400 metres in MJ-1. The formation is richer in limestone and marl in the part of the basin lying in our study area. Kh-10′ is most probably located on the periphery of the Fatha basin [14]. However, the facies changes, which are expected to occur in the peripheral part of the basin, seem to have altered the diagnostic features of this formation. Bellen and co-workers in 1959 advocated that in southern Iraq the Fatha Formation thins, and is represented only by dark shale with the Fatha index fossil *Ostrea latimarginata* (VREDENBURING) occurring between the Dibdibba Formation and the Ghar Formations [6]. Regional mapping of the area showed that the Fatha Formation crops as a narrow strip near the Euphrates River [17-20].

<u>Zahra Formation (upper Pliocene - Pleistocene):</u> Williamson in 1941 is the first to describe this lithostratigraphic unit [6]. He described this unit in an unpublished report in attempt to map the area. Later Mitchell in1956 named this unit after the type locality which is called Faidhat az Zahra, an ephemeral dry lake about 65 kilometres west of Busaiya town [8]. The thickness of this formation varies reaching its maximum about 31 metres. The age of this formation is controversial. Bellen and co-workers in 1959 are of the opinion that it is of middle Miocene age as it overlies in one locality the *Ostrea latimraginata* -bearing marls [6]. Buday in1980 reviewed the problem of the age of this unit, and favored an upper Miocene age based on lithological correlations [23]. Salman in1993, based on paleontological evidence showed that the age of the Zahra Formation in upper Pliocene – Pleistocene age [34]. It is found resting unconformably over the Jil, Dammam, and Ghar Formations. The

underlying formations are mentioned above. The Dibdibba Formation found only to cover the Zahra Formation unconformably.

This formation is penetrated only in Kh-3 at Al-Salman depression. However, the Zahra Formation is distributed in isolated outcrops over the whole area. The Zahra Formation in its outcrops in the studied areas can be divided into two units. The lower unit is pinkish and reddish massive sandy, and/or silty calcareous mudstone, occasionally pseudobrecciated, with an irregular white (worm-like wispy texture). The upper unit is white and reddish organodetrial, and calcsiltite limestone. In some area are stromatolitic or with desiccations cracks. In areas, especially where devoid of stromatolites, closely and regularly spaced vertical tubular holes occur. Such holes were interpreted by previous authors as reed stalks [6]. In the study area, these holes usually of uniform dimension though two groups can be distinguished but separately. The vertical tubular holes are seen repeatedly at many levels. Terrigenous sandy influx increase towards the top as it gradually changes into sandy limestone and calcareous sandstone. Oxygen and isotopes studies on selected limestone samples show negative values of $\delta^{18}O$ and $\delta^{13}C$, which indicate fresh water limestone deposited in cool temperature climate [35].

Dibdibba Formation (? upper-Miocene-Pliocene-Pleistocene): Macfadyen in 1938 is the first to mention the Dibdibba beds from the Birjisiya area [5and 6]. Later Owen and Nasr in 1958 described this as a formal lithostratigraphic unit but without specifying a type locality [9]. The lithology of the Dibdibba Formation in the Birjisiya area comprise mainly of sand and gravel of igneous rocks including pink granite, various liver-coloured, and slate grey intrusive, dolerite etc., and white quartz pebbles. Not infrequently the rock is cemented to hard grit. Buday (1980) reviewed the literature on the lithology of Dibdibba Formation, and maintained virtually the same lithology in addition to some limestone, marl, silty claystone and some anhydrite. The age of the Dibdibba Formation is uncertain owing to the lack of age determining index fauna. The accepted age is considered as Upper Miocoene-Pilocene-Plesistocene.

Dibdibba Formation is penetrated in two boreholes namely Kh-9 at Bataya Police Center, and Kh-10′ at Ritchi. This formation outcrops in the southern corner of the study, as well as in the adjacent areas as well. The thickness of the formation in Kh-9 is about 29 metres, and in Kh-10′ is about 81 metres. In the later borehole, the formation can be divided into two units. The unit is more clayey.

The Dibdibba Formation in the studied boreholes is comprised of white, pale grey and pale pink quartzose sandstones. Coarse, medium and fine grained, pebbly and/or granular at times. The grains are subangular to subrounded. The sandstone are generally friable though not uncommonly are medium tough. The cement is fine to medium crystalline calcite. Gravel size particles are not restricted to particular levels. The lower part in Kh-9′ has a distinctive bimodality.

The Dibdibba Formation is found in Kh-9, and in many outcrops fond to overlie the Fatha Formation conformably as seen in many oil wells and outcrops. In the absence of the Fatha Formation, it would be difficult to distinguished both Ghar Formation and Dibdibba Formation due to their close lithological resemblance. Nonetheless in Kh-10′, the contact is placed at the top of the eight metres marl bed which possibly belongs to the Fatha Formation.

Conclusions:

Findings worth mentioning include the following:

1. The observation that with the exception of the Paleogene succession, the Upper Cretaceous and Neogene succession are no different from those found in other parts of southern Iraq. For instance, the Upper Cretaceous sequence was found to be constituted of the common Hartha, Qurna, and Tayarat Formations. The same could be said about the Neogene sequence which is found to be again made of the common Ghar, Euphrates, Fatha, Zahra and Dibdibba Formations.
2. In contrast, the Paleogene succession is found slightly different from those commonly encountered in other parts of southern Iraq. This difference emanates from the intense sulphidization as manifested in the common occurrence of anhydrite, gypsum, and vanished evaporite being observed through the Paleogene sediments of south west, Iraq. Because this phenomena exhibits strong lateral variation, this sequence was divided into an evaporitic portion, which is introduced in this article under the name of the Jerishan Group (Paleocene-upper Eocene), inclusive of Umm Er Radhuma, Rus/Jil, and Jil Formations. The latter

formation is newly introduced stratigraphic rock unit representing the non-evaporitic equivalent for the Rus Formation. The less evaporitic portion of the Paleogene is found to be the same as the ones found in other parts of the south Iraq. That is inclusive Umm Er Radhuma, Rus, and Dammam Formations.

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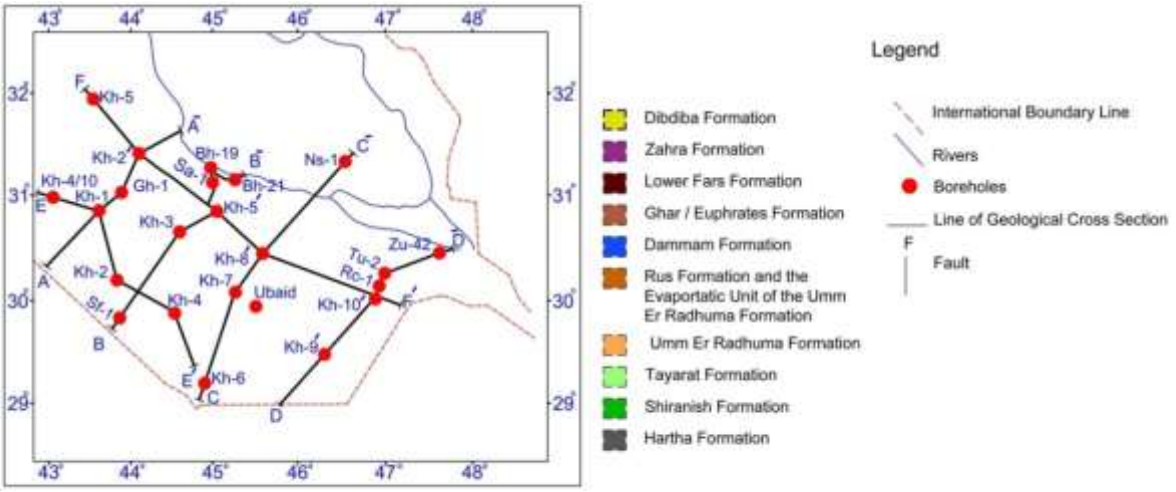
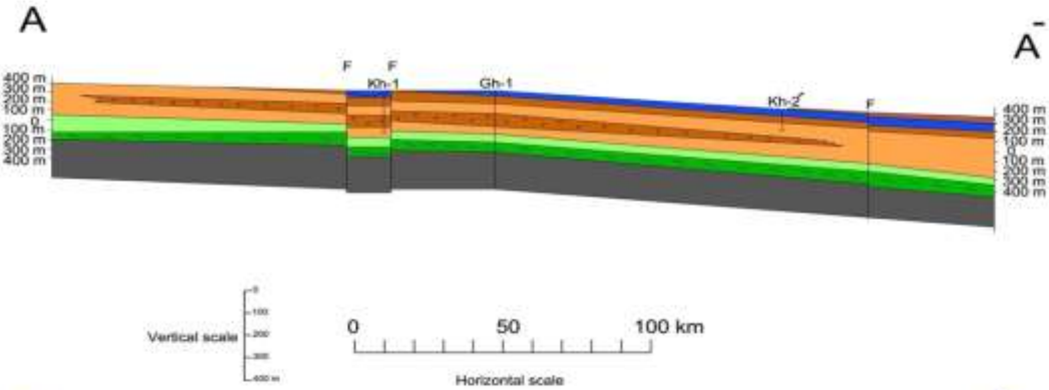
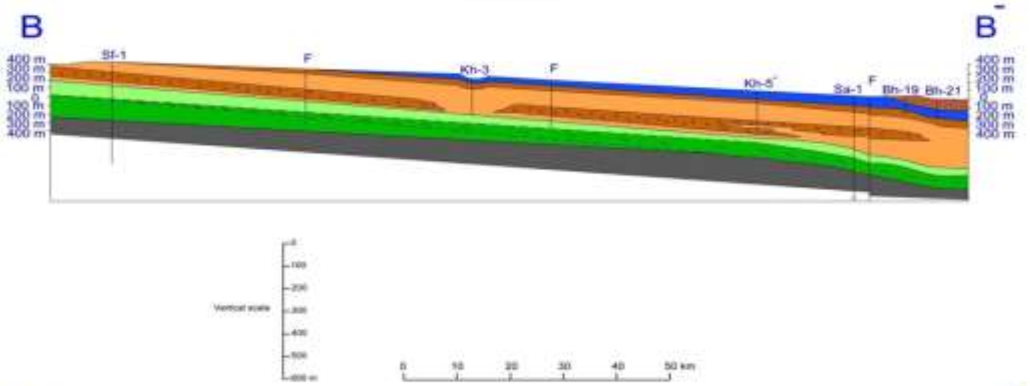
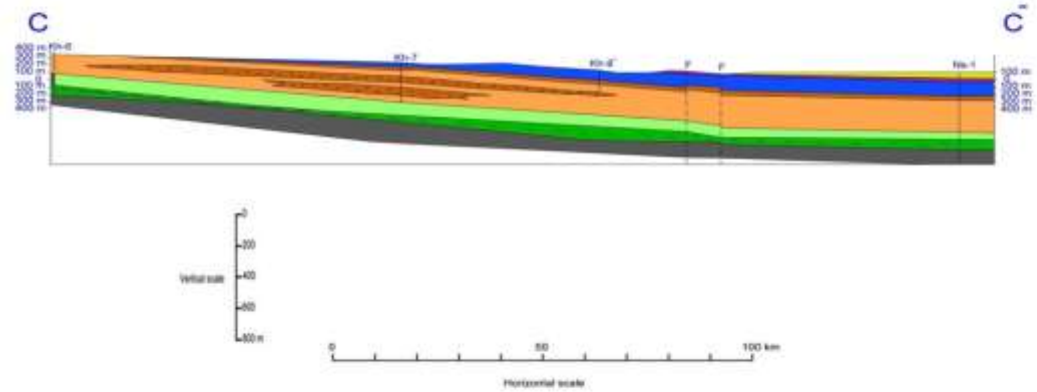
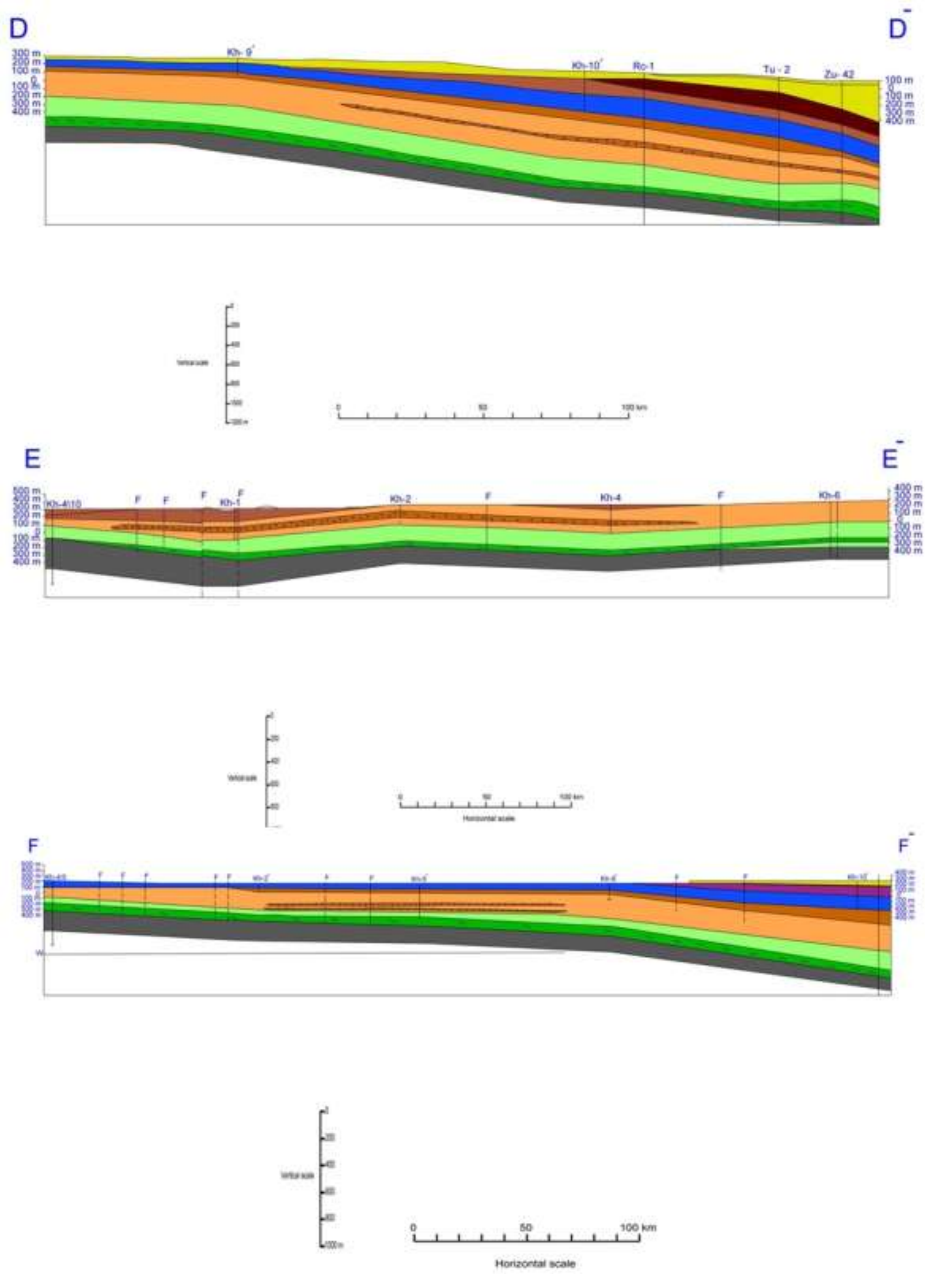
APPENDIX I: Map showing cross section lines locations, Legend and the cross sections.



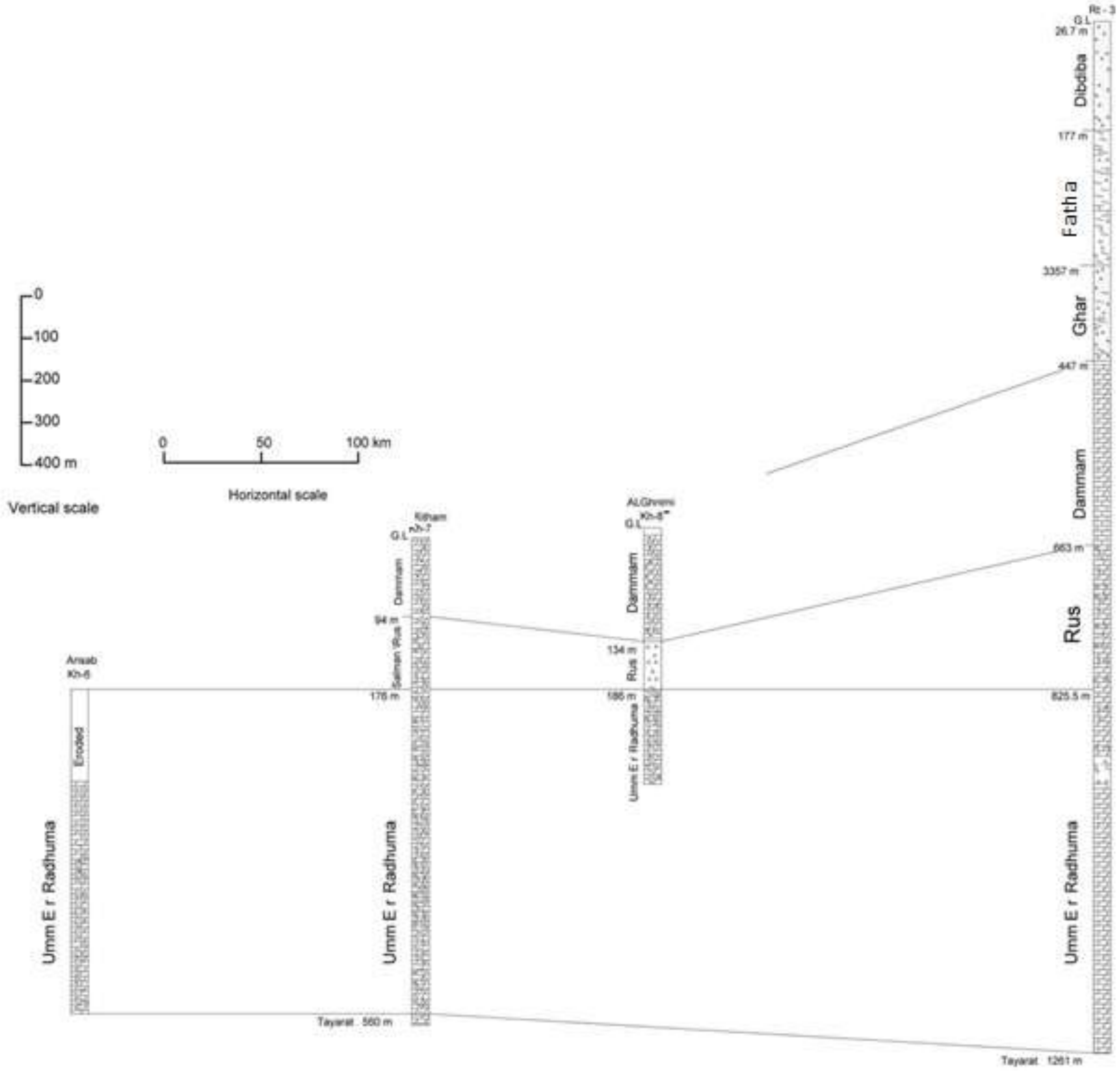


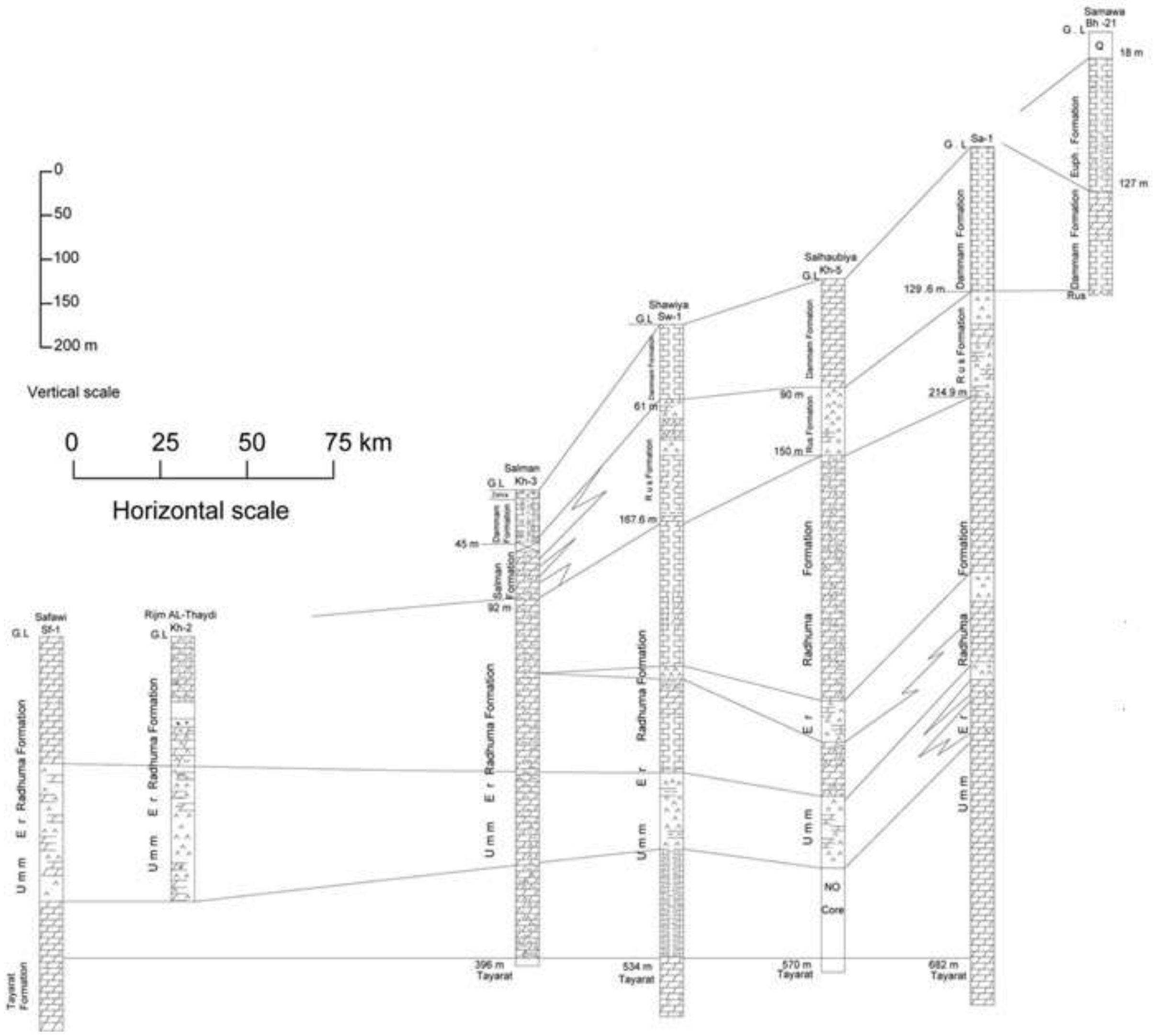


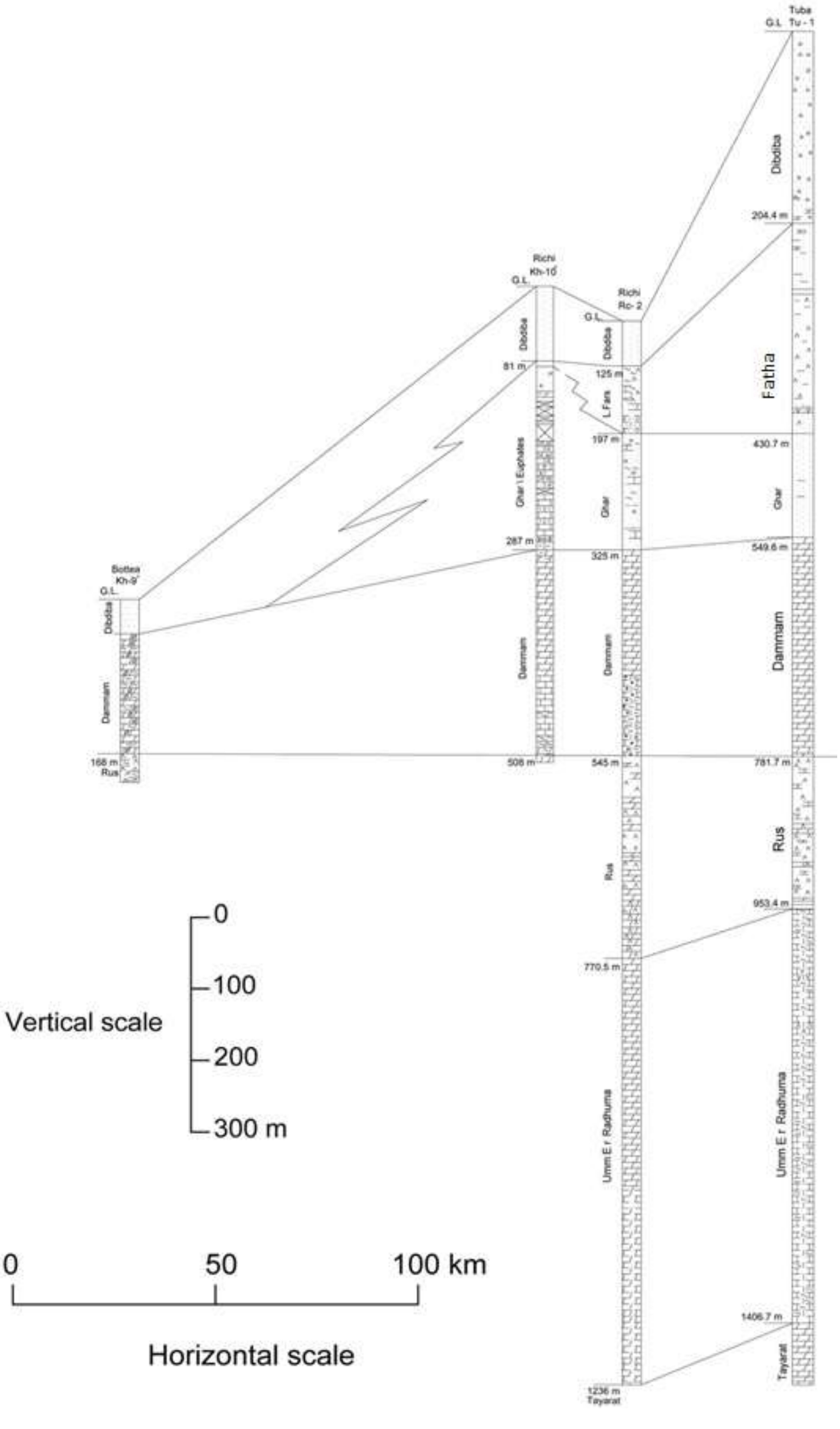



D
D-
Kh-9
Kh-10
Ro-1
Tu - 2
Zu-42
E
E-
Kh-4/10
Kh-1
Kh-2
Kh-4
Kh-6
F
F-
0
50
100 km
Horizontal scale

APPENDIX II: Stratigraphic correlation diagrams.




Vertical scale
Horizontal scale
0 25 50 75 km
Safawi Sf-1
Rijm AL-Thaydi Kh-2
Salman Kh-3
Shawiya Sw-1
Salhaubiya Kh-5
Sa-1
Samawa Bh -21
Umm Er Radhuma Formation
Rus Formation
Dammam Formation
Salman Formation
Tayarat Formation
NO Core
396 m Tayarat
534 m Tayarat
570 m Tayarat
682 m Tayarat



Bottea
Kh-9
G.L.
Dibdiba
Dammam
168 m
Rus
Richi
Kh-10
G.L.
Dibdiba
81 m
Ghar \ Euphates
287 m
Dammam
508 m
Richi
Rc- 2
G.L.
Dibdiba
125 m
L.Fars
197 m
Ghar
325 m
Dammam
545 m
Rus
770.5 m
Umm E r Radhuma
1236 m
Tayarat
Tuba
Tu - 1
G.L.
Dibdiba
204.4 m
Fatha
430.7 m
Ghar
549.6 m
Dammam
781.7 m
Rus
953.4 m
Umm E r Radhuma
1406.7 m
Tayarat
0
100
200
300 m
Vertical scale
0
50
100 km
Horizontal scale