GENESIS AND AGE DETERMINATION OF AL-SALMAN DEPRESSION, SOUTH IRAQ

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ABSTRACT

Al-Salman Depression is one of the largest karst forms in the Southern Desert of Iraq. It is of doline type, being formed in carbonates of Dammam Formation of Eocene age. The length of the depression is 20 Km, whereas, the width is variable, it is (6.5, 10 and 4.5) Km, in the northern, central and southern parts, respectively, whereas, the depth ranges from (5 – 35) m.

The Iraqi Southern Desert is one of the most extensive karstified areas in Iraq. Different types and forms of karst were developed with different sizes. Among the karst forms is Al-Salman Depression. The main reason of karstification is the presence of the carbonates of the Dammam Formation, which are underlain by the Rus Formation (Early Eocene); it consists mainly of anhydrite with limestone interlayers.

The Pleistocene Period witnessed wet climate in the studied area, which had contributed in the karstification of the Iraqi Southern Desert, in which karst forms have played a big role in development of special landscape, which is characterized by special drainage system and enormous amount of closed depressions and blind valleys. Originally, Al-Salman Depression was consisting of three main depressions, which merged together due to karstification, head ward erosion and collapsing parts of the rims. The presence of the sediments of Zahra Formation (Pliocene – Pleistocene) in the Salman Depression indicates Pliocene and most probably uppermost Late Miocene age for the depression that has developed due to karstification and collapsing, which are still active processes. This age and genesis hold good for all those large depressions in the Iraqi Southern Desert.

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المستخلص

يعتبر منخفض السلمان أحد أكبر المنخفضات في الصحراء الجنوبية العراقية، وهو من نوع "دولاين" والذي تكوّن ضمن صخور تكوين الدمام من عمر الإيوسين. يبلغ طول المنخفض 20 كم، بينما يتراوح عرضه بين (4.5، 10 و 6.5) كم، في المناطق الشمالية والوسطى والجنوبية، على التوالي، أما عمقه فيتراوح من (5 – 35) متر.

تعتبر الصحراء الجنوبية العراقية أحد أكثر المناطق المتخسفة في العراق، حيث تكونت أنواع عديدة من ظواهر الكارست وبأشكال مختلفة، ومن هذه الأشكال المتميزة منخفض السلمان. إن السبب الرئيسي للتخسف هو وجود الصخور الكاربوناتية لتكوين الدمام والذي يسفله تكوين الرص ويتكون من صخور الأنهايدرايت مع تداخلات من الصخور الكلسية.

إن عصر البلايستوسين يعتبر من الفترات المطيرة جداً والذي ساهم في تكون التخسفات في الصحراء الجنوبية العراقية، حيث ساهمت الأشكال المتعددة للتخسفات بتكون شكل أرضي خاص (landscape) في المنطقة، يتميز بنظام تصريف خاص مع العديد من المنخفضات المغلقة والوديان العمياء. إن منخفض السلمان كان يتألف من ثلاثة منخفضات رئيسية، تلاحمت مع بعضها بسبب التخسف والتعرية الرأسية والانهيارات.

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إن وجود صخور تكوين الزهرة (البلايوسين – البلايستوسين) في المنخفض دلالة على إن عمر المنخفض هو البلايوسين وربما المايوسين المتأخر، وتكون بسبب عمليات الإذابة والتخسف والتي لا تزال مستمرة إلى الآن. وهناك أدلة أخرى على تقدير عمر تكون المنخفض، وهذا العمر وأصل النشوء ينطبق على كل المنخفضات الكبيرة في الصحراء الجنوبية العراقية.

INTRODUCTION

Al-Salman Depression is one of the largest depressions in the Iraqi Southern Desert, which is characterized by dense karstification features; it is a well-known depression in the Iraqi community, called "Nuqrat Al-Salman", which means Al-Salman Depression in the Iraqi slang language. The reason for being well-known, is that the depression was used as political prison since the forties of the last century, but it is abandoned hitherto. Many other depressions occur nearby to Al-Salman Depression; among them are Al-Haddaniya and Al-Sa'ah Depressions, and other karst forms of different forms and sizes.

Al-Salman Depression is developed within the Middle Member of the Dammam Formation, with longitudinal form; being almost in N – S direction. The floor is covered partly by Zahra Formation (Pliocene – Pleistocene) and partly by depression fill sediments of Holocene age. However, the bedrock is exposed in some parts, especially near the rims and in the main valleys, which drain towards the depression.

▪ Location

Al-Salman Depression is located in the Iraqi Southern Desert, 129 Km south of Samawa city, which is about 550 Km south of Baghdad. The Salman town is located in the northwestern part of the depression, which has its name from the name of the town (Fig.1).

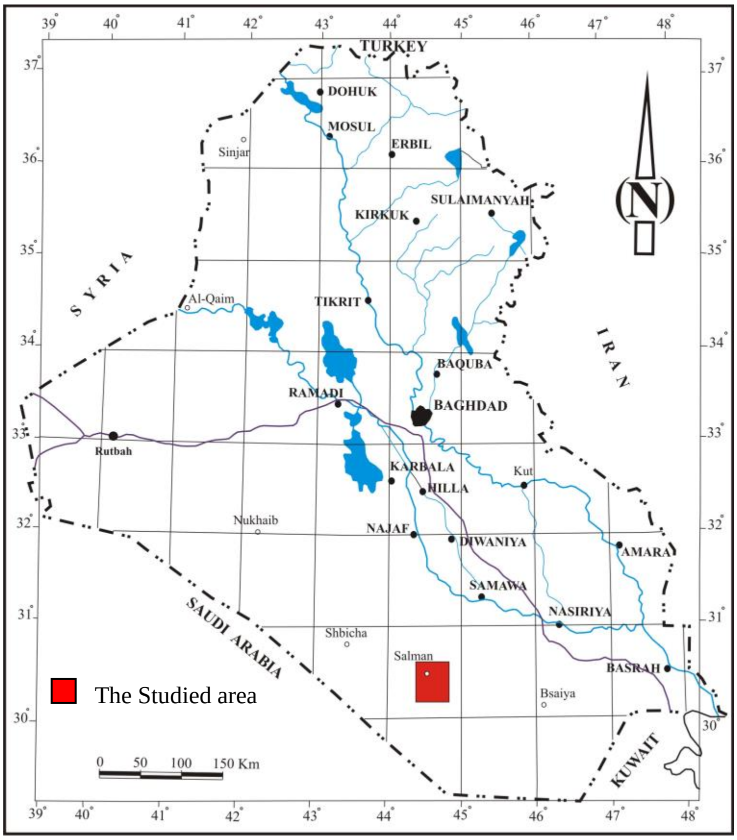

Fig.1: Location map of the studied area

▪ **Aim**

This work aims to study the genesis and age estimation of Al-Salman Depression, using sound data with field work including checking the existing data and to acquire new data about the characteristics of the depression, which are used to prove the genesis and age estimation.

MATERIALS USED AND METHODOLOGY

In order to achieve the aim of this study, the following materials were used:

- Topographical maps at scale of 1: 25000, 1: 100000 and 1: 250000
- Geological maps at different scales.
- Tectonic and geophysical maps.
- Landsat images, Google Earth images and aerial photographs.

The aforementioned data were used as an integrated study to achieve the indications about the genesis and age estimation of Al-Salman Depression. Topographical maps were used to indicate the dimensions of the depression. To deduce the type of the exposed rocks and Quaternary sediments, geological maps and reports were used. Tectonic, structural, and geophysical maps were used to indicate the presence or otherwise of structural features, such as faults, folds, which might have contributed in the development of the depression. Aerial photographs, Landsat images, and Google Earth images were interpreted to indicate the geomorphological phenomenon, which have contributed in the development of the depression. All these data, beside a field visit to the depression to acquire the required data were used to achieve sound indications about the genesis and age estimation of the depression.

▪ **Previous Work**

Although no much specialized work was carried out concerning karstification and its influence on the development of large depressions in the Iraqi Southern Desert, but the hereinafter mentioned work has direct and/ or indirect relation with this study.

– Al-Ani and Ma'ala (1983) executed regional geological mapping of the eastern part of the Southern Desert in which the studied area is located. They reported about the karstification in the limestone of the Dammam Formation.
– Hamza (1997) compiled the Geomorphological Map of Iraq at scale of 1: 1000000 and considered the studied area as a karstified region.
– Sissakian and Ibrahim (2005) compiled the Geological Hazards Map of Iraq at scale of 1: 1000000 and included the studied area within the karst hazards region.
– Sissakian and Al-Mousawi (2007) reported about the karstification problems in Iraq and mentioned many examples from nearby areas of the studied area.
– Ma'ala (2009a) reported about the geomorphological units in the Iraqi Southern Desert and mentioned that the studied area is within the karst unit.
– Sissakian *et al*. (2011) reported about the geological hazards in Iraq and included the studied area within the karst hazards region, and mentioned many examples.
– Sissakian *et al*. (2012) studied the karstification influence on the drainage patterns in nearby areas to the studied area, and concluded that there are many abnormal drainage forms.

GEOLOGICAL SETTING

▪ Geomorphology

The studied area is a flat floored depression; the rims are intensely dissected by valleys, which flow towards the depression. According to Hamza (1997), the studied area is a part of large karst region. According to Sissakian and Ibrahim (2005) and Sissakian *et al*. (2011), the study area is a large depression within a karstified area. Ma'ala (2009a) reported about the geomorphology of the Iraqi Southern Desert and mentioned the following data.

─ **Chemical Weathering Processes:** These are inherited from pre-Miocene phase, which were continued during Late Miocene – Holocene. Some of the subterranean hollows and caves were enlarged and collapsed during Late Miocene – Pleistocene.

─ **Solution Processes:** The secondary fractures, which allowed the rain water to percolate, have accelerated the solution processes of limestone, and led to produce karst features (dolines, sinkholes, blind valleys). At the same time, some of subterranean hollows and caves have been collapsed to produce second phase of collapse sink depressions.

─ **Sinkholes:** Areas built-up by limestone are marked by sinkholes, formed due to dissolving by water (giving a more distinctive type of caves); even underground river channels being developed. The limestone of Al-Hijara Unit is marked by sinkholes, uvalas, dolines, caverns and karst valleys. Sissakian and Ibrahim (2005) pointed out that the sinkholes are common types in the Southern Desert, which are developed due to dissolving of limestone. Sinkholes are well developed in the anhydrite land, which can be named as Limestone Pavement (Bates and Jackson, 1983). It consists of hundreds of sinkholes, which are filled by polygenetic sediments.

─ **Karst Valleys:** These are subterranean passages running in NE direction, developed by solution of limestones (Eocene). Several of them were collapsed and produced abandoned valleys, which often end abruptly as blind valley (karst valleys).

▪ Stratigraphy

The studied area is covered by Dammam and Zahra formations of Eocene and Pliocene – Pleistocene age, respectively (Fig.2). The exposed parts of the two formations in the studied area are briefly described hereinafter.

─ **Dammam Formation:** The formation is divided into three members: Lower, Middle and Upper (Al-Mubarak and Amin, 1983) the age is Eocene. In the studied area, however, only the Middle Member is exposed. Jassim and Al-Jiburi (2009) reported about the Middle Member of the Dammam Formation in the Iraqi Southern Desert. Only two units are exposed in the studied area, these are:

1) Shawiya Unit: This unit consists of thickly bedded to massive, recrystallized, nummulitic limestone, alternated with thin horizons of limestone and (2 – 3) horizons of shelly limestone.

2) Chabd Unit: The lower part (15 – 20 m) consists of massive limestone, overlain by thinly bedded, nummulitic limestone, followed by (11 – 14) m of massive and crystalline limestone. The middle part (5 – 10 m) consists of alternation of thick horizons of thickly bedded and nummulitic limestone. The upper part (15 m) consists of thickly bedded nummulitic limestone.

─ Zahra Formation: Al-Mubarak and Amin (1983) mentioned that the Zahra Formation in the Southern Desert is composed of (1 – 3) cycles; its age is Pliocene – Pleistocene. Generally, each cycle is composed either of alternation of claystone, and limestone or alternation of claystone, sandstone, and limestone. The claystone beds (thickness of each bed is 1 – 5 m) are red to reddish brown, soft, conchoidally fractured. The sandstone beds (thickness of each bed is 1 – 2 m) are light to yellowish brown, friable, massive, medium to coarse grained, cemented by calcareous and gypsious materials. The limestone beds (thickness of each bed is 0.5 – 4 m) are white to whitish grey and pink, hard to very hard, bedded, undulated, highly jointed, highly recrystallized, rich with burrows, partly sandy and fossiliferous. The thickness of the Zahra Formation is (3.5 – 14.5) m.

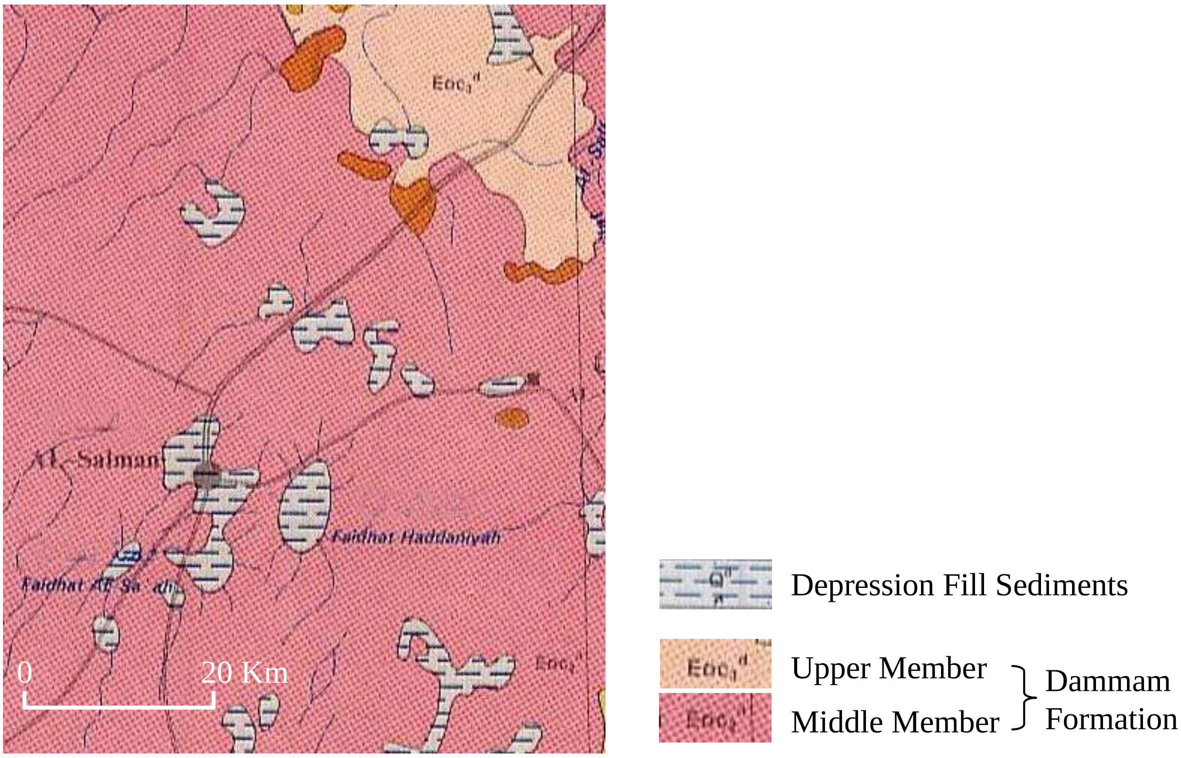

Fig.2: Geological Map of the studied area (after Sissakian, 2000)

▪ Structural Geology

The studied area is located within the Stable Shelf of the Arabian Plate (Al-Kadhimi *et al*., 1996). However, according to Fouad (2012) it is located within the Inner Platform of the Arabian Plate. The area had not suffered from tectonic disturbances, although Al-Mubarak and Amin (1983) have mapped many faults, but not in nearby vicinity of the studied area. Ma'ala (2009b) reported about the tectonic and structural evolution of the Iraqi Southern Desert. Hereinafter is a brief review.

The Southern Desert is a part of the northern Arabian Platform. The platform is divided into two parts, a stable one to the west and unstable one to the east. The boundary between them is taken along Euphrates Fault Zone (extension of Abu Jir Fault Zone).

The Late Miocene (~11 Ma) was the time of the final transition to continental condition, as collision along the eastern boundaries of the Arabian Plate proceeded, then culminated through the Pliocene (5.3 Ma). The compression, imposed lateral movement along the

NW – SE trending faults, and caused uplifting of the Stable Shelf area, including Safawi Arch and Dibdibba Basin.

The Pliocene – Pleistocene (5.3 – 2.83 Ma) was the time of strong influx of terriginous 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).

Sissakian and Deikran (1998) showed that the Southern Desert was uplifted since the Late Miocene with amount of (50 – 350) m, they also deduced that the rate of the regional uplift is about (0.1 – 0.2) cm/ 100 year, in the area involved.

AL-SALMAN DEPRESSION

▪ **Characteristics**

Al-Salman Depression is one of the largest depressions in the Iraqi Southern Desert, its length is 20 Km, whereas the width is (6.5, 10 and 4.5) Km, in the northern, central and southern parts, respectively (Fig.3). It is surrounded by rims, which range in height from (5 – 35) m, the eastern one being the least inclined with lesser height, as compared with other rims. The rims are inclined towards the center of the depression due to collapse of the limestone beds. The inclination amount varies from (5 – 25)° (Fig.4). The floor of the depression is almost flat with some irregular undulations, varies in elevation from (200 – 244) m a.s.l, whereas the surrounding areas vary in elevation from (258 – 287) m (Fig.3). It has longitudinal shape; being almost in N – S direction, the western rim is the higher and steeper, among the others. The term "collapse doline" fits with the aforementioned characteristics for Al-Salman Depression (White and White, 2006).

The N – S direction of Al-Salman Depression is a major and common trend of the main depressions in the Iraqi Southern Desert, such as Al-Had'daniyah and Faidhat Al-Sa'ah Depressions (Fig.2). The N – S trending rims in all existing large depressions in nearby vicinity of the depression, except those, which have circular or oval shapes, are more persistent than the other rims. This might indicate a regional structural trend in the involved area, but all existing geophysical, geological and structural maps did not show such features, neither on surface nor in subsurface. Moreover, the sinkhole in the floor of Al-Salman Depression is also developed along a main fracture zone that trends in 185°, which is almost in N – S trend. Moreover, towards east; in the southern part of the Mesopotamian Plain, all subsurface structures have N – S trend (Al-Kadhimi *et al*., 1996), this might have close relation to the aforementioned trend of the rims.

Al-Salman Depression originally was consisting of three main depressions. But, they were merged together due to continuous collapsing; karstification and head ward erosion, which contributed in removing parts of the rims to develop the main depression. Nowadays, the southern rim of the depression suffers from extensive head ward erosion and will merge (conjugate) with the neighboring Al-Sa'ah Depression (Point **A**, Fig.3), which in turn its northern rim suffers from extensive head ward erosion. The remaining distance between the two depressions to be merged is only 250 m (Fig.3). The remaining part of the rim will be removed after a considerable geological time, and hence the two main depressions' Al-Salman and Al-Sa'ah will form only one depression. The same holds good with the easterly lying depression (Al-Had'daniyah), which will conjugate with the eastern rim of Al-Salman Depression (Fig.3); especially the northeastern part of the latter.

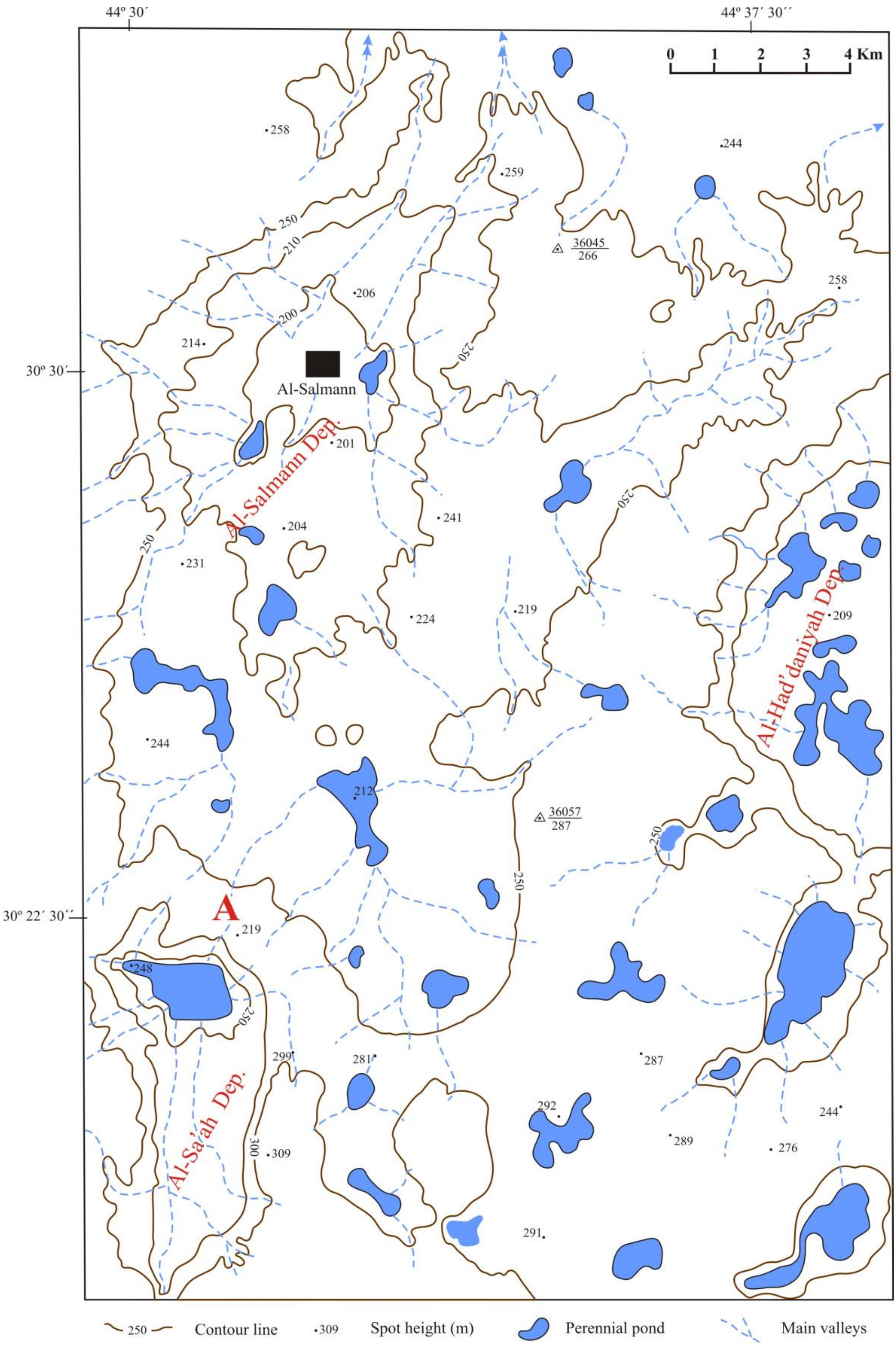

Fig.3: Topographic Map of Al-Salman Depression,
with neighboring Al-Sa'ah and Al-Had'daniyah Depressions

Fig.4: The western rim of Al-Salman Depression
Note the inclination of the beds towards the depression,
due to collapsing of the beds towards the depression

- **Infilling Materials of Al-Salman Depression**

Al-Salman Depression is infilled partly by the Zahra Formation, and mainly by Quaternary sediments. The thickness of the Quaternary sediments varies from less than one meter to about 15 m. In a sinkhole located in the floor of the depression, the thickness of the Quaternary sediments is about 9 m. They consist of three cycles, which are fining upwards, covered by gypcrete. The sediments consist of angular limestone fragments, which range in size from (1 – 10) cm, cemented by clayey and sandy materials (Fig.5).

The developed three cycles in the Quaternary sediments indicate successive three wet and dry phases during Pleistocene. The lower cycle includes the coarser fragments, as compared to the other two cycles. This is attributed to wetter climate, as compared to the climate of the other two cycles. Whereas, the uppermost part, which consists of gypcrete (3.5 m thick) (Fig.6) indicates that it is developed either in Late Pleistocene or early Holocene, during almost dry phase. The contact between the gypcrete and the underlying fluvial sediments is irregular, indicating a break in sedimentation (Fig.6).

Some of the existing rock fragments within the Quaternary sediments and/ or the exposed bedrock of the Dammam Formation in the floor of Al-Salman Depression are coated by desert varnish (Fig.4). The concentration of the coated fragments is largely variable in different places within the floor of the depression. Moreover, the rock fragments are locally surrounded by wind-blown sand (Fig.4). The sand is accumulated in form of sheets of different thicknesses, which did not exceed 1 m. Wind-blown sand is also accumulated locally along the rims of the depression, they often show ripple marks, as those in sand dune fields.

Fig.5: Quaternary sediments in the floor of Al-Salman Depression, as deduced from a sinkhole

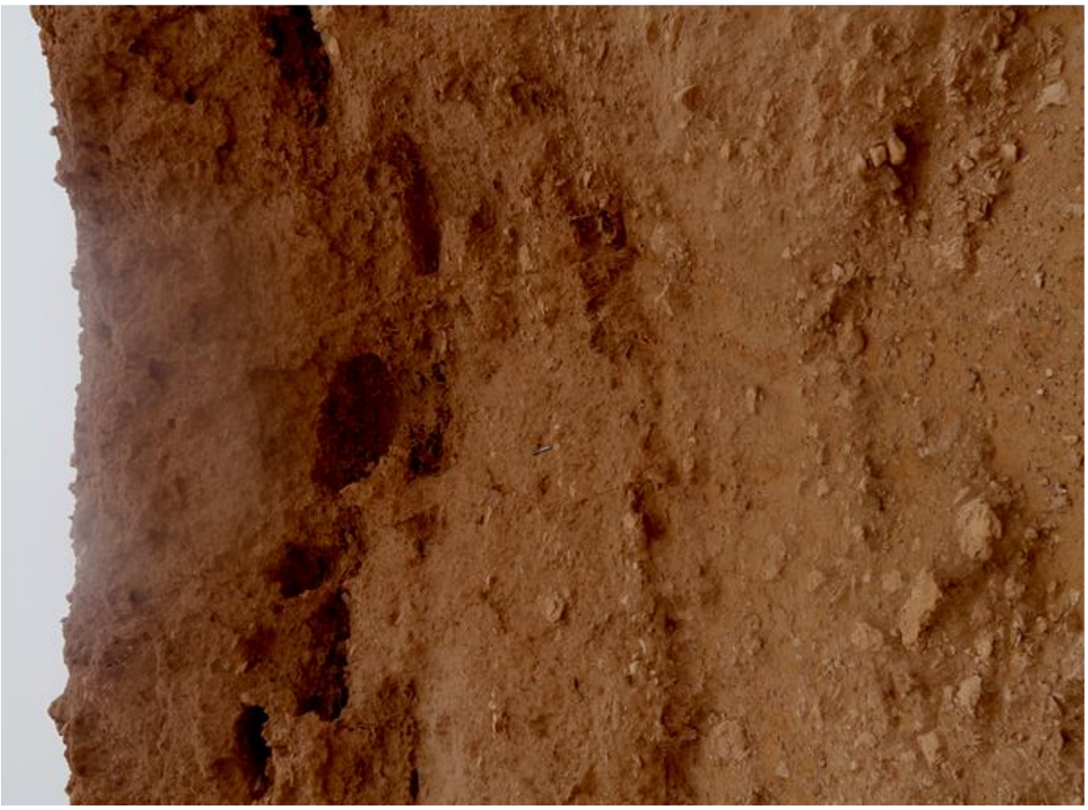

Fig.6: Gypcrete covering the Quaternary sediments in the floor of Al-Salman Depression

GENESIS AND AGE ESTIMATION

▪ General

The karst topography is a landscape shaped by the dissolution of a soluble layer of bedrock, usually carbonate rocks such as limestone (NWE, 2008). The studied area is of karst topography, which is formed due to mildly acidic water action on soluble bedrocks. The karstification in the studied area and near surroundings has resulted a variety of large or small scale features. Due to the presence of many sinkholes and a main doline in the area, then the term "Uvalas" can be used (NWE, 2008). Because the subsurface is also considered in karstification of the studied area, then the term "karst terrane" is used instead of "karst terrain" (Field, 1999; Ford, 2003, and Wekipedia, 2009).

▪ Activity of the Karstification

The karstification is still an active process in the whole Iraqi Southern Desert, as it is evident from development of many karst forms. A large sinkhole is developed in the floor of Al-Salman Depression, about 9 Km east of Al-Salman town. It is defined by the following coordinates: Longitude 44° 37' 02.6" E and Latitude 30° 29' 39.8" N. The groundwater level in the sinkhole is 20 m (below the depression floor), the depth cannot be estimated, whereas the diameter is 30 m and 16 m; for the outer (upper) and inner (lower) diameters, respectively. The intense weathering of the Quaternary sediments, development of the sinkhole and the presence of a blind valley (Fig.7) are good indication for the continuity of the karstification process.

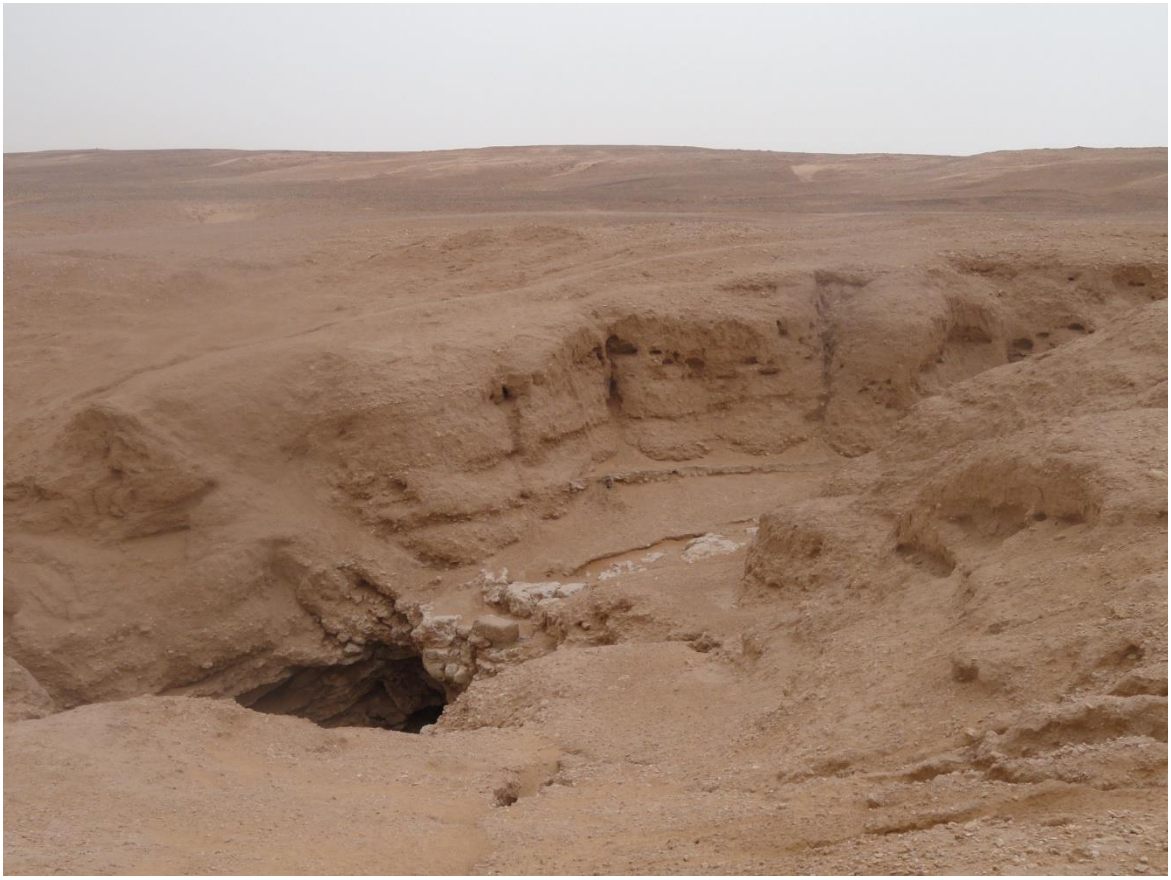

Fig.7: Sinkhole in the floor of Al-Salman Depression

The following event is another indication for continuation of the karstification phase in the Iraqi Southern Desert. On 5/ 3/ 1944 a large sinkhole was formed in limestone beds of the Dammam Formation (Eocene), after collapse of the roof forming beds, near Al-Shbicha police post (Fig.1), which is located about 70 Km west of Al-Salman. The collapse continued for a month, the local people, few kilometers from the formed sinkhole felt the sound of the collapse, whereas the local people from much far areas from the formed sinkhole felt ground shocks. The diameter and the length of the sinkhole are 33 m and 27 m, respectively. The estimated volume of the collapsed rocks, by a petroleum geologist is 1 230 000 cubic meters (Soosa, 1966).

Because the karstification process in the studied area is still active, therefore, both "**holokarst**" and "**merokarst**" types are present in the area. The former means wholly developed karst, whereas the latter means imperfectly developed, with some karstic features (Gams, 2003). The uppermost beds of the exposed limestones in the sinkhole are highly deformed, crushed and fragmented (Fig.8), which also indicate the activity of the karstification, and it is already a wholly developed karst, which means it is of "holokarst" type.

Fig.8: The uppermost layers of the exposed limestones in the sinkhole.
Note the intensity of deformed, crushed and fragmented layers
(overlain by Quaternary sediments)

▪ **Genesis**

Both the Dammam Formation and the underlying Rus Formation consist mainly of carbonate, for the former, and anhydrite with limestone, for the latter. Both rock types are highly soluble by water. Therefore, during the wet phases; starting from Early Pliocene and even uppermost Late Miocene, enormous quantities of these rocks were dissolved. The Rus Formation, which is about (50 – 75) m thick is totally dissolved in the studied area and near surroundings, as deduced from the drilled boreholes; towards north and northeast, within the Detailed Geological Mapping Project, started since 2010 and is still in progress (Dhiya'a Al-Deen Ajar and Immad Kadhum, personal communications, 2012). The depth of the drilled boreholes is 150 m, in majority of them it was found that the Dammam Formation is underlain directly by Umm Er Radhuma Formation, indicating total absence of the Rus Formation, due to dissolving. The continuous dissolution of the Rus Formation and the lower parts of the Dammam Formation lead to the subsidence of the layers of the Dammam Formation, then collapsing of the uppermost layers of the exposed Dammam Formation. Consequently, a large collapse doline was developed, which is called Al-Salman Depression. Development of such large karst forms due to solution of carbonate and/ or evaporite rocks, then collapsing of the overlying rocks (the roof) is a well-known phenomenon worldwide (White and White, 2006).

▪ **Age Estimation**

Ma'ala (2009a) claimed Pliocene age for Al-Salman Depression, Sissakian *et al*. (2012) adopted the claimed age. However, during the present study a thorough field check was carried out to acquire data, which were used in estimating the age of the karstification. The results showed that the age of the depression is Pliocene and may be even uppermost Late Miocene. The presence of the Zahra Formation (Pliocene – Pleistocene) in the depression confirms this estimated age, because the depression was present before deposition of the Zahra Formation, which means before Pliocene. Moreover, development of such huge depression and many others in near surroundings, with surface area of about 200 Km^2 and volume of about $(1 – 7) \times 10^9$ m^3 needs very long time to be developed, after dissolving of the rocks and collapsing of the roof. Therefore, the uppermost Late Miocene age seems to be more relevant than Pliocene. However, the collapsing was not totally developed during Late Miocene, but most probably had started during Late Miocene; accelerated during Pliocene and reached the climax during the successive wet phases during Pleistocene and is still in progress, as the dissolution is in progress, but with lower degrees of karstification.

The western rim of Al-Salman Depression, especially southwest of Al-Salman town, suffers from extensive erosion due to one of the valleys that drain the flat surrounding area; in the west towards the depression. The height of the rim is about 25 m, almost vertical with clear exposures of the Dammam Formation (Fig.9). There, the collapsed parts of the beds are already removed by erosion, but few tens of meters, northwards; where the rim does not suffer any more from the erosion of the mentioned valley, the collapsed beds are still preserved (Fig.4). Such phenomenon, to erode the collapsed beds, certainly needs a long time, which cannot be during Holocene and even Late Pleistocene. Therefore, the rim should be developed before this time interval, which proves that the depression was developed before Pleistocene. Moreover, the collapsed beds are almost in hanging position (Fig.4), indicating that their lowermost parts, which once were detached to the floor, are already removed by erosion. This is another prove that the depression was developed even before Pleistocene.

Fig.9: The western rim of Al-Salman Depression,
note that the collapsed parts of the beds are removed by erosion.
Therefore, no collapsed beds could be observed
(compare with Fig.4, which is few tens meters down stream)

DISCUSSION

The last phase of karstification in Iraq was during Pleistocene (Tyracek and Youbert, 1975 and Sissakian *et al*., 1986), when a wet climate was prevailing, successively. Although the climate nowadays is dry to semi-dry, in the Iraqi Southern Desert as a part of the main Iraqi climate, however, the authors believe that the last phase of karstification is still continuous as it is evidenced from the development of new karst forms and the rejuvenation of others, especially in the Southern Desert and other parts of Iraq, like Haditha vicinity (Sissakian and Al-Mousawi, 2007).

The aforementioned evidences are obvious indications for continuation of the Pleistocene phase of karstification, in the Iraqi Southern Desert, which is characterized by intense karstification. However, the authors believe that the karstification, there, could be older than Pleistocene for the following reasons: **1)** The karst morphology that prevails over very large areas of the Southern Desert, as indicated from topographic maps, aerial photographs and satellite and Google Earth images, and the presence of large circular forms with concentric drainage pattern, which are very common (Fig.10). **2)** The Deposition of the Zahra Formation (Pliocene – Pleistocene) in many of the large karst forms in the Southern Desert, like Al-Salman, Al-Had'daniyah and Fiadhat Al-Sa'ah Depressions, and other many depressions of different sizes. **3)** The absence of the Rus Formation (Early Eocene) in the subsurface sections of the area. It is composed mainly of evaporites, with subordinate limestone that are highly dissolved, by ground water, leading to the development of extensive karst morphology in limestones of the overlying Dammam Formation that crops out over majority parts of the Iraqi Southern Desert. However, the wedging out of the Rus Formation could not be ignored.

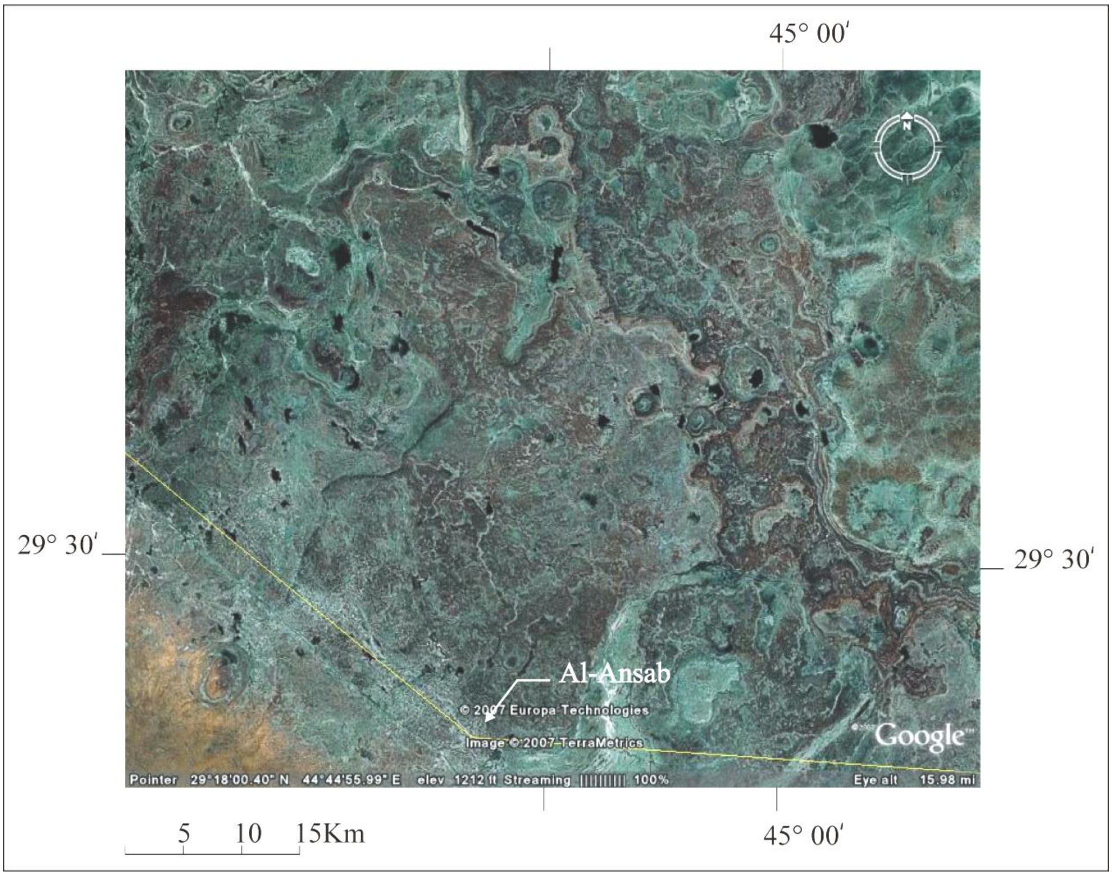

Fig.10: Karst morphology in the Iraqi Southern Desert.
Note the enormous circular forms,
which indicate different types of karst forms

In recently drilled water well, about 25 Km north of Al-Salman Depression, along Samawa – Al-Salman road, the Rus Formation was not encountered in the well (Oral communication with the driller on 06/ 05/ 2012). This is another indication for the dissolving of the Rus Formation, which contributes in development of large karst forms in the whole Iraqi Southern Desert, after subsidence of the lower beds of Dammam Formation and then collapsing of the uppermost limestone beds of the Dammam Formation. Therefore, the authors believe that the karstification, in the Southern Desert was developed probably during uppermost Late Miocene and/ or Pliocene, where the involved area was positive area, under the influence of continental depositional environment.

The continuous collapsing of the rims of Al-Salman Depression leads to its enlargement. A good example is the southern rim, which will be removed due to head ward erosion and collapsing, consequently the depression will be conjugated with its southerly neighboring Al-Sa'ah Depression, and latter on with the easterly neighboring Al-Had'daniyah Depression forming another very large depression. This is how Al-Salman Depression was developed in such large form. Such process certainly needs a long geological time. This is another indication that the depression is very old, might be developed during Early Pliocene and possibly even older; during the uppermost Late Miocene.

CONCLUSIONS

The present study has the following conclusions:

- Al-Salman Depression is a large doline of collapse origin. Originally, it was consisting of three main depressions, which were conjugated together forming the nowadays large depression.
- The enlargement process of Al-Salman Depression took place by continuous collapsing; due to karstification and head ward erosion, it is a continuous process, as evidenced by the southern rim, which will be removed and the depression will conjugate with Al-Sa'ah Depression, after a considerable geological time.
- The floor of Al-Salman Depression is covered partly by Zahra Formation and different types of Quaternary sediments.
- Al-Salman Depression is developed due to collapse of the roof beds, after dissolving of the underlying rocks. The presence of the Rus Formation contributed and accelerated the dissolving process, consequently the collapsing.
- Karstification process is still in progress, although not active like it was during wet phases of Pliocene – Pleistocene and even uppermost Late Miocene.
- The age of Al-Salman Depression is Pliocene – Pleistocene, however, uppermost Late Miocene age is most probably acceptable and could not be ignored.

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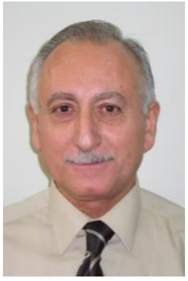

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