GRAVITY EVIDENCE OF WIDESPREAD SOLUSION BELOW SALMAN AREA, THE IRAQI SOUTHERN DESERT

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ABSTRACT

The area of study is (80 × 100) Km in dimensions and lies to the immediate NE of the town of Salman in the Southern Desert. The topography is flat with sporadic sediment – fill depression of which the Salman Depression is the largest and most conspicuous.

The Bouguer map of the area, is characterized by a number of local anomalies having closed contours. These gravity highs and lows have various shapes and dimensions with an average amplitude of one mGal. These anomalies can be grouped into two broad long highs enclosing a zone of gravity lows. These groups are elongated in an E – W direction.

Various workers have shown that solution of calcareous and evaporitic rocks in the Southern Desert by groundwater has been active since the early Miocene times. The subsurface geology of the present area consists of almost horizontal succession of Limestone (the Late Eocene Dammam Formation) underlain by evaporates and limestone of the Late Eocene Rus Formation, which in turn underlain by more than 400 m of limestone of the Paleocene Umm Er Radhuma Formation. Such lithology is highly susceptible to solution by continuously running water.

The aim of the present work is to relate the observed gravity anomalies to possible underground solution hollows and channels with attempts at estimating depth, dimensions and trends of such channels. No tectonic sources for the anomalies are feasible as the entire successions are regular and structurally conformable with no sign of any trend.

Detailed interpretations of the local residual anomalies have indicated the existence of an interconnected E – W trending channel of irregular boundaries occurring at a depth of about 50 m below the surface. It varies in width between 20 and 40 Km and in depth extent up to 60 m.

أدلة جذبية عن إذابة واسعة تحت السطح في منطقة السلمان، الصحراء الجنوبية العراقية

زهير داود الشيخ و عبد العظيم محمود المشهداني

المستخلص

إن أبعاد منطقة الدراسة هي (80 × 100) كم وتقع مباشرة إلى الشمال الشرقي من مدينة السلمان في الصحراء الجنوبية، وتضاريسها منبسطة عموما تتخللها بعض المنخفضات التي تحتضن رسوبيات حديثة. ويعتبر منخفض السلمان من أكبر هذه المنخفضات وأكثرها تميزا.

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وتتميز الخريطة الجذبية للمنطقة بكثرة الشواذ المحلية المغلقة وذات الأبعاد المختلفة وبسعات قليلة. ويمكن تجزئة هذه الشواذ إلى مجموعتين ذات قيم موجبة تفصلها مجموعة من الشواذ السالبة. تمتد مجاميع الشواذ هذه عموما باتجاه شرق – غرب.

وقد بين عدد من العاملين بأن إذابة الصخور الجيرية بواسطة المياه الجوفية في الصحراء الجنوبية كان فعالا منذ بداية المايوسين. وتتألف التكوينات الجيولوجية في المنطقة من تتابعات شبه أفقية من الحجر الجيري (تكوين الدمام، الإيوسين) وتقع تحته متبخرات تكوين الرص (الإيوسين) والتي يليها بالعمق أكثر من 400 متر من الحجر الجيري التابع لتكوين أم الرضمة (الباليوسين المبكر). إن مثل هذه الصخارية تكون عرضة للإذابة السريعة بالمياه الجوفية الجارية.

يهدف البحث إلى ربط الشواذ الجذبية المقاسة مع الأوضاع الجيولوجية السطحية والضحلة في المنطقة بما يتضمنه ذلك من فجوات وقنوات إذابه. ويستخدم البحث المعلومات السطحية وتحت السطحيه المتوفرة في منخفض السلمان والمنخفضات المجاورة في تخمين أعماق وأبعاد وامتدادات هذه الفجوات والقنوات، خصوصا وأن الشواذ المقاسة والامتداد الأفقي الواسع للتكوينات لا تشير إلى أي امتدادات تكتونية مؤثرة.

وقد بين التفسير التفصيلي للشواذ المحلية وجود قناة طويلة ذات حدود غير منتظمة تمتد باتجاه شرق – غرب وتقع على عمق يقرب من 50 متر تحت السطح وبعرض يتراوح بين 20 و 40 متر وبارتفاع يصل إلى 60 متر في بعض المواقع.

INTRODUCTION

The area of study extends for some 85 Km to the north east of the town of Salman and for 100 Km to its east. It occupies a general flat topography that slopes very gently towards the east and northeast from about 250 m (a.s.l.); near Salman to about 5 m close to the Euphrates River. The location of the area is shown on the geological map (Sissakian, 2000) of Fig. (1). Physiographically, it lies within Al-Hijara Unit (Ma'ala, 2009), which is an elevated terrain capped by the Dammam Formation (Eocene) with dips some (1 – 2)° to the northeast. It is characterized by karstic depressions, undulations and scarps. The surface shows evidence of mechanical weathering, which produces rock blocks and fragments of variable sizes.

Structurally, the area lies within the Inner Platform of the Arabian Plate (Fouad, 2012) and in particular within the Salman Zone (Buday and Jassim 1987) where the Cenozoic succession is exposed and slopes gently towards the Mesopotamian basin; beyond the Euphrates River to the east of the area.

▪ The Geology

Figure (1) shows the geological map of the Southern Desert with the boundaries of the present area superimposed (Sissakian, 2000). All the exposed rock units belong to the Cenozoic. The oldest formation is Umm Er Radhuma (Paleocene), which is widely exposed in the neighborhood of the Saudi Arabian boarders. It is some 450 m thick dolomitic, microcrystalline porous limestone as well as anhydrites. It lies unconformably over the Cretaceous Tayarat Formation. The formation slopes gently northwards and northeastwards. It is overlain by the Rus Formation (Early Eocene). This is some 90 m thick, predominantly anhydrite with some limestones and marl. This lithology, according to Bellen *et al*. (1959), is found mainly in the deep wells of the Mesopotamian basin. It changes laterally westwards into mainly chalky limestone below the western parts of the Southern Desert. The formation is nowhere exposed in the study area. It is overlain by the Eocene Dammam Formation, which is some 200 m thick, porous, dolometized limestone. It is the main outcropping formation within the Southern Desert and forms the dominantly outcropping rocks in the study area, save for minor sporadic outcrops of the Zahra Formation over the eastern part of the area.

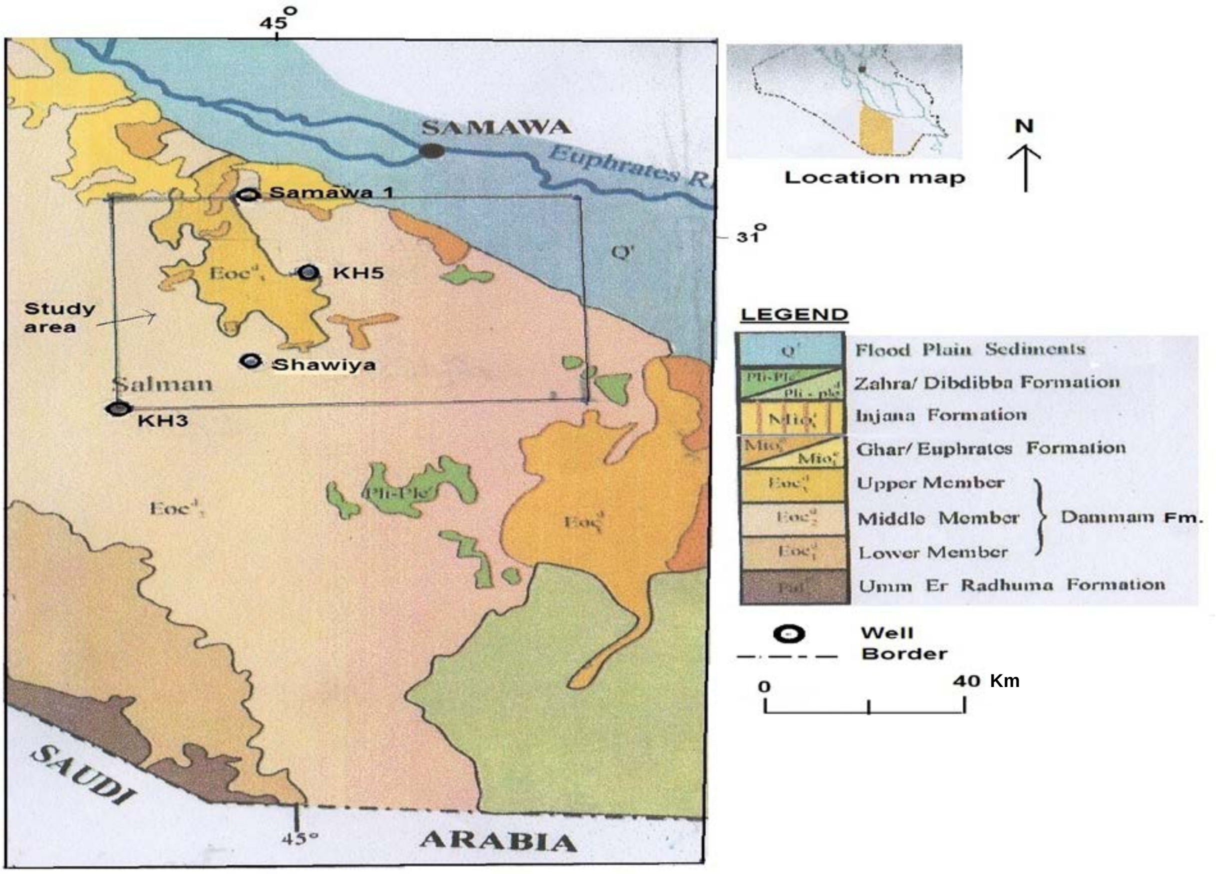

Fig.1 Geological map with location of the studied area of part of the Iraqi Southern Desert (after Sissakian, 2000)

The Zahra Formation (Pliocene – Pleistocene) is white and pink limestone, occasionally sandy with sandy marl and calcareous sands. The formation within the Southern Desert occurs in topographic lows with respect to the surrounding older rocks (Jassim and Al-Juburi, 2009). It forms parts of the floor of the Salman topographic depression (Tamar Agha, 1984).

▪ **Rock Solution**

Evaporites and calcareous rocks are susceptible to solution by surface and groundwater with the evaporites being more so. Such lithology is found abundantly in the formations underlying the Southern Desert, both at shallow and deep levels. Surface running water and water percolating through the subsurface rocks since the Miocene times have created solution hallows and cavities of all sizes and shapes at various depths.

Ma'ala (2009) described the shapes, sizes and extents of a number of these hallows found in the Southern Desert. Uvalas are broad depressions with uneven floors formed by breaking down of walls between a number of sinkholes. An example of these is found northeast of the Salman Depression. The exposed rocks in the cliffs are limestones of the Dammam Formation. Caverns are subterranean hallows enlarged by solution and erosion, eventually forming large collapse sink depressions, some extend for tens of kilometers in lengths and widths. Dolines are rounded hollows varying from (1 – 2.5) Km in diameter and occur at (10 – 65) Km of depths. Connections at depth of such cavities may form subsurface drainage systems many kilometers long.

It is believed that an alternating conditions of arid continental and shallow marine prevailed in the Southern Desert during the Neogene (Ma'ala, 2009). So that during the continental period of the Oligocene, the elevated topography was subjected not only to mechanical weathering but also to active chemical weathering (solution) caused by groundwater. As such the first subterranean hollows and cavities were initiated. These were eventually developed and enlarged then some collapsed after the Miocene, others collapsed during the Pleistocene and Holocene and is still collapsing. The collapse occurred due to enlargement of chambers and thinning of roofs with no tectonic influence. Some other depressions, thus formed, are floored with the clastic deposits of the Zahra Formation, as is the case with the Salman Depression, which stretches for 21 Km in a north – south direction and varies in width from (2 – 10) Km with the town of Salman lying within it.

- **Aim and Method of Study**

The aim of the present study is to locate and map any shallow solution system that may be present in the area. The map is planned to include the shape, depth extent and lateral distribution of such systems.

To achieve this aim, gravity maps are used. It is known that the subsurface cavities have a reduced density as compared to the surrounding host rocks. Such reduction in density will produce gravity low over shallow solution system of appreciable dimensions. As such, the gravity map of the area is analysed so as to produce and emphasize any local gravity low that, through its interpretation a suggestion of a subsurface drainage system may be made. The interpretation is assisted by the lithological logs of the four boreholes located within the area: K.H.3 (at Salman), Shawiya 1, K.H..5 (at Salhubiya) and Samawa 1.

PREVIOUS STUDIES

Most of the preliminary geological and geomorphological data used are based on the studies made by the GEOSURV’s personnel. The geological map of the Southern Desert (Fig.1) is obtained from the 1: 1000 000 scale map of Iraq (Sissakian, 2000). The geomorphological map is based on the 1: 1000 000 scale map of Iraq (Hamza, 1997). The detailed lithological description of the formations within the Salman area is obtained from Hassan *et al*. (1994) in Ma'ala (2009). Borehole lithological information is based on a detailed report by Tamar Agha (1984). No previous gravity analyses have been carried out on the gravity map of the present area.

THE BOUGUER GRAVITY MAP

The observed Bouguer map of the area is extracted from the Iraqi Petroleum Company's map. Figure (2) shows the part of this map, which covers the area of study drawn with 1: 500 000 scale with boreholes location superimposed.

The map is characterized by its highly irregular closed contours, which range in values between lows of – 32 mGal to highs of – 24 mGal. The overall view of the map shows two broad highs (up to – 24 mGal): One occurs in the northwest of the map and the other (up to – 26 mGal) occurs in the southwest (around the town of Salman). Between these two highs, occur an approximately east – west zone of broad lows that include variously shaped culminations of about one mGal each. Beyond this zone and beyond the adjacent highs, the field decreases rapidly in the northeast of the area and to the south (east of Salman) to about – 32 mGal. Besides this distribution of anomalies, no clear, sharp trend is observed in Fig. (2).

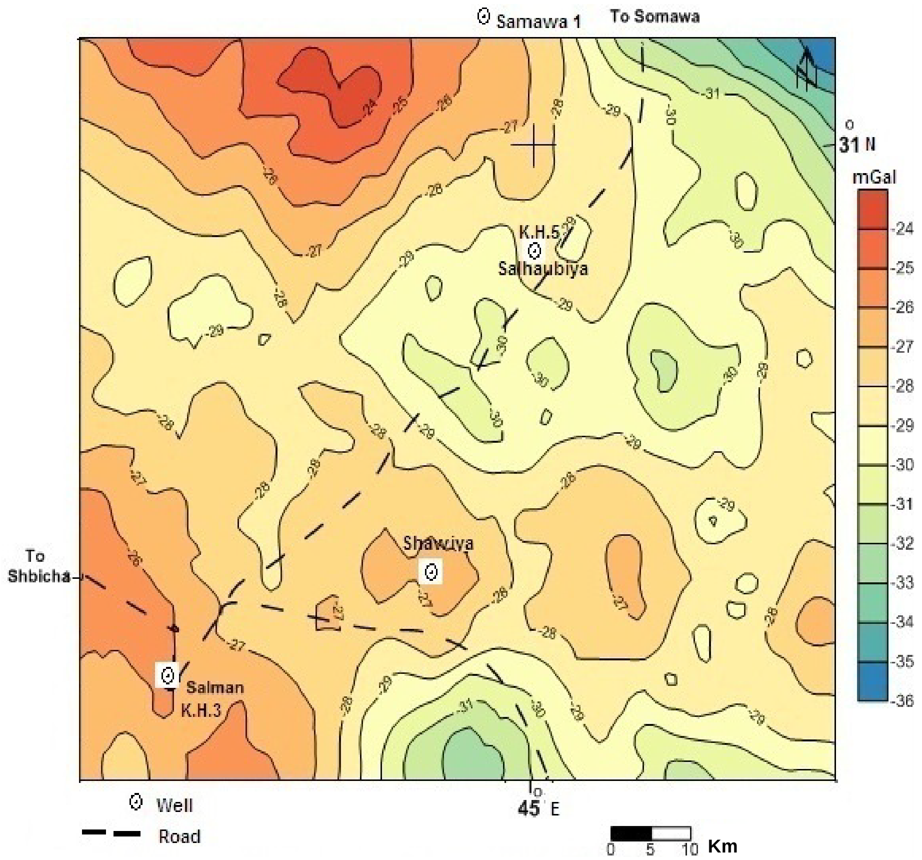

Fig.2: Observed Bouguer anomaly map with borehole locations

- **Isolation of Local Anomalies**

To separate the local anomalies of limited aerial extent from the broader, smooth anomalies observed in Fig. (2), a filter procedure is used. In this study, the low – pass filter given by Surfer version 10.1.561 (Surfer 10, 2011) is used to construct the regional map that represents the background field. Therefore, the observed map of Fig. (2) is digitized into a (3 × 3) Km grid.

The digitized map is then filtered through a number of filter sizes to test the effectiveness of each filter on the isolation of the local anomalies. It is found that filter 5 × 5 with 60 passes (number of times the filter is applied) produces a smoother regional background than other filters. This filter; therefore, is considered efficient enough to isolate the local shallow anomalies. Figure (3) shows the residual anomalies (b) and the regional background (a) as obtained by the mentioned filter. It can be seen that the filter has emphasized the observed local anomalies described above. Figure (4) shows the residual map as obtained by the 5 × 5 filter with boreholes and the modelling profiles marked. The figure shows the main E – W low undulations in the middle of the area, together with the two adjacent highs. The main low in the middle has prominent culminations such as A, B, C, D, E and F. This main low has also extensions of smaller widths and amplitudes to the north and south such as the extension of culmination B to F in the south, and the culmination C to the north and towards F in the south. The northern and the southern highs; therefore, appear broken at places by the extensions of the low. The amplitude of the lows ranges between (– 1.9 to – 0.4) mGal, while the highs range up to 1.6 mGal. Figure (4) also shows the locations of modelling profiles AA\, BB\, CC\ and DD\ all trending NNW – SSE across the area, two of them, namely BB\ and CC\ pass through boreholes.

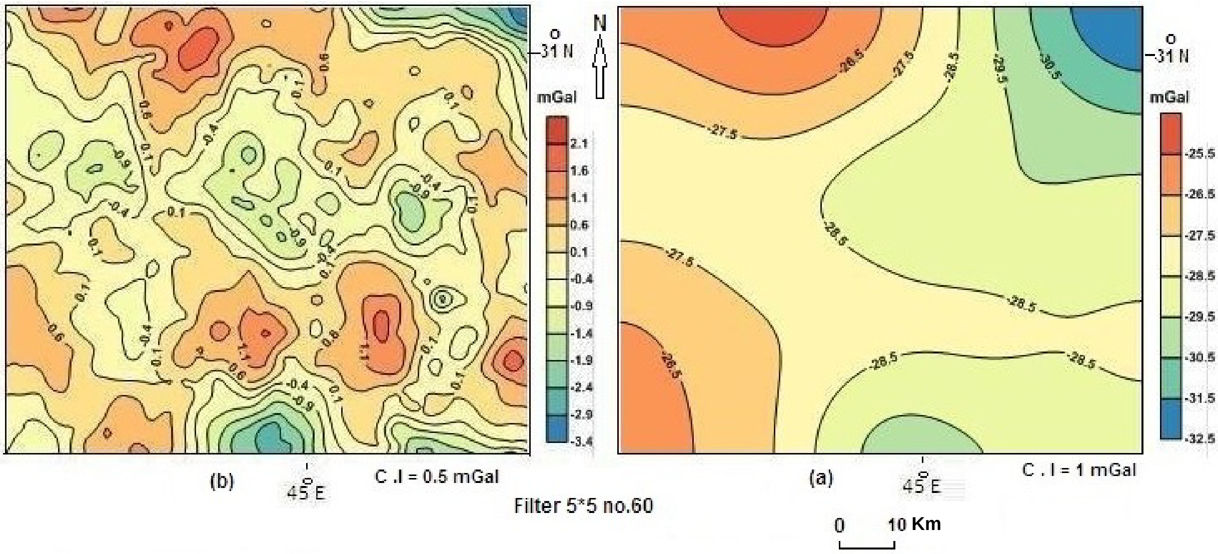

Fig.3: Isolation of local anomalies a**)** Regional field, b**)** Residual anomalies

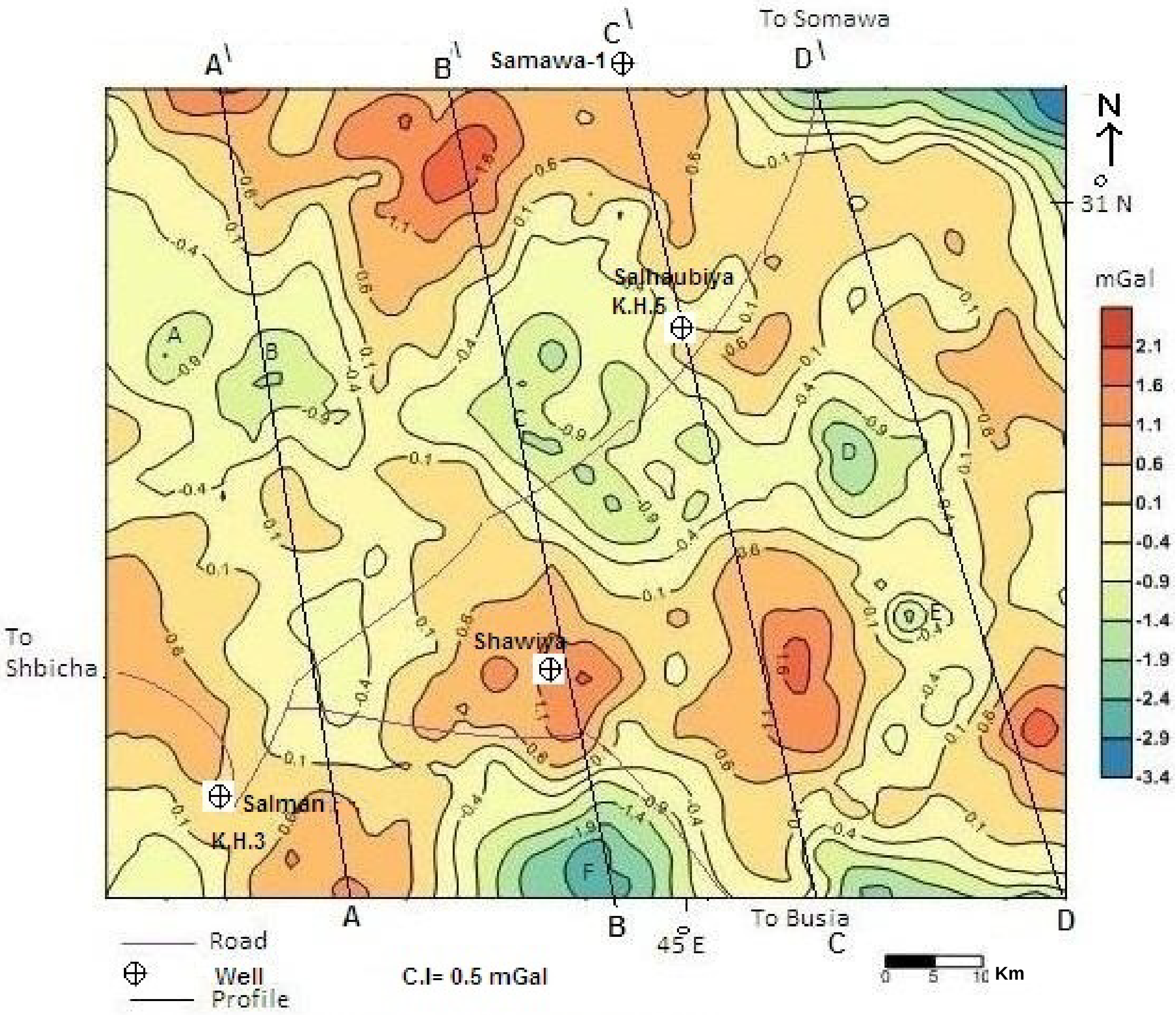

Fig.4: Residual anomaly with profile locations

INTERPRETATION

Numerous references are found in the open literature on karstification in the Southern Desert and major effects of groundwater solution in the formation of subsurface cavities and surface depressions (e.g. Ma'ala, 2009, Sissakian *et al*. 2012 and 2013). The most susceptible rocks to solution are the evaporites and the carbonates. The geology of the area as given earlier consists of the Dammam Formation (essentially limestones) at the top, largely outcropping, underlain by the Rus Formation (with dominant proportion of evaporites). It is expected; therefore, that large scale solution of these rocks is the main source of karstification at the surface and the formation of systems of connected cavities at the subsurface.

As such, most of the gravity lows observed on Fig. (3) are attributed to shallow cavity chambers filled wholly or partly with water. Such chambers will have a low density if compared to that of the host rocks, and will give rise to gravity lows at the surface. And, since no apparent evidence of any tectonic feature that could explain the observed gravity anomalies is observed in the present locality, all these negative anomalies will, in the following interpretation, be attributed to subsurface solution. The positive anomalies, on the other hand, will be attributed to subsurface undesolved succession.

However, the gravity lows observed in Fig. (3) have wide lateral extent and can not be explained by sinkholes of limited sizes observed on the Dammam Formation as those shown by Sissakian *et al*. (2012). The solution chambers with the expected density contrast would have to be of appreciable lateral and vertical extents to satisfy the gravity anomalies. Therefore, the source of the observed negative anomalies must lie partly in the dissolved parts of the Dammam Formation, but mainly in the evaporites of the Rus Formation.

Figure (5) shows the detailed lithological logs of the four boreholes whose locations are marked on the map of Fig. (2) (Tamar Agha, 1984). It can be seen that the Rus Formation varies laterally in thickness and lithology. It is 84 m thick in Samawa 1, made up essentially of evaporite with occasional limestone layers. At Salhaubiya (K.H.5), it becomes mainly evaporites with a reduced thickness of 60 m, at Shawiya 1, the Rus Formation becomes thicker (about 110 m) consisting of upper evaporitic part, some 50 m thick and a lower calcareous part; 60 m thick. At the neighboring Salman borehole (K.H.3), the Rus Formation becomes 48 m thick with the total disappearance of the evaporitic layers. Figure (5) suggests that the disappearance of these rocks at K.H.3 is caused by lateral variation in lithology. However, the formation of Salman Depression indicates that the evaporites of the Rus Formation has been removed by solution.

The Depression is characterized by a positive gravity anomaly (Fig.4) and borehole K.H.3 within the depression indicates the absences of 50 m of evaporites from the Rus Formation. Therefore, the absence of these rocks must have created a cavity chamber 50 m high within the formation. Were such chamber still present, the gravity anomaly over it would be negative. The collapse of the overlying rocks, however, has filled the cavity and the gravity anomaly observed is therefore a positive one.

In the following interpretations of the observed anomalies of Fig. (4), the formation of Salman Depression will be considered as a case study guiding the models to be constructed to explain the gravity anomalies of the present area.

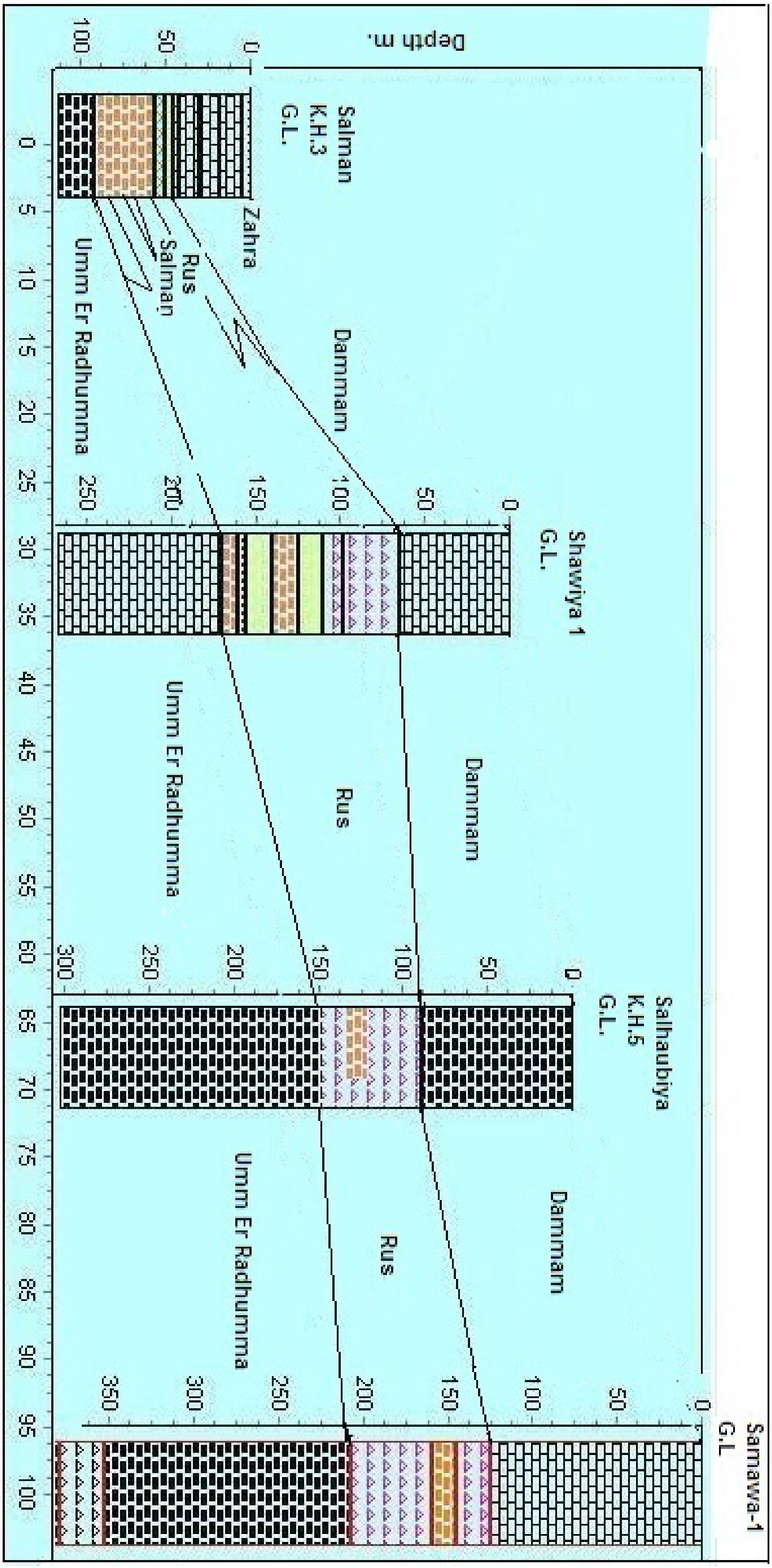

Fig.5: Stratigraphic correlation between boreholes Salman K.H.3, Shawiya 1, Salhaubiya K.H.5 and Samawa 1 (after Tamar Agha, 1984)

- **Density Considerations**

The solution cavities are considered to be formed mainly within the Rus Formation in addition to sporadic solution effects occurring within the overlying Dammam Formation. Density of rocks present in the area is scanty. The density within the cavities is entirely speculative. As such, the following interpretations will only be approximate. Their authenticity can only be assessed by their closeness to observed topographic features and the geological logs of the subsurface.

Using the interval velocity obtained from various formations encounted by boreholes in southern Iraq, the corresponding average densities are calculated. The average density of the Umm Er Radhuma Formation is found to be 2.44 gm/cc. The average density of the Dammam and Rus formations together is found to be 2.56 gm/cc.

The density of the cavity chamber; however, can not be determined with any accuracy. The cavity may not be empty. It may be filled with water and may contain remains of collapsing products or variously shaped undesolved rock columns. As such, the size of the cavity (its height) that can be calculated will depend mainly on the density used for the cavity. If this density is made 1.0 gm/cc (cavity filled with water only), then the height of the cavity would have to be 20 m to satisfy the observed anomaly of 1 mGal. If, the cavity density is made 1.5 gm/cc, its height would have be at least 60 m to satisfy the same anomaly. It must be clarified here that since the Bouguer slab formula is being used in these considerations, the shape, and sharpness of the anomaly are not envolved.

In the following interpretations, an intermediate density for the cavity of 1.31 gm/cc is used. Such density would give a height for the cavity comparable to the thickness and depth of the soluble section of the Rus Formation in the area. This proposed solution would also agree closely with disposition of the Salman Depression.

- **Modeling**

The regional field (zero line) observed on Fig. (3) separates the top section of the ground that contains the anomalous sources from the deeper more uniform section. This level is considered to occur at the top of the Umm Er Radhuma Formation, since this formation consists of uniform succession of limestones more than 400 m thick. Therefore, all the anomalies modelled hereinafter are considered to be due to sources having density contrasts with that of the Umm Er Radhuma Formation.

The location of the four profiles modeled (AA\, BB\, CC\ and DD\) is shown in Fig. (4). Only the models along and AA\ and BB\, considered as example of models along profiles, are shown in Fig. (6). The cavity sources are assumed two-dimensional features whose cross-sections are shown in the figure.

The densities and dimensions used for these sources have already been discussed. The models consist of broad cavities, some (20 – 40) Km wide and varies in height up to a maximum of 50 m.

Height variations of each cavity on every section of the four profiles are contoured to produce an isopach map of the subsurface solution system (Fig.7) with a contour interval of 5 m. The map shows areas of no cavities in the north and also around the borehole Shawiya 1. The cavity areas, on the other hand, occur to the north and south of Shawiya area with the southern cavity area being the larger and more intensive. The cavity areas show a general trend towards the east, which is the regional movement direction of the groundwater.

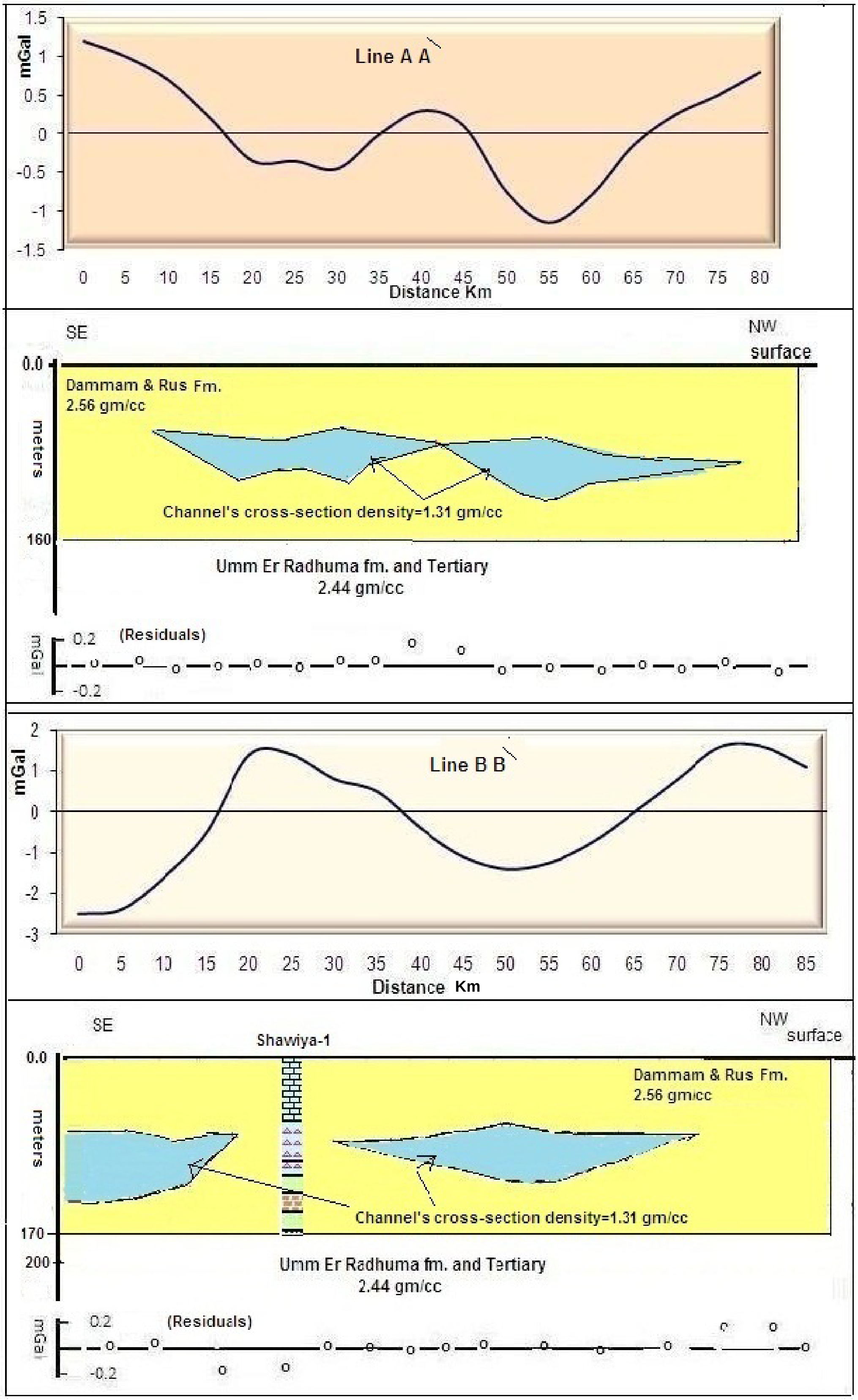

Fig.6: Possible subsurface solutions hallows along A-A\ and B-B\ profiles

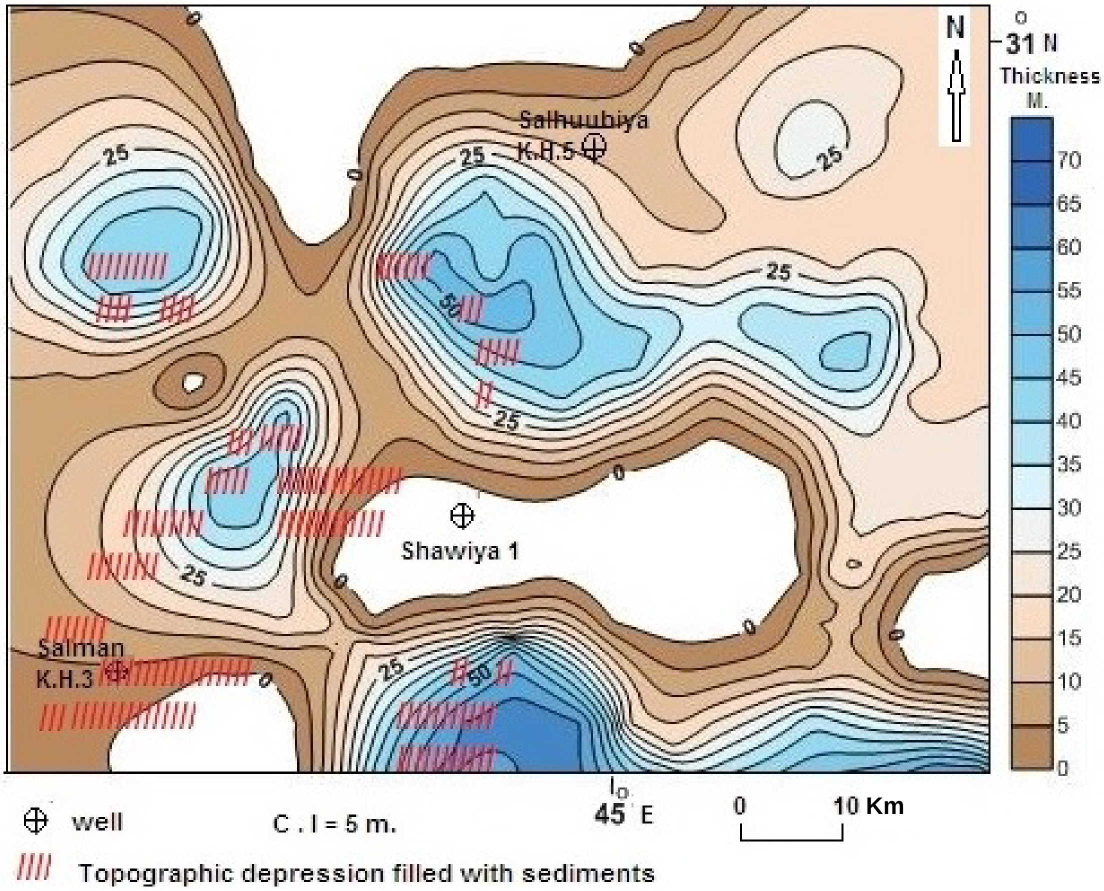

Fig.7: Isopach map of subsurface solusion system

DISCUSSION AND CONCLUSION

The subsurface solution chambers suggested in this study may seem large and deep. However, it must be born in mind that the assumption made is that most solution has taken place within the Rus Formation. That will make the chambers having the same height and depth as those of the Rus Formation. Furthermore, the case of the Salman Depression described above is followed closely. It must also be appreciated that the chambers are neither empty nor wholly filled with water. They are considered to be filled with material that make its average density 1.31 gm/cc. These material consist of, in addition to groundwater, products of partial collapses as well as undesolved, interconnected rock columns.

If the average density of the chambers is made greater than 1.31 gm/cc, then they will have to be shallower to satisfy the observed anomalies and this will mean that the process of solution has affected the Dammam Formation in addition to the Rus Formation. Such will of course, be another acceptable explanation of the observed gravity field.

Furthermore, the present area as observed on the geological hazards map of Iraq (Sissakian and Ibrahim, 2005) shows the occurrence of a number of sediments filled depressions. These are observed mainly within the western part of the area occupying both negative and positive anomaly locations. In both cases, the depression occurs as a response to subsurface major solution. A chief example of such depressions is Salman's, which lies in an area of positive anomaly and whose bottom is partly filled by some 15 m of sediments of the Zahra sediments. To the east of this depression, there is another large depression

(Al-Had'daniyah) partly filled with sediments where a low gravity field prevails. Except for the Salman and the Al-Had'daniyah depressions, most of these features seem to be of small lateral extent as compared to the suggested cavity chambers. Such difference in size, however, is expected, so that an appreciable depression at the surface would require a much larger solution cavity at depth to facilitate the process.

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