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Geological and Hydrogeological Implications of Gravity Data in the Aqra Plain Iraqi Kurdistan Region

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Abstract

A geophysical gravity survey was conducted in the Aqra plain in the Iraqi Kurdistan Region. The survey included 116 stations taken along the main highways and some unpaved roads. The objective of the survey was to study the structural situation of the subsurface and the effects of its geological structures on underground water to detect any gas seeps in some parts of the plain. Simple analyses of the present data were integrated with the observed surface geological features. Basement rocks underneath the plain seem to dip towards the north and northeast with a depth ranging from 5.5 to 6.5km. Gas seeps are shown to be related to a major fault between the two villages of Ruvia and Malabarwan. The condition of groundwater is fairly correlated with the residual gravity data and inferred faults. These faults are oriented in two directions, N-S and E-W.

Keywords: Gravity, groundwater, Aqra-Iraq, prospecting.

1. Introduction

In the Kurdistan Region of Iraq, the Aqra plain is located between Maqlub Mountain (30 km northeast of Mosul City) and Aqra Mountain (80km to the northeast of Mosul City). The Aqra plain has a huge aquifer that supports agriculture; some of the water wells dug in this plain are artesian. Many oil companies had carried out oil and gas exploration projects in this area over the last decade, but unfortunately, their data are not available for public use. The present study provides a gravimetric geophysical data addition to supplement other types of geophysical data for evaluating the subsurface structural framework of the region.

The objective of this work is to draw a preliminary picture in order to understand the subsurface geological structures. For this purpose, gravity prospecting was carried out in the area since gravity is among the cheapest geophysical, non-invasive, non-destructive remote-sensing methods. It is also a passive method of investigation, that is; no external energy needs to be put into the ground in order to acquire data. The collected data (from points at the surface) of gravitational attraction exerted by the earth are corrected and processed to give maps that can be interpreted in terms of geology. The strength of the gravitational field is directly proportional to the mass and, therefore, to the density of subsurface materials (Reynolds, 1997). Anomalies in the earth's gravitational field result from lateral variations in the density of subsurface materials and the distance to these bodies from the measuring equipment (Mariita, 2007).

116 gravity station measurements were carried out along the main streets and some unpaved roads. The surveyed area covers about 500 Km^2 within the almost flat areas of the plain (Fig. 1A).

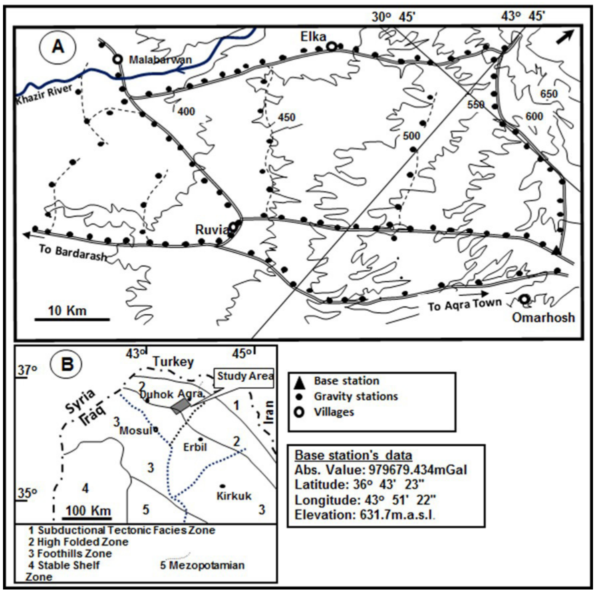

Figure 1. Location of the study area and tectonic map of Iraq

2. Geomorphology, Tectonics and Geology

The dominant geomorphology of the area is related to river deposits bounded from the extreme northern corner by ridges of the southern limb of Aqra Anticline (out of the scope of the studied part of the area) and truncated by the river Khazir in the western corner. Some of the seasonal valleys are also present. A maximum elevation of about 700 m above sea level is observed in the north and northeastern parts, while it is estimated at about 400 m in the western and southwestern parts.

According to the tripartite subdivision of the Iraqi territories (Bolton, 1958; Dunnington, 1958), the Aqra area

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is located within the Folded Zone, which is equivalent to the same nomenclature given by Buday (1973) and Buday and Jassim (1987) in another bipartite subdivision (Fig. 1B and Fig. 2). The latter authors subdivided the Folded Zone into the Foothills Zone and High Folded Zone. In view of the application of the plate tectonic paradigm into the geology of Iraq, Numan (1997) and Numan (2001) employed new terminology for the tectonic subdivisions of Iraq (Fig. 2). The Folded Zone consists of (a) Foothill Zone of the quasi-platform foreland in which successive major anticlines are separated by 40-50 km wide areas of sub-horizontal or very broadly folded strata and (b) the High Folds Zone of the foreland basin towards the north and northeast. The Aqra Anticline forms the northeastern boundary of the Foothills Zone, and it is suggested that it was formed by the basement uplifts in stages before the Lower Miocene ages as a horst combined by a reverse fault on its southern flank (Ditmar et al., 1971). Numan (1984) subdivided the basement underneath the Folded Zone into two major blocks on the bases of the total thickness of the sedimentary cover and two distinctive trends of anticlinal structures on the two basement blocks, mostly E-W, Taurus trending anticlines over the Mosul block (including the Aqra area) and NW-SE Zagros trending anticlines over the Kirkuk block. This regional change in the trending of the anticlines occurs abruptly along the Greater Zab River (about 10km to the southeast of the area), which is the line of demarcation between the two blocks.

The study area is located between two major anticlines both trending almost E-W (Fig. 2). These are the Maqlub Anticline to the west and the Aqra Anticline to the east. The broad area (about 50 Km) between these two structures implies the presence of a gigantic broad syncline as suggested by Al-Omari and Sadek, (1973) (Fig. 2). The southern limbs of both anticlines are of high dip, and are even overturned in some locations.

Most parts of the Aqra plain are characterized by surficial expectedly thick Quaternary and alluvial deposits that overlie the older formations, which crop out in and around the area of study (Fig. 3). Table 1 lists a brief resume of the lithostratigraphic descriptions for the study area (Bellen et al., 1959).

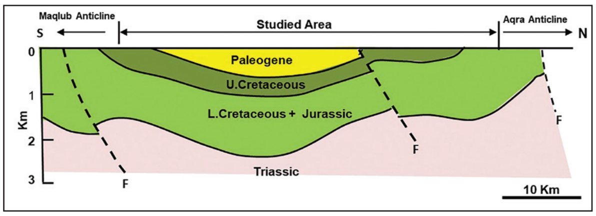

Figure 2. Cross-section between Maqlub and Aqra anticlines showing the studied area (modified after Al-Omari and Sadek, 1973)

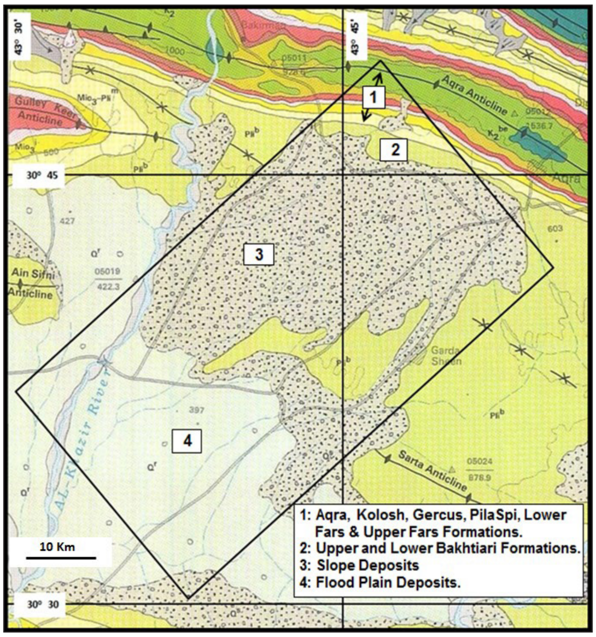

Figure 3. Geological map of Aqra area

Table 1. A brief formation descriptions in the area (Bellen et. al., 1959):

Formation Name	Age	Description
Aqra Limestone*	(Maastrichtian)	Reefal recrystallized bituminous limestone
Khurmala*	Paleocene	Bedded limestone
Kolosh*	L. Eocene	Siltstone and silty marl
Gercus*	M. Eocene	Mudstones, sandstones and siltstones
Pila Spi*	M. and U. Eocene	Crystalline dolomitic and chalky limestone.
Lower Fars	M. Eocene	Limestone, marl and gypsum
Upper Fars	U. Miocene	Loosely packed claystone and sandstone
Lower Bakhtiari	L. Pliocene	Sandstone, claystone and siltstone
Upper Bakhtiari	U. Pliocene	Conglomerate, siltstone and claystone
Slope deposits and Surface alluvium	Recent	Gravelly, sandy and silty clay

**: Not cropping out in the study area, but present underneath the plain (i.e. syncline structure).*

3. Fieldwork and Data Reduction

The fieldwork through the course of this study involved the collection of gravity data and making some geological observations in order to do more realistic interpretations. LaCoste and Romberge gravimeter (model G) and Garmin GPS were used to measure gravity, coordinates, and elevation. Rock samples were also collected to calculate densities in order to carry out corrections. The mean density of surface rocks was calculated to be 2.173 gm/cm^3 [details are given by Ghaib, (2001) and is shown in Table 2]. The local base station which was established at one of the crossroads (Fig. 1A) was tied to the Shaqlawa primary base station, some 100 Km to the southeast of Aqra town (details of looping process are again given by (Ghaib, 2001). The datum for gravity corrections was taken at the elevation of 250 m above sea level. Free air, Bouguer and Terrain corrections were also carried out.

Types of error due to gravimeter, density, elevation, and location were checked in details and given in Table 3. The total error was found to be ± 0.3 mGal (Ghaib, 2001) according to a formula given by Bhimasankaram and Gaur (1977).

Table 2. Mean density of the cropped out rocks at the north-eastern part of the area.

Formation name	Mean density (gm/cm^3)	Formation name	Mean density (gm/cm^3)
Upper Bakhtiari	2.41	Pilaspi	2.45
Lower Bakhtiari	2.31	Gercus	1.93
Upper Fars	2.34	Kolosh + Khormala	2.47
Lower Fars	2.27	Cretaceous rocks	2.57

4. Bouguer Anomaly Map

The Bouguer anomaly map of the Aqra area (Fig. 4) shows minimum systematic indications for the synclinal trough. This reveals that the synclinal trough in between the two anticlines (Aqra and Maqlub) is never simple. Generally, the gravity values decrease towards the north and northeast (i.e. towards the Aqra Anticline). The most conspicuous anomaly extends between Malabarwan and Ruvia villages. It is a linear anomaly separating two groups of anomalies in the south and north. It has a maximum amplitude of about 7 mGal and a mean gradient of 1.2 mGal/km. On the surface and along the whole trend of this anomaly, two phenomena are noted in the field. The first is the presence of gas leakage around the Malabarwan village while the second is the artesian flow of water in most of the water wells that are drilled around the Ruvia village in contrast to the other parts of the Aqra Plain. The two phenomena clearly follow the above-mentioned linear anomaly. Moreover, the Khazir river course in the western corner also shows an abrupt bend when truncated by this anomaly (see figure 8). The best geological interpretation for this anomaly is that it delineates a fault. The general increase of gravity values towards the west probably reflects the effect of the northern limb of Maqlub Anticline.

To the north of Malabarwan anomaly, another nearly closed two-dimensional negative anomaly exists to the south of Elka village (Fig. 4). It has a minimum gravity value of –48 mGal with a NE-SW direction swinging to an almost N-S direction (approximately perpendicular to the anticline) in the northern corner of the area. The Elka anomaly is bounded from the northwest and east by two linear, high gradient anomalies likely reflecting two faults, trending NE-SW and N-S respectively.

In the eastern corner of the Aqra area, another two-dimensional, ENE trending negative anomaly is present north and northwest of the Omarhosh village. It has a minimum value of –52 mGal, which is again bounded by the linear contour lines from the northwest and the southeast.

Although the Aqra area is bounded by two surface anticlines (i.e. Aqra and the Maqlub), the pattern of anomaly shape and distribution does not show a clear indication of the presence of a gigantic syncline between the above two widely separated anticlines of the type described by Parsons (1955) and later reiterated by Al-Omari and Sadek (1973).

The thickness of the sedimentary cover overlying the basement complex, i.e. the depth to the basement is calculated from gravity data using the best approximation density contrast between the sedimentary cover and the basement, which is 0.18 gm/cm^3 (Ghaib, 2001). Using this value in the simple slab equation of Bouguer, the depth of basement in the Aqra area ranges from 5.5 to 6.5 km becoming deeper towards the north and northeast. This inferred thickness of the sedimentary cover coincides with value of the sedimentary cover thickness for the Mosul Basement Block (which includes the present study area) obtained by Numan (1984) using isopach maps and lithostratigraphic data.

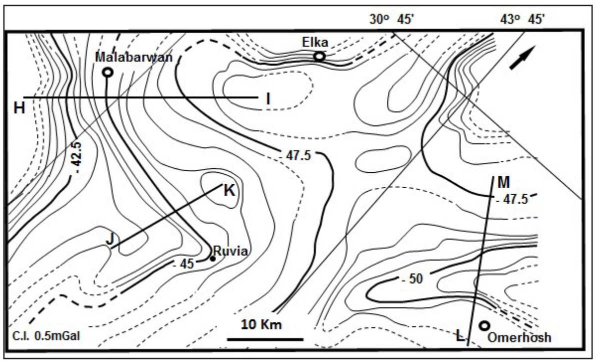

Figure 4. Bouguer anomaly map of the studied area, note the cross sections taken in this study, their descriptions are given in the text.

5. Regional and Residual Anomaly Maps

The contour smoothing method was applied to separate the regional and residual anomalies. The regional anomaly map (Fig. 5) most probably reflects the deep effects of the basement surface and its topography. This regional Bouguer anomaly map shows a regional gravity gradient towards the NNE and NE (about 0.8 mGal/km decreasing to about 0.6 mGal/km in the central part indicating a north and northeastward dip of the basement-sedimentary cover interface).

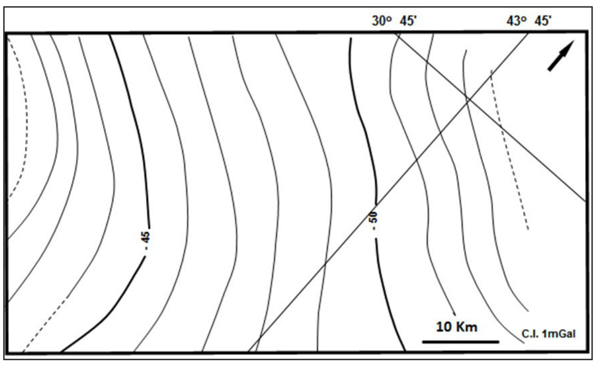

Figure 5. Regional anomaly map of the studied area

The residual anomaly map (Fig. 6) shows many positive and negative anomalies. Two negative closed anomalies occupy together the central part in approximately E-W direction (Omarhosh and Malabarwan). This central area is consistent with a low gradient on the regional map (Fig. 6). The area by definition represents a sedimentary trough between the Aqra and the Maqlub anticlines that bound it from the north and south respectively.

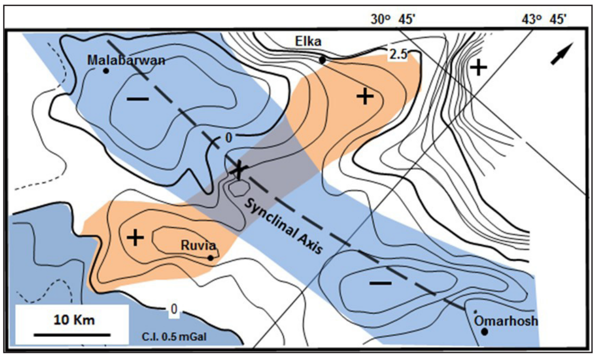

Figure 6. Residual anomaly map of the studied area

On the other hand, two positive anomalies occupy both the northern and southern parts of the studied area. The northern anomaly, trending in an E-W direction, has a high gradient. It is interpreted as being due to a rapid change of density that is related to the overturned southern limb of the Aqra anticline and/or the suggested fault (Fig. 2), while the southern Ruvia positive anomaly trending E-W again is mostly related to a local positive structure.

A special structural situation can be observed as reflected by the distribution of positive and negative anomalies within the synclinal area. In addition to the two negative anomalies mentioned above which both can reflect the general axis direction of the syncline, two positive anomalies are observed as if they cut each other perpendicularly (Fig. 6). This situation of cross-cutting negative and positive anomalies is envisaged to be the result of the syncline in this area whose axis is trending in an E-W direction and a positive anomaly trending in N-S direction. Nevertheless, the positive N-S trending anomaly can be the result of one of three possibilities as follows:

1. An N-S trending compositional variation in the basement rocks. This is in line with the N-S trends in the Precambrian rocks of the Arabian Shield and are manifested by the Najd and Hejaz orogenies in Saudi Arabia (Brown and Coleman, 1972; Shackleton, 1986) as well as the N-S trending Assyntic orogeny in the Precambrian rocks in Iran (Stocklin, 1968). According to Shakleton (1986), the N-S trending Najd and Hejaz orogenies are marked by zones of ophiolites (having high specific gravity) which resulted from collisions of Proterozoic tectonic plates. The positive anomaly in the study area may have resulted from such an N-S ophiolite zone in the basement rocks.
2. There is also an N-S trending fault system such as the Sinjar Sharaf Divide (Ditmar et al., 1971; Buday and Jassim, 1987) in Iraq. These N-S lineaments can also be discerned on satellite imagery (Numan and Bakos, 1997). The N-S trending positive anomaly in the study area could be stemming from two adjacent N-S trending faults that resulted in uplifting a basement corridor in the form of an N-S trending horst structure. Such a structure may lead to an N-S trending positive anomaly in the basement rocks (Fig. 7).
3. The third possibility requires an N-S trending rotational fault in the basement rocks. The rotational movement on the vertical fault plane would raise parts of the basement along the N-S trend of the fault plane, (Fig. 7). The presence of the positive anomalies cross-cutting the zone of negative anomalies calls for further geophysical exploration for oil and gas.

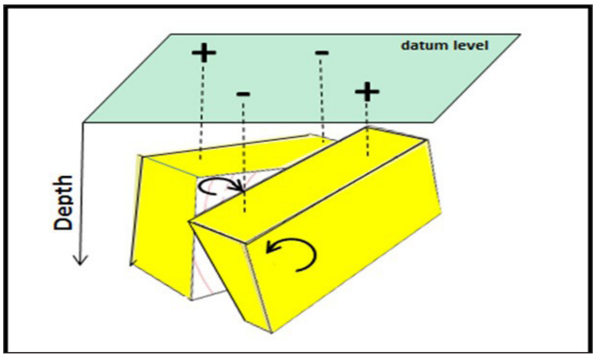

Figure 7. Example of rotated block along vertical faults

6. Quantitative Interpretation

The first step in this interpretation is the visual inspection of the Bouguer map to choose the profile across the anomaly of interest. The second is to estimate approximately the horizontal extension, depth, shape, and thickness of the target using one or more of the rapid methods of calculation such as those described by Bott and Smith (1958); Skeels (1963); and Grant and West (1965). The third step is to construct a geometric n-sided polygon, which satisfies the abovementioned estimations and is consistent with the geologic situation.

For the preliminary estimations and the final calculations as well, the density of different rock units of the causative bodies and the surroundings should be known as precisely as possible in order to calculate the density contrast which is the cause of the gravity anomaly.

The gravity anomaly, observed over a layered sedimentary basin, is close to that calculated over a basin, with the same configuration and depth, but is filled with homogenous (none layered) sediments with a density equal to that of the real layered basin. Accordingly, it is not necessary to composite the effects of the layers separately. In relatively thick successions, the density contrast approaches a minimal value with an increasing depth (Litinsky, 1989).

For each version of the geophysical models of a profile, trials of the gravity effect of an anomaly source are carried out with the density contrast kept constant. In this study, the densities which were calculated by Ghaib (2001) were utilized in modeling, using a computer program based on Talwani et al., (1959) which is one of the familiar methods that are widespread and are used all over the world. The amount of fault dip can hardly be defined in quantitative gravity interpretations. A description of the interpreted profiles across three anomalies (Fig. 8) is given bellow:

A. The Malabarwan Anomaly: Profile (H-I) (Figs. 4 and 8A) extends for about 13 km cutting the linear anomaly around the Malabarwan village. The anomaly reaches a maximum amplitude of 8 mGal and reflects a typical fault shape. The interpretational model represents a normal fault which throws the Upper Cretaceous formations (Footwall) against the Paleogene formations (Hanging Wall). The density contrast between these two groups is 0.25 gm/cm3. There are many surface indications for the presence of this fault; some of them are discussed in the previous sections. The most conspicuous of these indications is the gas seepages noticed south of the village of Malabarwan. The fault apparently offsets Upper Cretaceous rocks and possibly continues downward to a hydrocarbon reservoir that supplies the leaking gas through the fault plane or a fault zone.

B. The Ruvia Anomaly: Profile (J-K) (Figs. 4 and 8B) extends for about 7 km and cuts the eastern end of the Malabarwan anomaly in the NNE-SSW direction. The anomaly shows an amplitude of 2 mGal. The model is designed on the same basis of profile (H-I) as a normal fault which throws the same groups of formations. The density contrast, in this case, is taken to be (0.17) gm/cm3 because the left-hand side block contains a part of the Lower Cretaceous succession of higher density. Mutib et al., 2019 interpreted this anomaly in another traverse trending N-S and concluded the anomaly to be reflected by a small anticline bounded by two faults. Depending on this study, it seems that the other fault might be present farther to the south-southwest.

C. The Omarosh Anomaly: Profile (L-M) (Figs. 4 and 8C) extends for about 10 km in the N-S direction, and cuts the Omarosh negative anomaly. It has a maximum amplitude of 3 mGal. The anomaly is expected to arise from the contrast in density between the Lower Cretaceous and the Upper Cretaceous rocks which is (– 0.17) gm/cm3. The model which satisfies the observed anomaly is in the form of a local graben of a 2.3 km width and a vertical displacement of about 0.5 km.

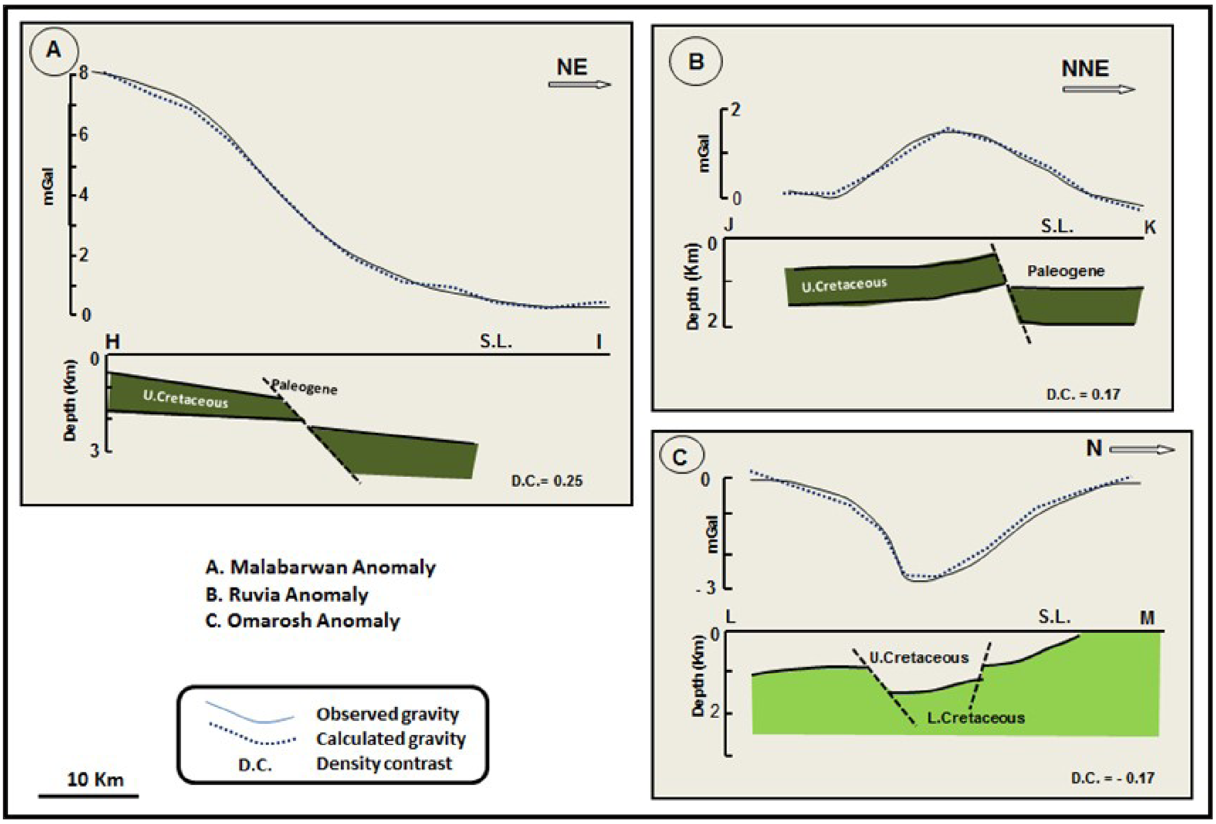

Figure 8. Quantitative Interpretation of main Bouguer anomalies used in interoperating the results of this study.

7. Geological and Hydrogeological significance

The subsurface structure of the Aqra Plain has been described in the past by Al-Omari and Sadek, 1973 as consisting of one gigantic syncline that is 50 km wide. However, the results obtained by this study show that the subsurface structure of the Aqra Plain is more complex than one major syncline with a 50 km width. There are normal faults, grabens as well as a possible horst structure in the basement rocks in the study area and they have been so pronounced to the point that they have appeared on the Bouguer anomaly map. The total thickness of the sedimentary cover was inferred from this study to be between 5.5 and 6.5 km. This finding coincides with the thickness calculated by Numan (1984) from regional isopach maps for this area.

Moreover, the lithostratigraphic data from the surrounding areas based on surface geology as well as the subsurface data from oil wells indicate the thickness of the Pre-Quaternary deposits to the basement rocks to be around 5.5 km. If this 5.5 km succession was to be thrown into a gigantic syncline that is 50 km wide, this synclinal fold geometry would require the thickness of the Quaternary deposits in the presumed syncline to be at least several kilometers more, and since in reality the total thickness of the sedimentary cover is just 5.5 to 6.5 km and most of it is

Pre-Quaternary, the gigantic syncline model does not work. In fact, the subsurface strata have to be sub-horizontal with flexure and very gentle folds including the faults that have been described. The area of study follows the pattern for the Foothill Zone of the quasi platform Foreland where major anticlines are widely separated (40-50 km) by intervening plain areas that have sub-horizontal strata to mild flexures in the strata. This is also exemplified by the Sheikh Ibrahim anticline (to the west of the study area) that is followed by the Bashiqa anticline with an intervening 40 km distance to the northeast of Sheikh Ibrahim. The Mosul area separates those two mentioned anticlines, and the outcrops of the strata under the Mosul City are demonstrably horizontal in the field.

It is geologically accepted that deeper structures are usually reflected in shallower depths. The residual gravity map of the Aqra plain (Fig. 6) shows prominent low gravity values which dominate the western part of the area (near Malabarwan village). Two conspicuous gravity anomalies as well as the inferred faults are superimposed on the net flow map of groundwater in the Aqra plain prepared by Aqrawi (1989) (Fig. 9). The flow net map is a reflection of the influence of relatively shallow geologic features (above the gravity datum level). An interesting correlation can be observed. The coincidence of the gravity low anomalies (Malabarwan anomaly in figure 8), with the main area of underground water accumulation, shows the usefulness of gravity maps in the quest of water aquifers. The artesian water wells in the Aqra plain are mainly located around the southern high residual gravity anomaly (Ruvia anomaly in figure 6). On the other hand, the locations of the faults coincide with the diversion from the usual system of groundwater flow with curvatures in the course of flow in the extreme southern part of the study area (Fig. 9).

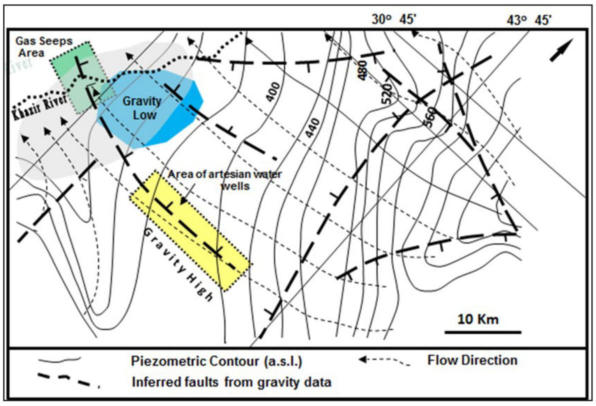

Figure 9. Net flow map of groundwater in the studied area. (modified after Aqrawi, 1989)

8. Conclusions

- The Bouguer anomaly map of the Aqra area shows a less obvious relation with the geological position of the area that is located between two widely-separated anticlines.
- The Bouguer gravity values generally decrease towards the north and northeast indicating that the basement-cover interface dips towards the north and northeast.
- A critical visual inspection of the Bouguer map reveals a gravity low zone in the central part of the Aqra area. This low gravity zone is better seen on the residual anomaly map, and extends in the E-W direction. A cutting positive anomaly is also identified. Three possibilities have been suggested for this pattern of linear positive Bouguer anomaly cross-cutting a zone of negative Bouguer anomaly.
- The thickness of the sedimentary cover overlying the basement complex ranges from 5.5 to 6.5 km. The inferred thickness of the sedimentary cover from this Bouguer gravity study coincides with the sedimentary cover thickness value for the Mosul Basement Block (which includes the present study area) obtained by Numan (1984) using isopach maps and lithostratigraphic data.
- There is a distinctive density contrast within the stratigraphic succession between the Upper Cretaceous formations (2.57gm/cm^3) and the Paleogene formations (2.28 gm/c^3).

Recommendations

Areas that are bounded by widely-separated anticlines like the Aqra area are sites of considerable thicknesses of Quaternary and recent deposits. This feature renders them as very good water aquifers, which may very well solve a lot of water shortages in the region. Further thorough geophysical investigations on the lines following this work need to be done in such areas (such as Harir and Shahrazour plains) in order to properly delineate the aquifers with their expected water yields and water quality. The possibility of stratigraphic traps is valid in such areas which have good subsurface potential for source, reservoir, and cap rocks which may well be helped by suitably situated subsurface faults. A few exploratory deep boreholes are needed in the region for this purpose.

Regional strips of gravity and magnetic studies running transverse to the trend of the Foreland Folds Belts and Thrust zone are needed in the Kurdistan region both for academic and applied purposes. A number of primary base stations need to be established in addition to the existing ones.

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