KARSTIFICATION AND RELATED PROBLEMS, EXAMPLES FROM IRAQ

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ABSTRACT

Karstification is a common phenomenon in different parts of Iraq, where large areas are involved, causing severe damages to infrastructures and occasionally life losses. The main Karstified rocks are limestone and gypsum. The latter is restricted to the Fat`ha Formation, which covers considerable parts of Iraq, especially in the Al-Jazira vicinity. Whereas, the former is exposed in different formations that are exposed almost every where. Among the involved formations are Euphrates, Anah, Dammam, Ratgah, Pilaspi, Aqra – Bekhme, Qamchuqa… etc. Among Quaternary deposits, the gypcrete is another potential deposits that are highly karstified after being in contact, shortly, by water. The gypcrete also covers considerable parts in Iraq.

Beside the economic lost caused due to karstification, some death causalities are also recorded. Moreover, in the Western Desert, karstification plays big role in miss leading the stratigraphic position of different horizons within different Jurassic and Cretaceous formations, making them in very complex situation, although they are in horizontal (not folded) position.

التخسفات والمشاكل المرافقة لها، أمثلة من العراق

فاروجان خاجيك سيساكيان و هالة عطا الموسوي

المستخلص

إن التخسفات ظاهرة معروفة في العراق، وتتأثر مناطق كبيرة بهذه الظاهرة وتسبب مشاكل وخسائر مادية كبيرة وخسائر في الأرواح أيضا. أن الصخور الرئيسية المتأثرة بالتخسف هي الكلسية والجبسية. وان الأخيرة تكون موجودة بشكل كبير في تكوين الفتحة والذي يغطي مناطق واسعة من العراق. بينما تتكشف الصخور الكلسية في مناطق عديدة في العراق وضمن تكوينات جيولوجية مختلفة مثل الفرات، عنة، الدمام، الرطكة، بيلاسبي، عقرة – بخمة، قمجوقة ... الخ. ومن ترسبات العصر الرباعي فان الجبكريت يشكل ترسبات قابلة للتخسف بعد تشبعها بالماء، وهي أيضا تغطي مناطق واسعة من العراق.

إضافة إلى الخسائر المادية الناتجة من التخسف فهناك خسائر بشرية مثبته أيضا. كما أن التخسفات في الصحراء الغربية العراقية سببت تعقيدا جيولوجيا في تكوينات عصري الجو راسي والطباشيري، بالرغم من كون المنطقة شبه مستوية لعدم تعرضها لعمليات الطي.

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INTRODUCTION

Different parts with considerable coverage areas in Iraq are suffering from karstification. Some of them are very old, since the Cretaceous, others are of Pleistocene age, some of them are inactive (fossil), however others are still active. Moreover, some are under development and many others are rejuvenated, after being inactive for long periods, as it is clear from the filling materials.

The main karstified rocks (in Iraq) are gypsum and limestone. The former is present in the Fat`ha Formation (Middle Miocene) as one of the main constituents that are alternated with green marl, red claystone and limestone in cyclic nature. The latter is present in many formations, like Euphrates, Jeribe, Anah, Rus, Dammam, Ratgah, Pilaspi, Aqra – Bekhme, Qamchuqa, Chia Gara, Najmah, Muhawir, Hussainiyat, Ubaid, Kurra Chine, Geli Khana, Chia Zairi ….etc.

KARSTIFIED AREAS IN IRAQ

The main karstified areas in Iraq are distributed in different parts. Hamza (1997) demonstrated the karstified areas within the Geomorphological Map of Iraq, scale 1:1 000 000. Moreover, Sissakian and Ibrahim (2005) demonstrated the karstified areas, in more details, within the Geological Hazards Map of Iraq, scale 1:1 000 000 (Fig.1). In Mosul vicinity the gypsum of the Fat`ha Formation is highly karstified, especially the Lower Member and are concentrated in the anticline areas. This is due to the thickness of gypsum beds, in the Lower Member and fracture density (Jibrail, 1990). However, this doesn't mean that no more karstified areas occur in Iraq. The two maps show the karstified areas in Iraq according to the available data, accuracy and scale limits of the aforementioned two maps.

KARSTIFICATION

The last phase of karstification in Iraq was during Pleistocene (Tyracek and Youbert, 1975 and Sissakian *et al*., 1986 a), when a wet climate was prevailing. Although the climate nowadays is dry to semi-dry, in majority parts of Iraq that are involved in karstification. However, the author believes 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 Haditha and the Southern Desert vicinities.

The following event is another indication for continuation of the karstification phase. 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 300 Km south of Baghdad. The collapse continued for a month, the local people, few kilometers from the formed sinkhole felt the sound of the collapse, whereas ground shocks were felt by the local people from much farther areas from the formed sinkhole. 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, (Sossa, 1966).

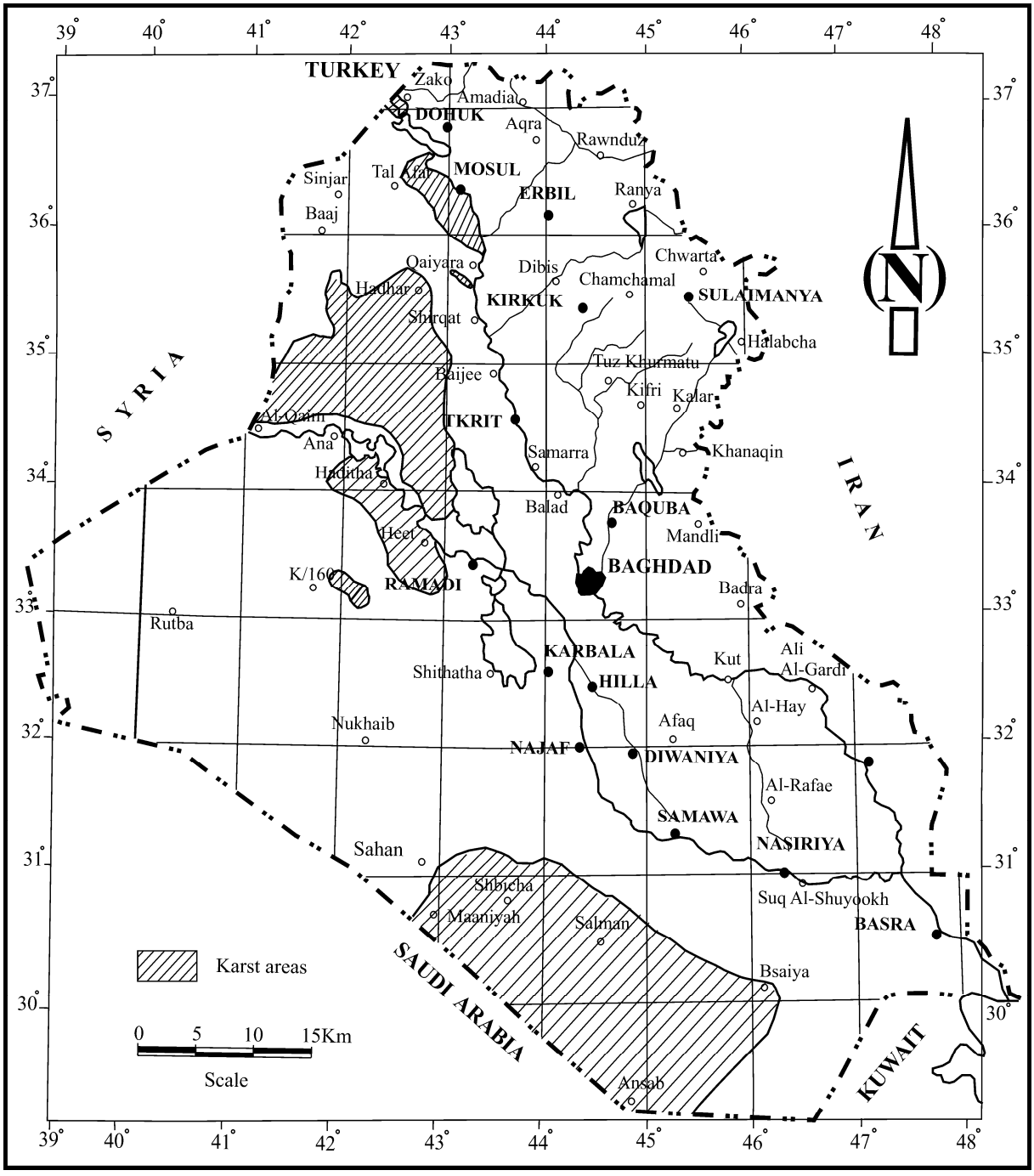

Fig. 1: Showing karst areas in Iraq (after Sissakian and Ibrahim, 2005)

Although the aforementioned event is obvious indication for continuation of the Pleistocene phase of karstification in the Iraqi Southern Desert that is characterized by intense karstification. 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, as it is indicated from topographic maps, aerial photographs and Google Earth on line (2006). Large circular forms with concentric drainage pattern are very common (Fig.2).

2- The Deposition of the Zahra Formation, which is Pliocene – Pleistocene? in age in many of the large sinkholes in the area.

3- The absence of the Rus Formation (Early Eocene) in the subsurface sections of the area, which is composed mainly of evaporites that are highly dissolved, by ground water, leading to the formation of extensive karst morphology in limestones of the overlying Dammam Formation that crops out over the majority of the Iraqi Southern Desert.

Therefore, the karstification, in the Southern Desert was developed probably during Late Miocene and/ or Pliocene, where the involved area was positive area, under the influence of continental depositional environment.

Other older phases of karstification, in the Iraqi Western Desert were during Cretaceous and Jurassic. This is indicated from the geological maps of the involved area (Al-Mubarak and Amin, 1983 and Al-Azzawi and Dawood, 1996). The rocks of a certain formation are deposited in sinkholes that are formed in an older formation. The traces of the sinkholes are still clear, with the infilling rocks of the younger formation. Examples are, rocks of Hussainiyat Formation in sinkholes of Uba`id Formation (both are of Jurassic age). Rocks of Muhaiwir Formation in sinkholes of Hussainiyat Formation (both are of Jurassic age). Rocks of Nahr Umr Formation (Early Cretaceous) in sinkholes of Najma Formation (Late Jurassic). Another indication of karstification during Cretaceous is the presence of bauxite deposits, as karst bauxite, in Ubaid Formation in the Western Desert (Mustafa *et al*., 1994, Al-Atiya and Sa'ad Allah, 1995 and Al-Bassam, 2005). Although the aforementioned indications are obviously clear for Cretaceous and Jurassic phases of karstification, however some much younger sinkholes of Miocene and Pleistocene ages are present in the area in Miocene rocks, too. The karst forms are large and locally matched together. This led to misunderstanding of the surface geology, therefore occasionally faults were supposed to explain this complexity. However, the detailed geological mapping and road excavations of the Highway No.1, between Amij and Rutba, revealed the karst morphology.

The extreme western parts of the Western Desert is characterized by presence of numerous shallow depressions of circular and/ or oval shapes. Their diameters range from few hundred meters up to few kilometers, whereas the depth does not exceed few meters, in general, they are filled by loamy materials. Majority of them are believed to be of karst origin (Jassim and Buday in Jassim and Goff, 2006). The authors confirm their karst origin. Some of them are associated with tectonic activities and are located along lineaments and/ or their intersections (Sissakian, 2007). All of these depressions are located within the carbonates of the Ratga Formation. The authors believe they are most probably of Miocene – Pleistocene in age.

KARST MORPHOLOGY

In this study, only karst features that may cause any type of problem are considered. However, others are considered very briefly. Because karst forms are developed mainly in limestone and gypsum beds and because they exhibits different forms and dimensions, therefore each type is described, separately.

- **Forms and dimensions in limestone beds**

The forms of sinkholes in limestone beds are almost uniform. They have circular or oval apertures. They form spoon, conical and cylindrical shapes. This depends mainly on their activity. Those, which are inactive, have spoon shape with gently inclined walls. Whereas, those, which are active, have conical or cylindrical shapes with steep or vertical walls. Very rarely they are in irregular shapes, this is due to very active forms, highly jointed cap rock and due to enlargement of the sinkhole by conjunction of two or more sinkholes to form one irregular sinkhole (Sissakian *et al*., 1986 a).

The dimensions of the sinkholes differ in different parts of Iraq. Those of the Southern Desert are very large, (Fig.2) their diameters range from few tens of meters up to few kilometers, like Al-Salman, Al-Sa`a, Al-Zahra. Whereas their depths range from few meters up to 15 m and rarely reach 30 m, like those at Al-Chibritiyah in Al-Ma`aniya vicinity (Fig.3). In other parts of Iraq the dimensions are much smaller, their diameters range from one meter up to 50 m and exceptionally reaches 100 m. Whereas their depths range from one meter up to 25 m and exceptionally reaches 50 m, like the one called Salman Rosa sinkhole, near Haditha (Fig.4) (Sissakian *et al*., 1986 b).

- **Forms and dimensions in gypsum beds**

The forms of sinkholes in gypsum beds, which are mainly developed in Al-Jazira vicinity (Figs.1 and 5) are very irregular in shape and in dimensions. These depend on the thickness of the gypsum bed, its properties, slope, dip amount, depth of the ground water, annual rainfall, type of the underlying rock and joint intensity. The shape is mainly irregular, formed due to enlargement of joints and dissolving of the top layer. This is the case, mainly in Al-Jazira vicinity. In other areas like Mosul and Qaiyarah the form is mainly cylindrical, which means it is formed due to collapse of the top layer after the dissolving of the underneath rocks.

The diameter of the sinkholes ranges from one meter up to 10 m and very rarely exceeds that. Whereas the depth ranges from less than one meter up to 5 m and very rarely exceeds that, especially in Al-Jazira vicinity. Hundreds of sinkholes filled by inhomogeneous materials like washed marl and clay, limestone fragments could be seen in Mosul vicinity, due to excavations of roads or constructions. They have clear surface expressions (Sissakian and Abdul Jabbar, 2005).

ACTIVITY OF SINKHOLES

Sinkholes are either active or inactive .Those, which are still active have one or more outlet in their floors, which extend into shallow funnel shaped caves (Al-Naqash and Al-Talabani, 1988) this means that the active sinkholes have the ability to drain the infilling water to deeper horizons, or ground water runs through them. These types of sinkholes are certainly more problematic. The indications of the activity are:

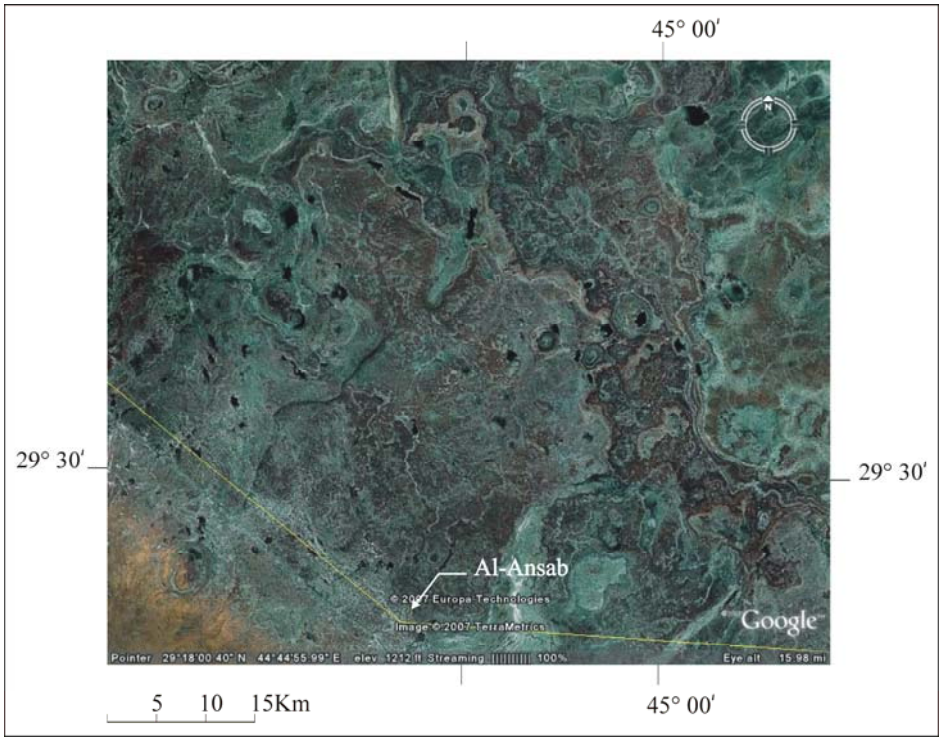

Fig. 2: Karst morphology in the Iraqi Southern Desert

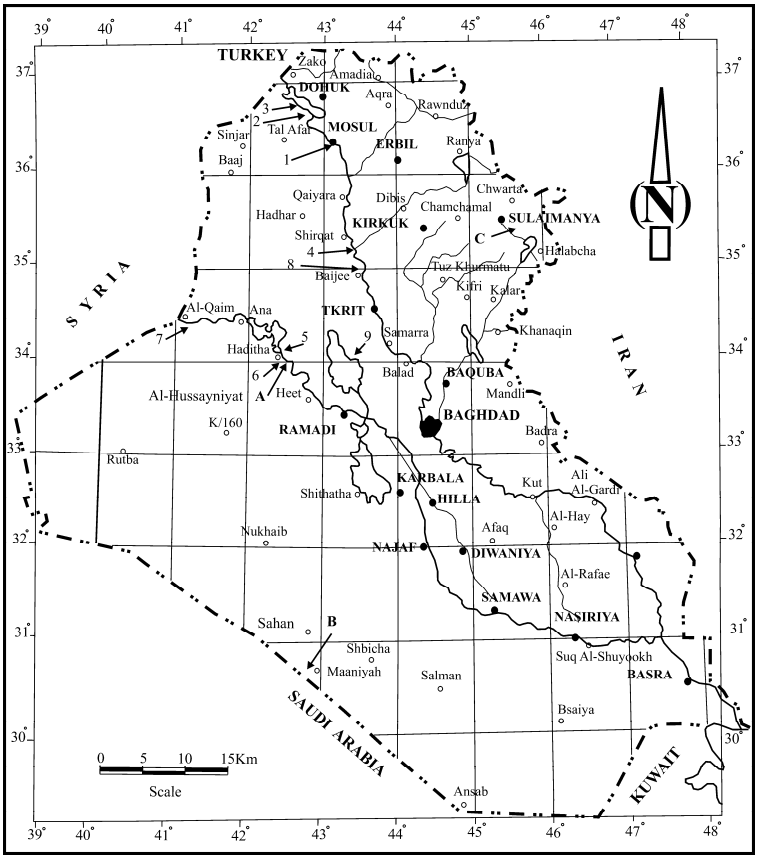

Fig.3: Showing the locations of the mentioned cases, in the text

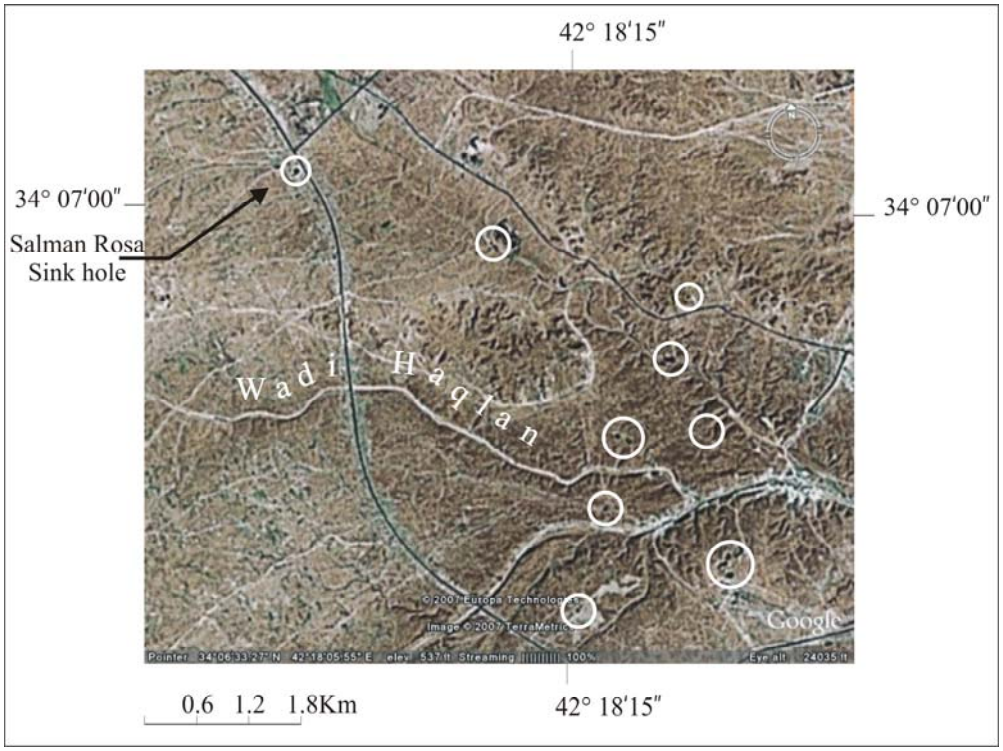

Fig. 4: Karst morphology in Haditha vicinity, sinkholes are encircled

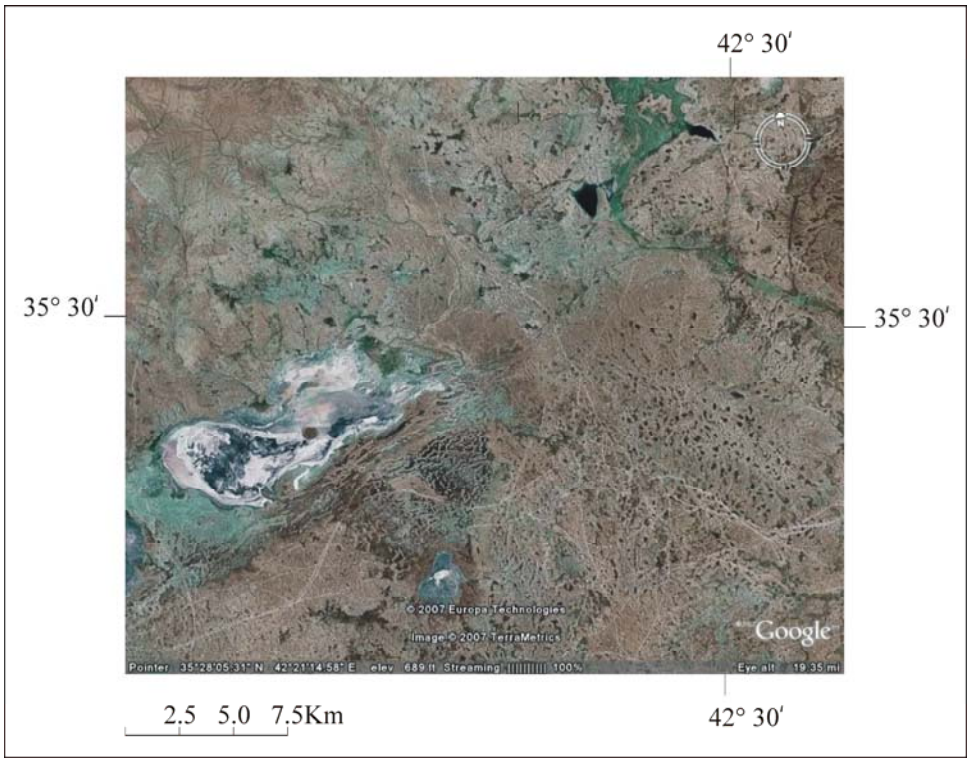

Fig. 5: Karst morphology in Al-Jazira vicinity, the large depression in the left side is Al-Ashqar salt marsh

* bare floor or with very rare soil cover
* presence of one or more outlet in the floor
* presence of fallen rock blocks from the rim in the floor
* presence of circular or crescentic cracks around the rim
* presence of ground water in the floor (Milanovic, 1981)

Those sinkholes, which are inactive are less problematic, because they exhibit less deformation to the near surroundings. Their inactivity is indicated by:

* spoon shape
* cover of thick soil in the floor
* absence of fallen blocks from the walls and /or the rims in the floor
* absence of outlets in the floor
* presence of outlets in the rim
* presence of water accumulation after heavy rain showers, in the floor
* presence of vegetation in the floor during rainy seasons
* absences of cracks around the rims

PROBLEMS INDUCED BY KARSTIFICATION

Different problems are associated with many structures due to karstification. Some of them have caused large economic losses, additional allocations have been spent to maintain many other infrastructures. Few of them have caused even life losses. Moreover, others have caused extreme complexity to the geological setting, both to the stratigraphy and mineral occurrences.

- **Sites**

Hereinafter are many cases recorded by different authors from different parts of Iraq, the location of the cases are demonstrated in (Fig.3).

1- Mosul Town, it is built over an area where the Fat`ha Formation is exposed. Many buildings are collapsed after being highly cracked (Numan and Adeeb, 1997). Roads and sewages piping are continuously repaired due to continuous subsidence, caused by continuous dissolution of gypsum beds and development of sinkholes.

2- Wax Plant, it is located northwest of Mosul. The site suffers from extreme karstification (Jassim *et al*., 1987). Because the gypsum of the Fat`ha Formation is exposed in the site. Beside the surface and subsurface karst forms, the limestone and marl beds, which are in cyclic repetition with the gypsum, are highly undulated and deformed, leading to highly crushed and weakened rocks, which are unfavorable for foundation. Many subsurface caverns, which were not identified during site selection have increased the dangerousness of the site and its cost, although many indications exist in the site for subsurface karstification (Sissakian and Abdul Jabbar, 2005).

3- Mosul Dam, it is located northwest of Mosul on the Tigris river in an area that is built up by the Fat`ha Formation. Although the dam construction have been terminated since last eighties of the last century, but grouting of cement is still continuous to re-in force the dam foundations due to sever karstification. The continuous grouting needs high allocations beside that the karstification decreases the safety of the dam. Hijab and Al-Jabbar (2006) conducted

detailed geophysical works in the dam site. The obtained negative microgravity anomalies results indicate the presence of huge weakness zones, cavities, fractured zones and a probable fault. The depth of the discovered cavities ranges up to 50 m bellow the surface. Some of them are in critical locations from the dam facilities.

4- Northern Fertilizers Complex, it is located west of Baiji (central part of Iraq). The site is built over thick gypcrete deposits that are developed from the presence of thick gypsum beds within the Fat`ha Formation in Makhoul anticline. The used water for treatment of the waste beside rainwater is infiltrated through the gypcrete. Consequently the gypcrete is dissolved leading to large subsurface caverns (Al-Bdaiwi and Hijab, 1999). The formed subsurface caverns have caused severe damages to the facilities of the complex.

5- Haditha Dam, it is located 290Km west of Baghdad on the Euphrates river, within limestones of the Euphrates Formation. The dam site and nearby areas are one of the most karstified areas in Iraq (Sissakian and Ibrahim, 2005. Figs.1 and 3). Due to the presence of numerous surface and subsurface sinkholes and caverns in the dam site, cement injection is still continuous, although the dam construction was terminated in 1986. The length of the surface curtain, along the axis, is about 13km on the right side of the dam. Cement is injected through drilled holes, which are spaced one meter apart for a depth of (10 – 25) m, to avoid water leakage along the dam. According to one of the Soviet experts from the construction team (personal communication, 1984) the traces of the injected cement was seen for few kilometers down-stream of the dam site. Certainly, the grouting has caused extra allocations and the presence of the sinkholes and subsurface caverns decrease the safety of the dam.

6- Rock Slabbing Factory, it is located near Haqlaniyah, 265 Km west of Baghdad. It is constructed over an area that is built up by the Euphrates Formation, which consists mainly of limestones. The site is in one of the most karstified areas in Iraq (Figs.1 and 3). About 60 sinkholes were recognized in the vicinity (Sissakian *et al*., 1986 b). The site suffers from continuous subsidence, due to the presence of subsurface caverns, which are developed in limestone of the Euphrates Formation. The platforms are highly cracked, leading to bending of the beams, which consequently caused the diss-leveling of the saws off their centers (Sissakian, 1987). Many attempts were carried out to maintain the factory by cement grouting, but all attempts were invain. Therefore, the factory was abandoned, it was a governmental property. Then was sold, it is working now with about 50% of the designed efficiency.

7- Al-Qaim Complex, it is located 300Km west of Baghdad. It is constructed over an area, which is built up by the Euphrates Formation that consists mainly of limestones. The complex that deals with phosphate industrialization suffers from severe karstification. The main reason is the presence of the subsurface caverns within the limestone. Moreover, thousands liters of HCl was splashed in the site. This was accelerated the development of new subsurface caverns and enlargement of the existing caverns. Many attempts were carried out to maintain the complex and stop the effect of the karstification, which is manifested on surface by ground subsidence, but all attempts were invain. Certainly, large allocations were spent for the maintenance, beside the economic losses due to decreasing the production efficiency.

8- Baiji Electric Power Station, it is located 210 Km north of Baghdad, along the Tigris river. Some parts of the station are constructed over a highly gypsiferous soil (gypcrete). Unfortunately, the water treatment facilities are one of them. They suffer from continuous subsidence. It is due to the development of surface and subsurface karst features due to

dissolving of the gypcrete. The subsidence has decreased the efficiency of the station in generation of electric power. Now, the authorities of the station are trying to treat the case (Dr. Safa Al-Dean Fouad, personal communication, 2005).

9- Al-Tharthar Residential Complex, it is located along the eastern bank of the Al-Tharthar Lake. The site is constructed over an area, which is built up by gypcrete deposit (Sissakian and Hafidh, 1994). After one year of construction, some of houses start to suffer from severe cracking. This is mainly due to subsidence of the foundations, due to dissolving of the gypcrete after being saturated by irrigation water of the gardens (from the author's observations).

- **Life Losses**

The following three cases are related to life losses, however many other cases may exist too?, but unfortunately no data are available to the authors.

A. Salman Rosa Sinkhole, it is located in Haqlaniyah vicinity (Figs.3 and 4). It is one of the largest sinkholes in the area with depth of 50 m and diameter of 100 m. Because the involved area is flat, the sinkhole could not be seen until from very close distance; and because it is very close to the Haqlaniyah – Anah main road, a car accident was recorded in sixties of the last century, the driver and two passengers were dead, because the car failed in the sinkhole, which is named after the drivers name. (Personal communication, Mr. Hameed Sa`eed, 2006).

B. Al-Ma'aniyah sinkhole, many sinkholes are located in Al-Ma'aniyah vicinity with depths of more than 10 meter and diameters of (20 – 40) m. According to a police sergeant in Al-Sahan police post (Fig.3) a police patrol that was patrolling the Iraqi-Saudi Arabian border, at a dark night, the car failed in a sinkhole in Al-Ma'aniyah vicinity leading to the death of three policemen. The accident took place in 1975 (Personal communication with a police sergeant, 1979).

C. Another historical accident is recorded by one of the migratory who was traveling in Iraq in 1920; he is called James Ridge. He mentioned in his memories that tens of people were lost and consequently died in caves of Qara Dagh mountain, which is located south of Sulaimaniyah (Fig.3) (Noori, 1951).

Such events could be happened in different caves too, but there is no record. However, according to the local people of Haditha vicinity, many sinkholes in the area and many caves, which are located along the Euphrates bank, have subsurface channels and chambers, which extend for few kilometers. Some of them extend even below the Euphrates river, and their following is very dangerous, because easily the passage route could be missed and be lost there (under ground), which means death. But, no such accident is recorded or could be remembered by the local people (From the author's communications, with the local people).

- **Geological Complexity**

Other type of problems caused by karstification is the geological (stratigraphical and structural) complexity in the Iraqi Western Desert, especially in Rutba – Hussainiyat vicinity (Fig.3). There are many karstified formations of Jurassic and Cretaceous ages, they are karstified before the deposition of the younger formation, leading to filling of the sinkholes of the older formation by the sediments of the younger formation.

Before discovering the karstification phenomenon, during regional and local geological mapping (Al-Mubarak and Amin, 1983 and Al-Azzawi and Dawood, 1996, respectively), the following misleading features were recorded:

* Ignoring or misunderstanding of the true lithological sequence of many formations, like Ubaid and Muhaiwer.
* Miss-identification of many geological formations, like Amij, Hussayniyat, Nahr Umr and Najmah, in the involved area.
* Miss-leading of the sedimentary cycles and combination a cycle with other or correlation of a cycle with another one that is in different stratigraphical level.
* Proposing of faults with different directions and extensions to solve the presence of rocks of a certain formation in abnormal contact and position with the rocks of older or younger formation.
* Miss-understanding the true status of many economic deposits and the mode and age of their deposition, like the bauxite.

All these examples were time consuming for geological mapping and mineral exploration, which means more allocations were spent to compile the geological maps of the involved area, as compared to the near surroundings, which show very clear and easy geological conditions, due to horizontal rocks.

CONCLUSIONS

The following could be concluded:

- Karstification is very common phenomenon in different parts of Iraq
- Limestone and gypsum are involved in karstification besides a highly gypsiferous soil (gypcrete)
- Sinkhole forms are irregular (circular or elliptical) in limestone beds, whereas in gypsum beds they have mainly irregular shapes.
- The dimensions of sinkholes in limestone beds are much larger than those in gypsum beds.
- Two types of sinkholes could be observed, concerning the activity, these are active and inactive.
- Severe damages are caused to infrastructures, buildings, roads…. etc, mainly due to subsidence caused by karstification.
- Some death accidents are recorded too, due to existence of sinkholes.
- Geological complexity is formed due to karstification, leading to miss–understanding the true geological conditions of many formations.
- The investigation and exploitation of some economic mineral occurrences were met large difficulties due to karstification.

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