A GRAVITY STUDY OF THE NUKHAIB DEPRESSION AREA, WESTERN DESERT OF IRAQ

Zuhair D. Al-Shaikh[1] and Abdul Adheem M. Al-Mashhadani[2]

Received: 02/ 11/ 201١, Accepted: 31/ 05/ 2012
Key words: Nukhaib Depression, Rock solution, Wadi Ubaiyadh, Wadi Ghadaf, Western Desert, Iraq

ABSTRACT

The studied area, which includes the Nukhaib Depression extends from Wadi Ubaiyadh in the south to Wadi Ghadaf in the north. The depression is marked by the outcrops of a N – S strip of alluvial fans. The gravity field as observed on the Bouguer anomaly map, scale 1: 500 000, is found to decrease by 8 mGal over the area. This reduction in gravity is argued to be related to a widespread subsurface solution, which has reduced the average density of subsurface rocks. The gravity map further shows local undulations, which when isolated, produce positive and negative anomalies that are distributed irregularly over the whole area including the depression strip. These anomalies are interpreted as due to variations in the intensity of subsurface solution, which reflects the local nature of rocks. Intense solution at some locations forms local subsurface basins of dissolved, broken and collapsed rocks of average low density. It was found that these basins cause topographic down warping. Some of these basins occur below parts of the depression. The alluvial fans are thought to have been formed over these depressed topographic locations. It is emphasized that solution basins are not confined to the depression's outlines only and, as such, these outlines should be reviewed and so should the naming of Nukhaib graben.

دراسة جذبية لمنطقة منخفض النخيب، الصحراء الغربية، العراق

زهير داود الشيخ و عبد العظيم المشهداني

المستخلص

تمتد منطقة الدراسة، التي تتضمن منخفض النخيب، من وادي الأبيض في الجنوب إلى وادي غدف في الشمال. ويظهر المنخفض على الخريطة الجيومورفولوجية للعراق بشكل شريط من المراوح الفيضية ممتدا من الشمال إلى الجنوب. إن المجال الجذبي المشتق من الخارطة الجذبية للعراق ذات مقياس 1: 500 000 يبين انخفاضاً قدره ٨ ملغال فوق منطقة الدراسة. وقد أعزي هذا النقصان في الجاذبية الى انتشار فعالية إذابة الصخور تحت السطح بواسطة المياه الجوفية مما يخفض معدل كثافة هذه الصخور. وتبين الخريطة الجذبية، إضافة إلى ذلك، تموجات محلية التي إذا ما تم عزلها تعطي شواذاً موجبة وأخرى سالبة منتشرة بلا انتظام فوق جميع أجزاء المنطقة بما فيها شريط المنخفض. لقد تم تعليل هذه الشواذ بأنها تعود لاختلافات في مدى فعالية الإذابة التي تعتمد أساساً على الطبيعة المحلية للصخور. فالإذابة الفعالة في موقع معين يؤدي لتكوين "أحواضا" تحت السطح مؤلفة من صخور مذابة، مكسرة ومهدمة وذات كثافة منخفضة تعطي شواذاً سالباً. وبالمقابل تعطي الأجزاء الأخرى في المنطقة غير المتأثرة بالإذابة ذات الكثافة المرتفعة نسبياً شواذاً موجبة. ولقد تبين بأن وجود أحواض الإذابة المذكورة قد سبب تجلسات طبوغرافية يقع البعض منها ضمن شريط منخفض النخيب. ويعتقد بأن سلسلة المراوح النهرية قد تكونت فوق هذه التجلسات الطبوغرافية وكنتيجة لها. ولا يقتصر وجود أحواض الإذابة هذه على منطقة منخفض النخيب فقط وإنما تتوزع على جانبي المنخفض وبلا امتدادات محددة ولذلك فأن الحدود الموضوعة للمنخفض تستدعي إعادة النظر وكذلك تسمية انهدام النخيب.

[1] Professor, Baghdad University, College of Science
e-mail: dr.zuhairalshaikh@yahoo.com
[2] Assistant Professor, Ninavah Technical Institute, Mosul

INTRODUCTION

The geomorphological map of Iraq (Hamza, 1997) shows a large elongated outcrop of fluviatile deposits occurring on the eastern part of the Western Desert. The outcrop has an average width of 30 Km and stretches in a north – south direction from the Iraqi – Saudi borders in the south to Wadi Ghadaf in the north passing through the town of Nukhaib, (Fig.1). The eastern and western boundaries of this outcrop are marked by gentle cliffs and, as such, the location is referred to as a depression, and in the present study it will be referred to as the Nukhaib depression. The deposits of the depression made up of numerous alluvial fans arranged adjacent to each other and formed by the discharge of the eastward flowing valleys. The apexes of the fans mark the western edge of the depression, while their ends form its eastern boundary. The northern part of the depression, which starts from the town of Nukhaib and stretches in a near north-west direction has been referred to as the Habbariya Depression (Sissakian and Mohammed, 2007).

The main purpose of the present study is to consider the effect on the gravity field of the water that is brought by the eastward flowing wadies (valleys) and that sink below the surface of the depression and the areas to its east, and to speculate, as to the nature of the changes, that this water is imparting on the subsurface rocks and whether such changes are reflected on the surface geomorphology and the subsurface structure of the Nukhaib depression.

LOCATION

Figure (1) shows that the area of study lies between 42° – 43° E and extends form 32° N northwards towards Wadi Ghadaf. The figure also shows the long north – south stretch of Nukhaib depression (Hamza, 1997) and the numerous valleys that drain the western high plateau and supply water and sediments to the depression. It can also be observed that the actual depression occupies only part of the western half of the area of study as outlined above.

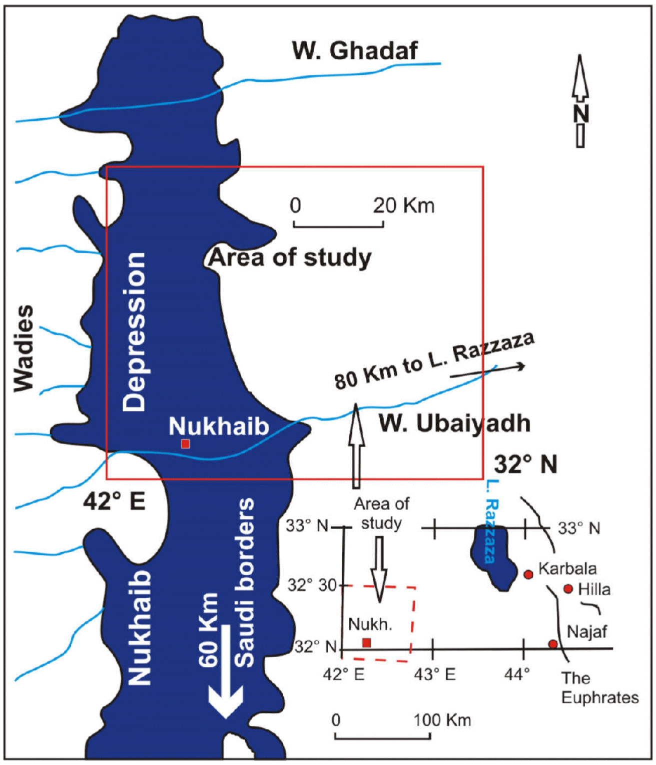

Fig.1: Location map (Hamza, 1997)

GEOMORPHOLOGY

The Nukhaib depression is bounded on the west by elevated lands whose height gradually increases westward. Nearly all valleys coming from the west discharge their water and sediment loads in the depression. Only the valleys of Ubayiadh and Ghadaf, however, continue their courses eastwards across the depression and head towards the Razzaza lake near the river Euphrates.

Evidently, the accumulating water seeps into the rocks below, saturates them and gradually leads to their partial solution. Local ponds and marshes can be observed in the area during some wet months annually.

The surface sediments of the depression are made up of fan sediments. Each fan represents the discharge of a single valley coming from the west. The fan's sediments consist of poorly sorted clastic sediments, usually gravels with some sands. The gravels are made up of limestone with some chert and are poorly cemented (Hamza, 2007).

The sediments of the northern part of the Nukhaib depression, north of the town of Nukhaib, are referred to by Al-Mubarak and Amin (1983) as the Habbariya and Hauran Gravels. The outcrop of the depression in this locality transgresses northwards across most of the gravity contours without any observable effect.

Only this part of the depression, which is the part lying to the north of Nukhaib is studied here. The southern part requires further considerations in view of the gravity anomalies present whose actual contributions are not yet ascertained.

GEOLOGY

The geological map of the area as taken from the map of Iraq (Jassim *et al.*, 1990) is shown in Fig. (2). The strata present are structurally conformable, being mainly horizontal or slightly dipping eastwards.

The oldest rocks present belong to the Tayarat Formation (Late Cretaceous), which occupies the western part of the area and forms part of the western high plateau from which water valleys flow eastwards. It is made up essentially of chalky, dolomitized sandy limestone. The formation gradually dips eastwards and becomes covered by later formations.

Umm Er Radhuma (Middle – Lower Paleocene) is a wide spread formation in the area and consists of some (120 – 180) m thick anhydritic, dolomitic and porous limestone (Sissakian and Mohammed, 2007).

Dammam Formation (Middle – Lower Eocene) outcrops locally around the Habbariya depression and consists of porous, dolomitic limestone. Its thickness exceeds 200 m in the type locality.

The Ghar Formation (Early Miocene) is exposed on the eastern parts of the area and is made up of (30 – 40) m of sands and gravels with rare sandy limestone, claystone and anhydrite.

The Euphrates Formation (Early Miocene) outcrops at the northeastern corner of the area and consists of shelly, chalky, well bedded and recrystallized limestone.

The Nfayil Formation (Middle Miocene) may be an equivalent to the Fatha Formation of elsewhere. It outcrops at the northeastern corner of the area and consists of cyclic sediments of green marl and limestone.

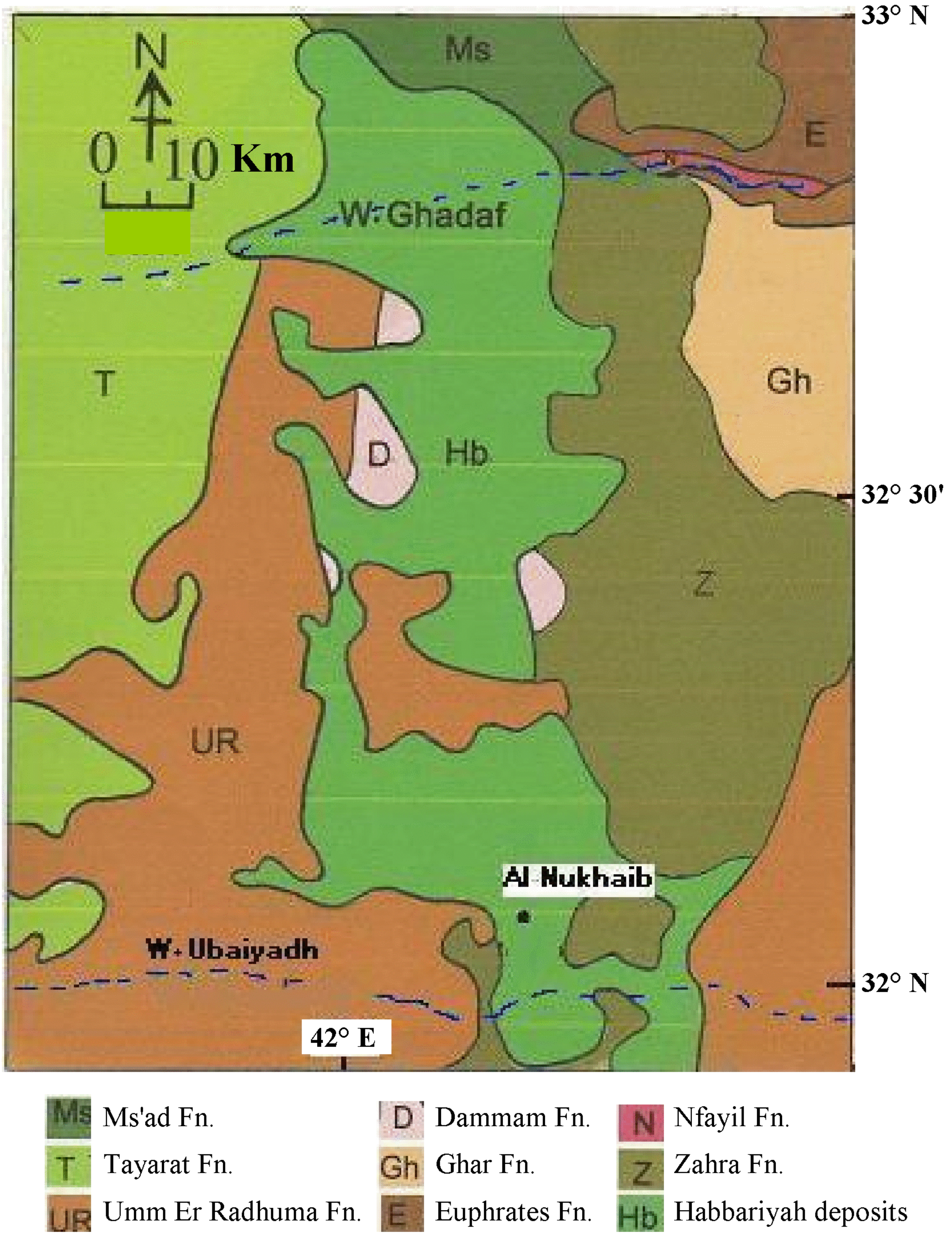

Fig.2: The geologic map of the studied area (after Jassim *et al*., 1990)

The Pliocene – Pleistocene deposits of the area are made up of the Dibdibba and Zahra formations. The first consists of sandstone with igneous pebbles, sometimes well cemented, and the second consists of cycles of coloured sands, clay and marl.

METHOD OF STUDY

The method of study followed here is to consider the gravity field over the area and isolate that part which is related to its subsurface structure. The field is then filtered to obtain the local gravity highs and lows present. These are closely correlated with the outcropping geology in the area and the depression.

The condensed Bouguer gravity map of the area, where only the 5 mGal contours are given is shown within Fig. (3). The gravity field of the area seems to be influenced by gravity highs on the east and by an intense, near circular gravity low on the west. The gravity highs of the east have possibly deep origin. The wide circular low on the west, referred to here as Ghadaf low, is attributed to a Precambrian salt diapir by Al-Bassam *et al*. (1996) and to a basement granitic intrusion by Ahmed (1998) and Al-Badani (2000). The area between these two groups of anomalies shows near flat gravity topography where only the – 25 mGal contour meanders around.

The more detailed picture of the gravity field is shown on the observed Bouguer map of Fig. (4), which is taken from the Bouguer map of Iraq (Al-Kadhimi, 1996) with a scale of 1: 1000 000. The area between these anomalies is occupied by gentle undulations of contours that form smooth, limited gravity lows and highs.

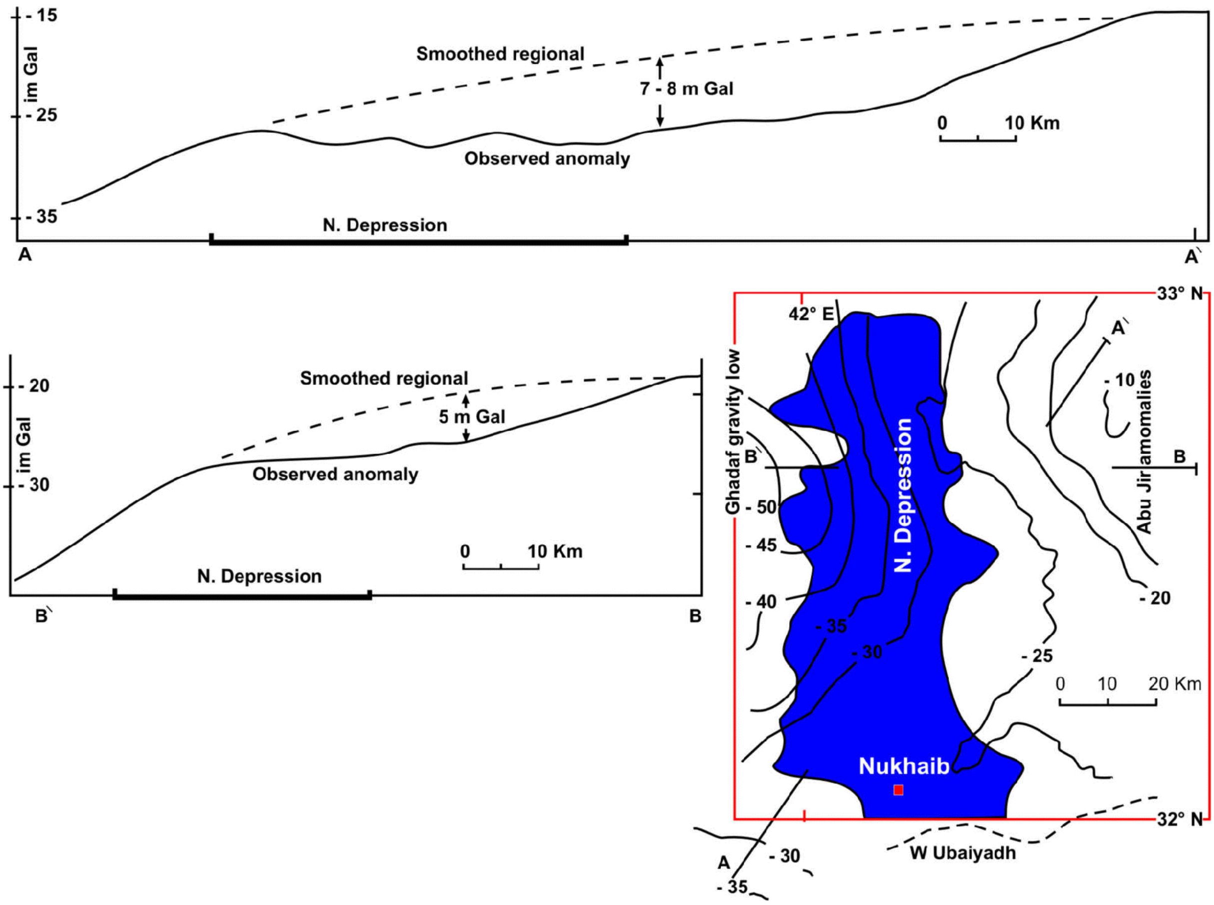

Fig.3: The Bouguer anomaly map of area of study showing the 5 mGal contours.
The anomaly profiles of AA\ and BB\ taken over the map are also shown

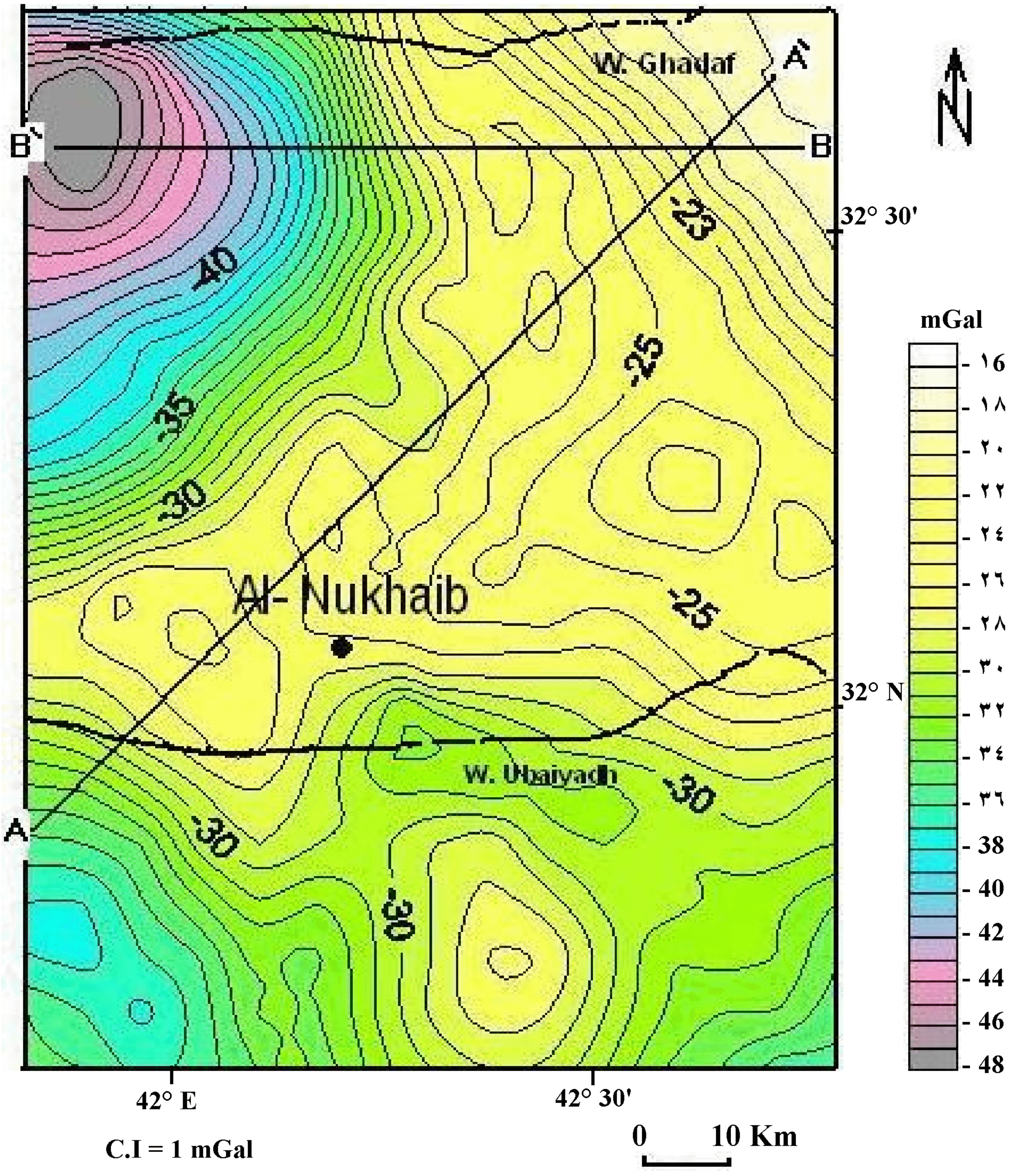

Fig.4: The observed Bouguer anomaly map
(after Al-Kadhimi, 1996)

INTERPRETATION

▪ General Considerations

The linearity of the depression and its deposits may suggest a linear structural origin. In fact, this linearity of outcrop together with its occurrence over relatively younger rocks (Zahra and Dibdibba formations) bounded on either side by older rocks (Umm Er Radhuma, Dammam and Ghar formations) have led to name the depression as Nukhaib Graben (Jassim and Goff, 2006). However, the observed Bouguer map shown in Fig. (4) does not indicate such structural feature. As such, this map will be analysed further in the following sections to examine any local anomaly that may be related to the named structure.

▪ Local Anomalies

The observed Bouguer map (Fig.4) shows local anomalies of various shapes and values. Apart from the main eastern and western anomalies described above, the area north of Wadi Ubaiyadh shows smooth circular as well as elongated local anomalies. The eastern margin of the Ghadaf low itself includes a number of such anomalies that appear hidden by the intense gradient of the low. As such, it is necessary to isolate and to clearly define the local anomalies without their regional background by the use of an effective filtering technique.

▪ Nukhaib Gravity Low

This low refers to the reduction in gravity field over the area that lies between the anomalies in the east and the negative anomaly of Ghadaf in the west. This low is referred to, henceforth, as the Nukhaib gravity low.

In an attempt to assess the magnitude of this low, two long profiles: AA\ and BB\, whose positions are shown on Fig. (3), are taken across the detailed Bouguer map (Fig.4). Profile BB\ runs east – west across the northern part of the low, while that of AA\ is taken to run from the SW corner of the area to its NE. These profiles are inserted within Fig. (3).

Both profiles show a broad flat gravity low. A smooth regional background for the low over each profile is drawn by free hand. The low over BB\ shows a reduction in gravity of about 5 mGal and that over AA\ is (7 – 8) mGal. The smaller reduction over BB\ is obviously due to the fact that the profile covers the end of the main anomaly only.

Furthermore, the two profiles show that the main part of the low in each profile does not occur over the outcrop of the Nukhaib depression and its sediments. The main part of the low, on the other hand, occurs over the broad area to the east of the depression.

It is believed that the Nukhaib gravity low is directly related to the general reduction of the density of the subsurface rocks in the area. Density reduction is brought about by the solution effects of the water coming along the valleys towards the depression. This water is absorbed through the gravely sediments of the depression and percolates through the strata below moving dipwise eastwards. The calcareous and gypsiferous nature of the succession may aid the solution process. With a reduction in density of 0.2 gm/cm^3 in these rocks, the observed gravity low of 8 mGal will indicate that the solution effect may occur at any depth up to one kilometer. If the density reduction is 0.1 gm/cm^3 the solution will penetrate to some 2 kilometers of depth. Such depths of solution may involve Cretaceous and perhaps even deeper rocks. No other approved sources of density variations within the subsurface rocks of the present area other than effective solution can be seen to sufficiently satisfy the gravity low of 8 mGal. Extensive solution effects on these rocks may lead to the formation of appreciable amounts of cavities and caves that may be followed by fracturing and collapse. Seismic reflection surveys over the Razzaza and Habbania lakes have shown local fracturing faulting and collapse down to the Late Cretaceous (Al-Sakini, 1984). Furthermore, Sissakian (2011) has attributed the formation of the Therthar Depression to the solution of the underlying Fatha rocks. It is believed that some similar action is in process in the Nukhaib area.

- **Isolation of Local Anomalies**

It has already been pointed out that the gravity low calculated over the Nukhaib area is caused essentially by the general reduction in subsurface rock density, which is, in turn, related to the solution effects of percolating groundwater. It is expected, therefore, that the subsurface succession will consist of localities where solution is highly effective and others where it is not. The differential solution that leads to this conclusion may depend to a large extent on rock's nature. It is assumed here, therefore, that the only source of the observed local anomalies and their nature is the conclusion stated above.

The local anomalies are isolated using the low-pass filter given by surfer version 8.02 software to construct at first a regional map. It is a process of moving average, which is a form of linear convolution applied to the digitized Bouguer map. The residual anomaly map is then obtained by subtracting these regional values from the observed map.

After digitizing the observed Bouguer map (Fig.4) into a (6 × 6) Km grid, the data are subjected to the process of filtering described above. Filters of 3 × 3, 5 × 5 and 7 × 7 each with various number of passes (the number of times the filter is applied) have been tested. All these sets of filters produced regional maps with essentially similar features. All residual maps show groups of approximately linear positive and negative anomalies. The main difference between these anomalies as taken from different filters lies in the amplitudes of the anomalies and their widths. Smaller anomalies are produced from 3 × 3 filter. The 7 × 7 filter, on the other hand produces larger local anomalies. The criteria used in choosing one filter rather than other is the smoothness and uniformity of the resulting regional anomaly map. It was found that using the 7 × 7 filter with passes number of 15 has produced a smooth uniform regional map with no trace of local anomaly effects (Fig.5). The corresponding residual anomaly map is shown in Fig. (6), drawn with contour interval of 0.5 mGal in order to clarify the anomalies.

The regional gravity map of the area (Fig.5) made by the removal of local anomalies from the observed gravity map (Fig.4) shows smooth contours expressing the intense circular Ghadaf low in the west and the gentle gravity high in the east. The latter high extends southwestwards forming a tongue covering the town of Nukhaib.

The negative anomalies shown in Fig. (6) have different dimensions and tend to occur within the depression although some of them occur outside it. The positive anomalies, on the other hand, are more widespread, some linear, others three dimensional and are found both inside the outlines of the depression and outside it. The amplitudes of these anomalies range between (1 – 3) mGal.

Some of the positive anomalies are correlative with outcropping Umm Er Radhuma Formation.

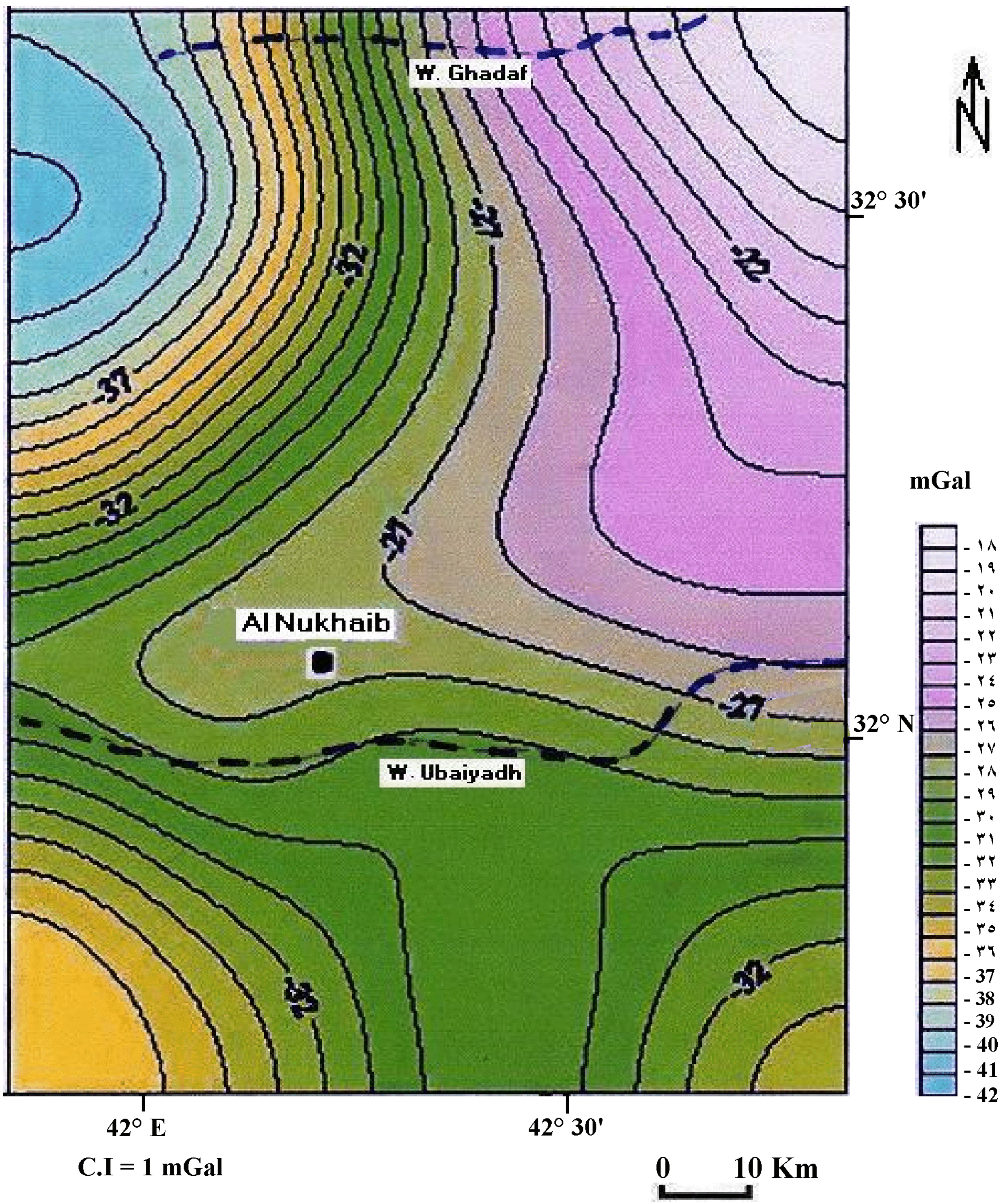

Fig.5: The regional gravity map of the study area

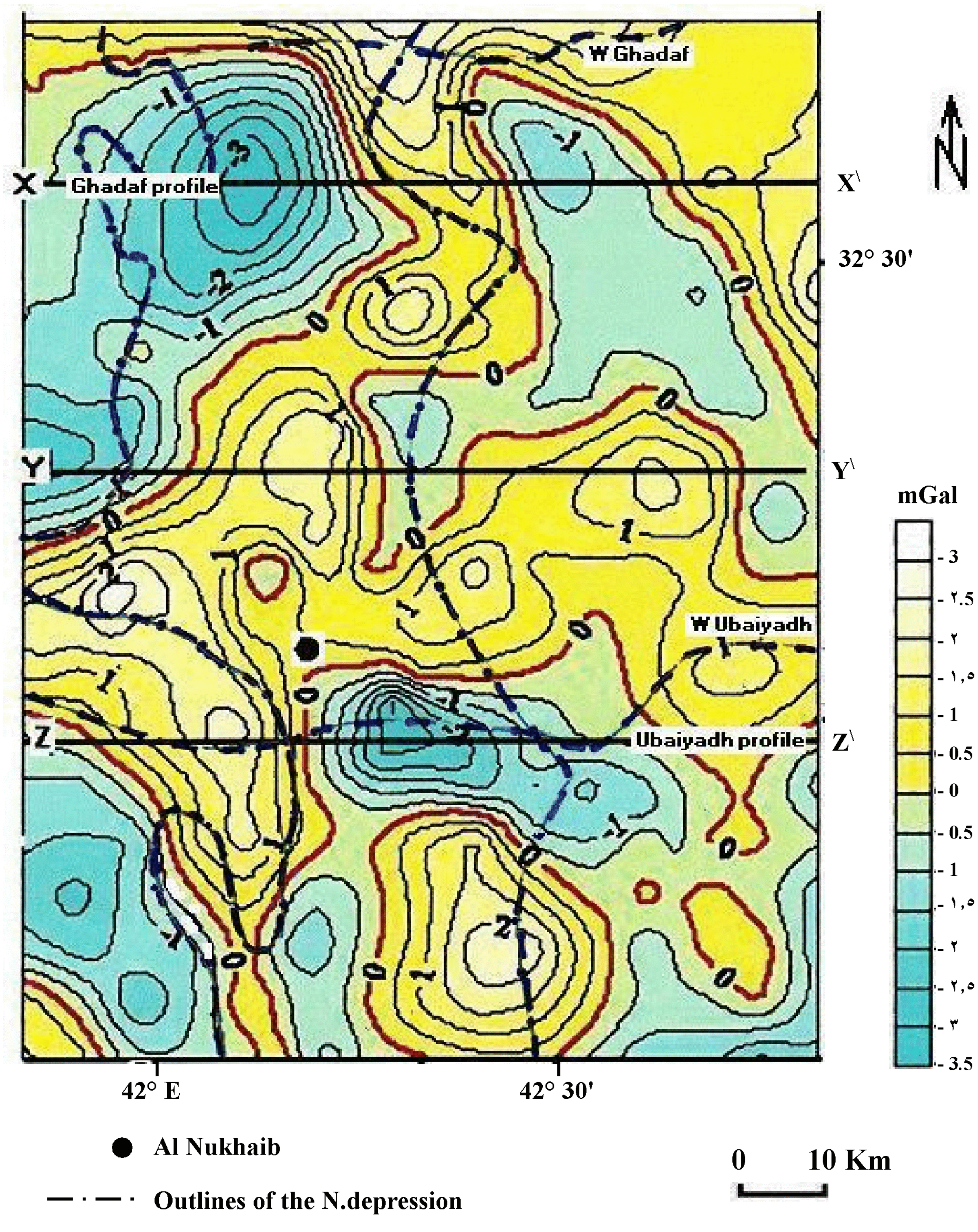

Fig.6: The residual map of the study area

One outcrop occurs west of the town of Nukhaib causing an eastward shift of the depression by some 25 Km. The outcrop is closely followed by the positive anomaly (Fig.6). Clearly the outcropping Umm Er Radhuma Formation in this locality must have resisted solution by running water. Other similar localities occur to the north of the town of Nukhaib where gravity highs overly outcrops of the same formation. No other outcrop of the formation with an associated gravity high is observed in the study area. The positive, narrow N – S trending anomaly observed at the middle of the Ghadaf profile (XX\) (Fig.6) may overly resistive rocks of shallow depths. It is believed that resistive rocks such Umm Er Radhuma Formation may form subsurface ridges surrounded by broken dissolved and collapsed rocks. These resistive rocks themselves, however, are selectively and partially dissolved and broken according to their local nature and minor structures and thus contribute to the formation of some gravity lows of which the Habbariya depression is the most prominent.

- **Modeling**

The subsurface distribution of localities of effective rock solution in the area can be assessed by modeling over selected profiles. All anomalies shown on the residual map of Fig. (6) are treated as two-dimensional and, where some of them tend to be circular, provision is made for correction.

— **Density Contrasts:** Rock densities have been calculated from the interval velocities of the different formations involved in the present study using Nafe and Drake exponential relation (1959) :

$$\rho = 0.23\ V^{0.25}$$

Where V is the interval velocity of the formation and ρ is its corresponding density.

Values of the interval velocity are obtained from Rezooki (1999). An average density for the formations: Fatha, Dammam, Umm Er Radhuma, Tayarat and Hartha (giving a thickness of some one kilometer – nearby well Kifil 1) comes to be 2.45 gm/cm^3 taking into account the thickness of each formation as weightings.

The gravity low over the Nukhaib area is found to be about 8 mGal (section 5, Fig.3). If this low induces a reduction in the average density of the formations mentioned of 0.2 gm/cm^3 then their average density will be 2.25 gm/cm^3. In this case, local negative anomalies (Fig.6) over areas where extensive solution and collapse are active, negative density contrast for these rocks with respect to the above average are expected. These weak-rocks will constitute what is referred to below as "basins". On the other hand, positive local anomalies (Fig.6) over rocks of little or no solution effects operating will have a positive density contrast. They will form what is referred to below as sound rock block.

It must be clarified that what is called "basin" here refers to a space within the subsurface that is occupied by broken and collapsed beds and contains excessive solution products having an average density of about 2.07 gm/cm^3. The boundaries of these basins may be marked by flexures, sagging and possibly fractures.

The existence of such subsurface basins may have contributed to the subsidence of the overlying surface rocks and led to the formation of the downwarped localities.

Three E – W profiles taken across the map of Fig. (6) are modeled. They are XX\ (the Ghadaf profile) YY\ and ZZ\ (the Ubaiyadh profile).

It should be emphasized here that the structures given below represent one possible solution to the observed local anomalies based on the density distribution discussed above.

— **Ghadaf (XX\\) Profile:** At its western part, the profile crosses an important negative anomaly of more than 3 mGal. It has a large areal extent with some N – S elongation. It overlies the northern part of the depression in the area. It is separated from another two-dimensional negative anomaly on the eastern part of the profile by a relatively narrow N – S trending positive anomaly (Fig.7).

The negative 3 mGal anomaly is related to a mass of weak, partially dissolved rocks of density 2.07 gm/cm^3 forming a basin-like structure with a maximum thickness of 400 m. The outcrop of the N. Depression as outlined by the geomorphic map overlies this locality. This elongated basin is bordered on the east by an elongated sound rock block of density 2.35 gm/cm^3 that rises to a depth of 200 m below the surface. A minor elongated basin occurs to the east of this block. The sound rocks here may be represented by Umm Er Radhuma and the overlying Dammam formations, a conclusion that is drawn from the local association of the positive local anomalies with outcrops of this formation. The regular western boundary of the N. Depression, in this locality as expressed by the linear arrangement of alluvial fans must be partly related to these N – S trending subsurface structures.

— **Profiles YY\\:** This E – W profile occupies the middle of the study area. The cross-section, whose calculated gravity fits perfectly with the observed gravity, shows two blocks of sound rocks (undesolved mass) rising to outcrop or near outcrop positions. These blocks represent Umm Er Radhuma and underlying formations as can be seen on correlation with the geological map of Fig. (2).

The present geomorphic map of Fig. (2) puts the N. Depression over the whole of the western block of this section (Fig.7), while the actual basin occurs more to the west. In fact, most of the section here does not show the existence of a depression.

— **Wadi Ubaiyadh ZZ\\ Profile:** The section (Fig.7) over this profile shows a sound rock block outcropping in the west, followed by a basin on its east. The outcrop of the Nukhaib Depression as presented by the geomorphic map closely overlies the basin in the section. The sound rocks here are represented by the outcropping of Umm Er Radhuma and the overlying Dammam formations, which occurs directly west of the basin.

▪ Discussion and Conclusions

The Nukhaib area studied here has a large, flat topography into which numerous E – W flowing wadies discharge. The subsurface rocks are, therefore, constantly supplied with water.

The gravity field over the area shows a flat, broad gravity low of 8 mGal. No deep source can readily be found from the known geology to reasonably account for this anomaly. The only explanation, therefore, is the one adopted here. The source is relatively shallow and broad. It is the regional reduction in rock density due to widespread solution.

It has been shown (section 6.5) that the average density of the subsurface rocks is reduced by continual solution from 2.45 to 2.25 gm/cm^3. Such reduction will explain the anomaly of 8 mGal if the depth of solution is taken to be within one kilometer.

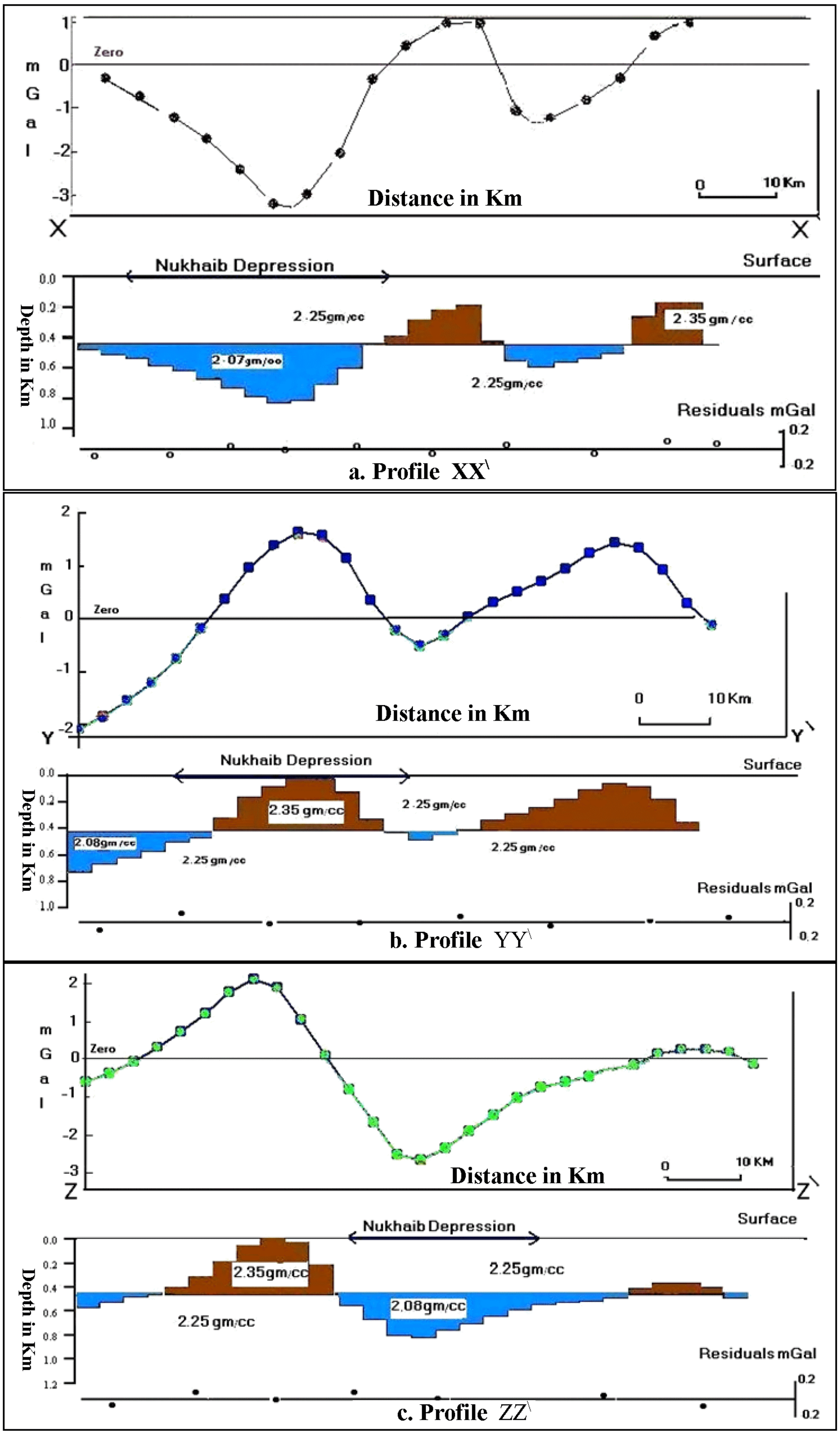

Fig.7: Anomaly models on profiles a. XX\, b. YY\ and c. ZZ\
Location of Nukhaib Depression is taken from the residual map of Fig. (6)

The residual anomaly map (Fig.6) shows local gravity highs and lows superimposed on the negative background of 8 mGal. These local anomalies are considered to represent variations in the intensity of solution so that the low reflects active solution, fracturing and collapsing of rocks, while the gravity high reflects less affected rocks. The Nukhaib Depression, in its northern part includes both types of anomalies. The modeling of Fig. (7) shows the subsurface distribution of the sources of these local anomalies.

Two outcrops of Umm Er Radhuma Formation within the area are characterized by distinct positive local anomalies. One outcrop occurs west of the town of Nukhaib immediately outside the boundary of the depression. The other outcrop occurs in the middle of the study area extending from within the depression. This association between these outcrops and the positive anomalies suggests that all other similar anomalies in the area are related to this formation that may not necessarily be outcropping. It should be emphasized here that the Umm Er Radhuma Formation used here to explain the positive local anomalies may also involve the underlying Dammam Formation.

It is believed, therefore, that Um Er Radhuma and the underlying formations, whether outcropping or thinly covered, occur in patchy and sporadic localities within the area both inside and outside the present outlines of the depression. In other words, the normal stratigraphic succession in the area is complete unless substantial solution and collapse has affected some localities.

It is suggested that the present boundaries of the depression, which mark the starting line of the alluvial fans on the west and their ending line on the east are somewhat an over simplification. The starting line of the fans is not regular, but follows the local geology and topography including the contact between the softer rocks of Zahra and Dibdibba formations and the underlying harder rocks. Furthermore, the fan's deposits themselves constitute only a thin veneer of conglomerate.

As such, it is believed that, where the depression forms a distinctive topographic feature, it overlies localities underlain by solution basins. In other words, it is the solution basins and not the line of alluvial fans that delineate the depression. Accordingly, the formation of the basins must have preceded the topographic depression, which was followed by the alluvial fan formation.

Tectonic sources for the basins are not favored. The models shown in Fig. (7), though, in places, indicate sharp dispositions between the sound blocks and the basins, they do not suggest faulting in view of the extreme vertical exaggeration. A gradual sagging of rocks as a source for the basin's formation is thought to be more likely. It is possible that the neotectonic activity described by Sissakian and Deikran (2009) in Western Iraq may have contributed to the sagging and subsidence of these basins as their uplift contours run N – S parallel to the basins location in the area.

A more realistic outlines of the Nukhaib Depression in the area can be mapped by delineating the gravity lows shown on Figs. (6 and 7).

REFERENCES

Ahmed, T.Y., 1998. Basement granitic rocks below west Ghdaf, the Western Desert. Raf. Jour. Sci., Vol.9, No.1, p. 40 – 45 (in Arabic).

Al-Badani, M.A., 2000. Possible interpretation of gravity and magnetic data over southwest Iraq. Unpub. M.Sc. dissertation, Mosul University, 86pp (in Arabic).

Al-Bassam, K.S., Al-Bedaiwi, J.A. and Al-Kadhimi, J., 1996. A study on the extension of Hail Arch in Iraq: new findings from Al-Nukhaib region, south Iraq. Geoscience and Arab Development, Vol.Y2, p. 12 – 23.

Al-Kadhimi, J., 1996. Bouguer anomaly map of Iraq, scale 1: 1000 000. GEOSURV, Baghdad, Iraq.

Al-Mubarak, M.A. and Amin, R.M., 1983. Report on the regions geological mapping of the eastern part of the Western Desert and western part of the Southern Desert. GEOSURV, int. rep. no. 1380.

Al-Sakini, J., 1984. The origin of the lakes of Habbariya and Razzaza and the possibility of oil occurrence in the structures forming them. The Second Exploration Conference of INOC, Baghdad, Iraq (in Arabic).

Hamza, N.M., 1997. Geomorphological map of Iraq, scale 1: 1000 000. GEOSURV, Baghdad, Iraq.

Hamza, N.M., 2007. Geomorphology. In: Geology of Iraqi Western Desert . Iraqi Bull. Geol. Min. Special Issue, p. 9 – 27.

Jassim, S.Z., Hagopian, D.H. and Al-Hashimi, H.A., 1990. Geological map of Iraq, scale 1: 1000 000, 2nd edit., GEOSURV, Baghdad, Iraq.

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

Nafe, J.E. and Drake, C.E., 1957. Variation with depth in shallow and deep water marine sediments of porosity, density and velocity. Geophys., Vol.22, p. 523 – 552.

Rezooki, S.J., 1999. 3D distribution of seismic velocities in the area of oil field, SE Iraq. Unpub. M.Sc. dissertation, Baghdad University.

Sissakian, V.K. and Mohammed, B.S., 2007. stratigraphy. In: Geology of Iraqi Western Desert. Iraqi Bull. Geol. Min., Special Issue, p. 51 – 124.

Sissakian, V.K. and Deikran, D.B., 2009. Neotectonic movements in west of Iraq. Iraqi Bull. Geol. Min., Vol.5, No.2, p. 59 – 73.

Sissakian, V.K., 2011. Genesis and age estimating of the Therthar Depression, central western Iraq. Iraqi Bull. Geol. Min., Vol.7, No.3, p. 47 – 62.