GRAVITY AND MAGNETIC STUDY IN WADI SHALGHA, EAST OF ERBIL, NORTH IRAQ

Ghalib F. Amin*, Abbas M. Yass and Manaf A. Yousif*****

Received: 30/ 3/ 2008, Accepted: 13/ 1/ 2009

ABSTRACT

Gravity and magnetic surveys were carried out in Wadi Shalgha, east of Erbil, North Iraq to identify and delineate subsurface structures. The survey extends along 250 stations with spacing about one kilometer between each two adjacent stations.

Interpretations of Bouguer gravity anomaly combined with total magnetic field data revealed information about the general subsurface structures and their depths in the involved area. Different analytical approaches were applied to isolate and study the subsurface structures. Magnetic interpretation also showed negative regional anomaly zone within the basement that may be attributed to major movements affecting the whole area, and may affect the overburden sequence.

Tectonically, the studied area is situated in the Chamchamal – Butmah Subzone, which forms the northeastern marginal part of the Foothill Zone and it is structurally the highest part of the concerned zone, which may reaches about (7.5 – 8.5) Km depth. Applied interpretations for both methods concluded that the studied area is a zone of subsided area within the basement, along Wadi Shalghah and forming submerged structure, which characterizes this subzone. This structure may have been influenced by the last Alpine collision and final folding and thrusting since the Late Paleogene – Early Neogene.

دراسة جذبية ومغناطيسية لمنطقة وادي شلغة، شرق أربيل، شمال العراق

غالب فاضل أمين، عباس محمد ياس و مناف عبد الجبار يوسف

المستخلص

اجري مسح جيوفيزيائي جذبي ومغناطيسي لمنطقة وادي شلغة، شرق أربيل لتعيين وتحديد التراكيب الجيولوجية تحت السطحية. وتضمن المسح 250 نقطة قياس جذبية ومغناطيسية وبفاصلة 1 كم بين نقطة قياس وأخرى. أن تفسير شواذ بوجير ومقارنتها بالمعلومات الخاصة بشدة المجال المغناطيسي أظهرت معلومات مهمة حول التراكيب تحت السطحية وأعماقها التقريبية. كذلك دلت الدراسة على أن المنطقة ربما قد تعرضت صخورها القاعدية إلى عملية خفض على امتداد وادي شلغة مكوناً بذلك تركيبياً تحت سطحيا" غير ظاهرا" على السطح.

استخدمت عدة طرق تحليلية لغرض عزل ودراسة التراكيب تحت السطحية، حيث بين تطبيقها على المعلومات الجذبية وجود تركيب تحت سطحي رئيسي يمتد على طول وادي شلغة والذي قد يمثل صدع، بينما المعلومات المغناطيسية أظهرت احتمالية وجود نطاق شاذة إقليمية سالبة ضمن صخور القاعدة والذي قد يكون بسبب حدوث حركة رئيسية أثرت على عموم المنطقة والتي أثرت بدورها على صخور القاعدة وعلى الصخور التي تعلوها.

تعتبر منطقة الدراسة جزءاً من نطاق بطمة – جمجمال الثانوي والذي استنتج على كونه نوع من الأحواض المحصورة التي لها أوطأ الأعماق لصخور القاعدة، ضمن نطاق الرصيف غير المستقر والذي قد يصل إلى عمق (7.5 – 8.5) كم، هذا النطاق يتميز بوجود تراكيب تحت سطحية بعضها يظهر للسطح والآخر يبقى مختفياً، هذه التراكيب قد تكون عبارة عن صدع والتي قد تكون تأثرت بالحركة الألبية الأخيرة خلال فترة الباليوجين الأعلى – النيوجين الأسفل.

* Senior Chief Geophysicist, State Company of Geological Survey and Mining, P.O. Box 986, Baghdad, Iraq

** Senior Chief Geophysicist, State Company of Geological Survey and Mining

*** Geophysicist, State Company of Geological Survey and Mining

INTRODUCTION

During the period from 5 Nov. to 2 Dec. 2006, gravity and magnetic measurements were carried out in Wadi Shalgha vicinity, east of Erbil to detect and delineate the presence or otherwise of any subsurface structure at the southwestern limb of Bana Bawi anticline, for the sake of exploring hydrocarbon occurrences. Both surveys were carried out along 250 stations, which follow the roads and tracks within the studied area (Fig.1).

Gravity data of I.P.C. covering the western flank of the studied area has been gathered from the previous works, which was carried out in the surrounding area, in order to confirm the interpretation of the present results (Fig.2). This compilation shows good coincidence between I.P.C. and GEOSURV data, also both data showed differences in Bouguer anomalies about (5 – 10) millgal, which is attributed to different elevation levels used in the same area (Blizkovsky, 1971).

Computer Microsoft Surfer and Grapher were used to perform the gravity and magnetic contour maps and profiles. Profile AB that trends E – W was chosen perpendicular to the direction of the principle anomaly of the studied area, which almost trends N – S, for the sake of quantitative interpretation.

The interpretation of gravity and magnetic anomalies usually involves separation of residual anomaly (which due to an object of interest) from the regional field, the separation was performed using polynomial surface fitting technique. These interpretations revealed information about the approximate depth of the subsurface anomaly, which is supposed to be a fault that extends along Wadi Shalghah and it might extend down to the basement.

GENERAL GEOLOGY

Tectonically, the studied area is located within the Foothill Zone (Dunnington, 1959 and Al-Kadhhmh, *et al*., 1996), Cham Chamal – Butmah Subzone, which forms the marginal parts of the Foothill Zone, being the highest part. It is also characterized by long anticlines with Neogene rocks exposed in their cores and very broad deep synclines containing thick Miocene Molasses with Quaternary sediments (Abdul Hassan *et al*., 2006). In Late Miocene – Pliocene this subzone became part of the Foothill Trough and was filled in by coarse molass sediments (Jassim and Buday in Jassim and Goffl, 2006).

The exposed rocks in the studied area range in age from Late Miocene to Late Pliocene (Abdul Hassan *et al*., 2006) and comprises the following formations (Fig.3).

- **Injana Formation** (Late Miocene)
  This formation consists of cyclic sediments of claystone, siltstone and sandstone. The sandstone is bedded, usually fractured and jointed, the thickness of the formation in the studied area reaches to 160 m (Abdul Hassan *et al.*, 2006).
- **Muqdadiya Formation** (Late Miocene – Pliocene)
  This formation consists of cyclic sediments of clastic rocks including sandstone, pebbly sandstone, siltstone and claystone, the thicknesses of the formation ranges from (430 – 500) m.
- **Bai-Hassan Formation** (Pliocene – Pleistocene)
  This formation is divided in two units; these are from older to younger:

* **Lower Unit**, is characterized by alternation of conglomerate, sandstone and claystone. The thickness ranges from (1000 – 2000) m.
* **Upper Unit**, is consists of cyclic sediments of conglomerate and claystone. The thickness ranges from (15 – 40) m, (Abdul Hassan *et al*., 2006).

- **Quaternary sediments** include valley fill and slope sediments, residual soil, flood plain sediments. These sediments contain rock fragments, gravel, sand and clay.

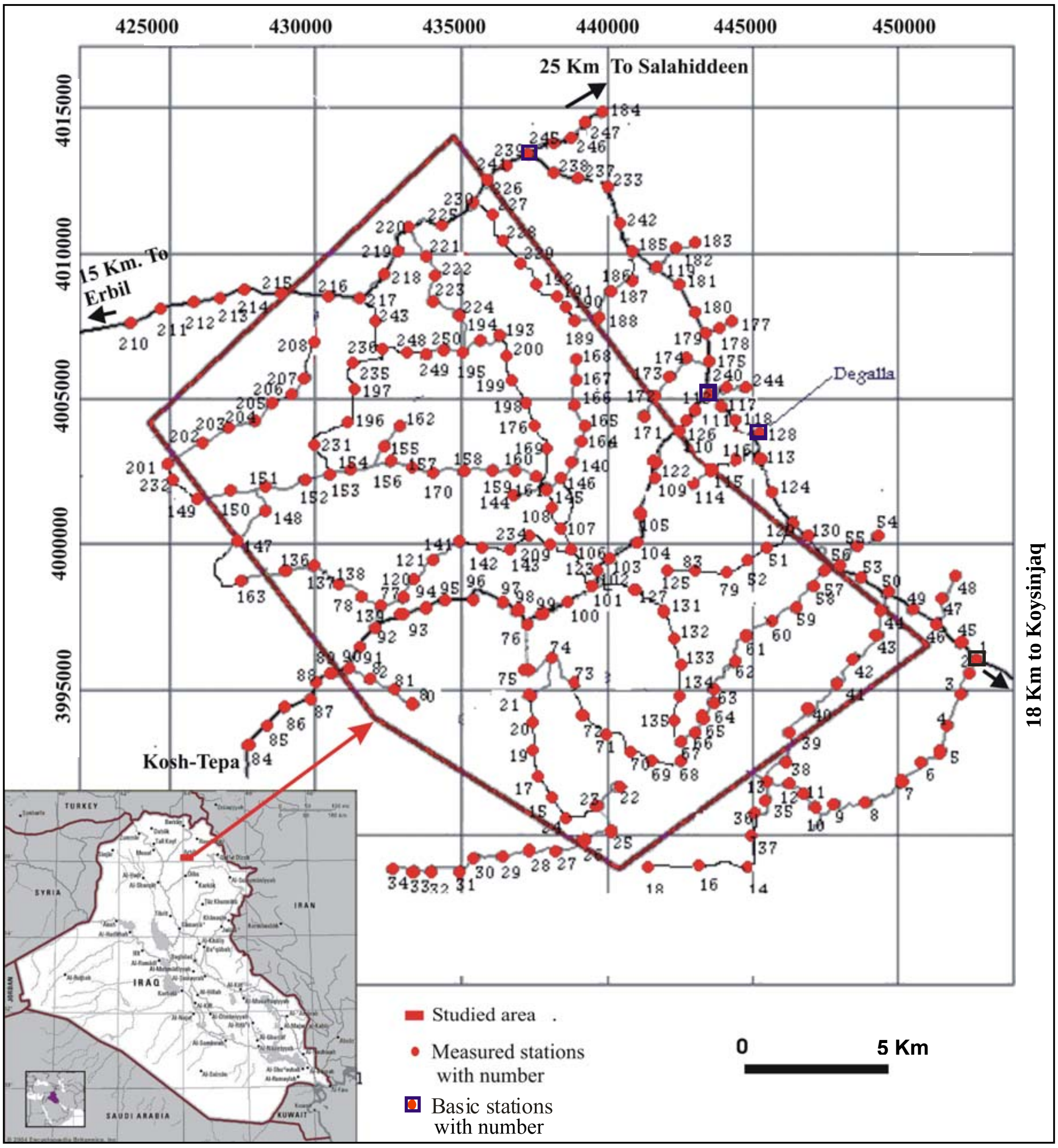

Fig.1: Location map of the studied area, shows the distribution of magnetic and gravity stations

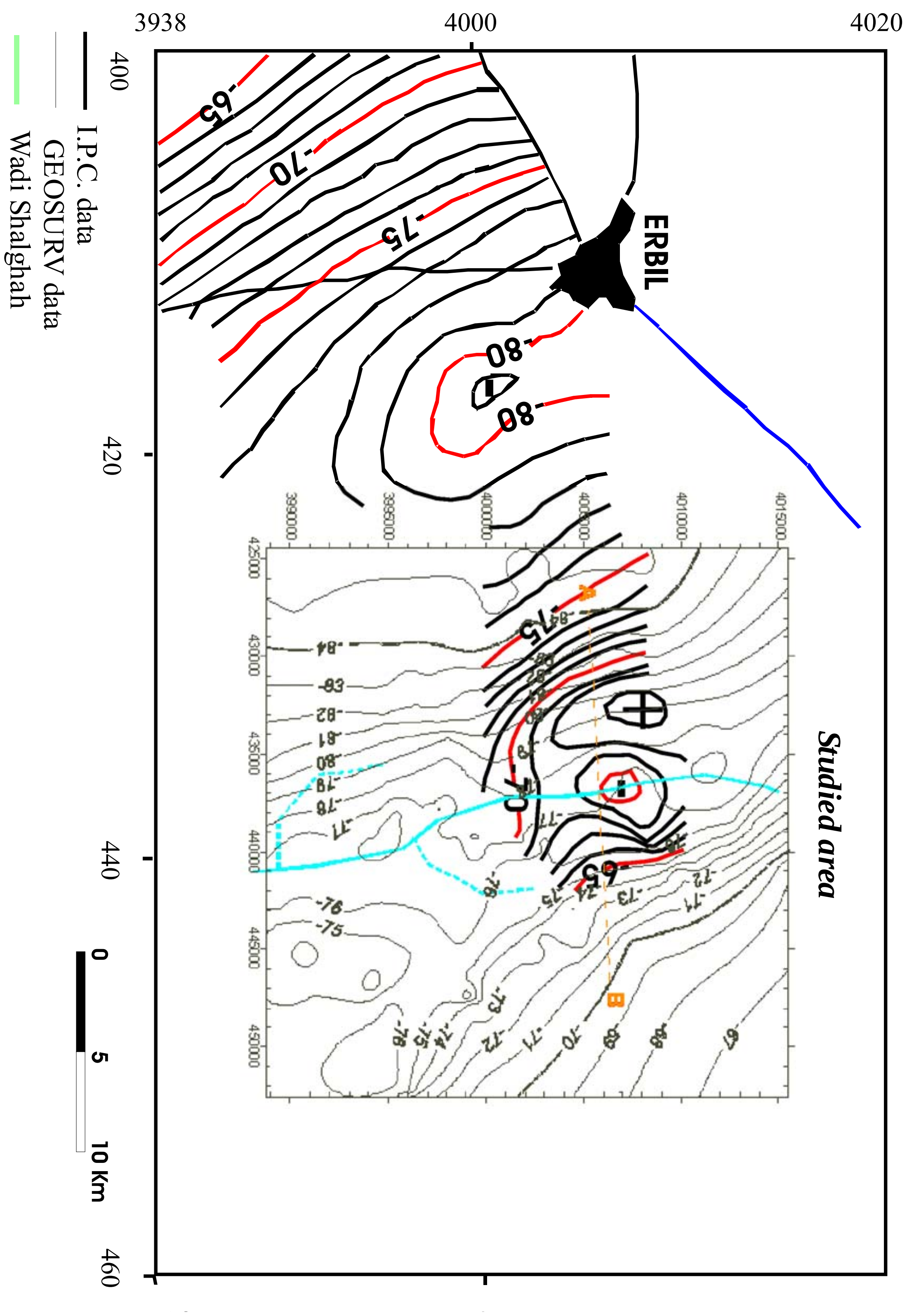

Fig.2: Comparison between I.P.C. data (1985) and GEOSURV Bouguer gravity data, in the studied area

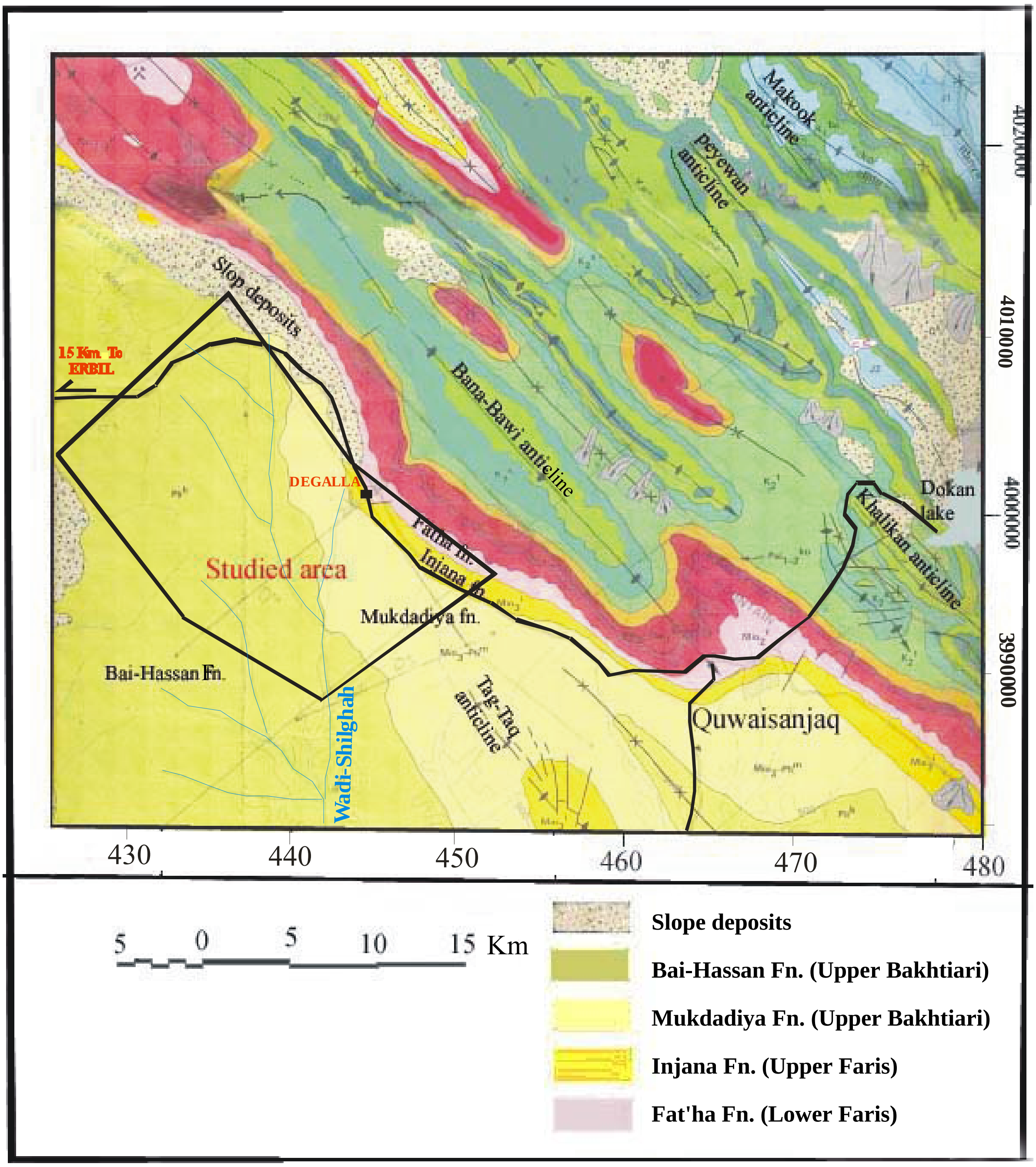

Fig.3: Geological map of Bana Bawi Mountain, including the studied area, (after Sissakian, 1997)

DATA COLLECTION AND REDUCTION

The gravity measurements were carried out using Lacoste and Romberg gravity meter model G-271. A reference basic station was chosen to be in Degala village, which has absolute gravity value 979621.85 mgl, (Al Kadhimi *et al.*, 1985). Also three local basic stations were constructed in the studied area (Fig.4) and tied with the reference basic station in Degala, to repeat the gravity readings every (0.5 – 1) hour.

The topographic measurements were conducted using the Automatic Leveling instrument (WILD NA2), Electronic Total Station (PC 405) and Distomate (DI 2000) for leveling with accuracy of 4 mm/ Km and GPS-GARMN-XL12 for detecting the direction, with accuracy of ± 4 m/ Km, thus a topographic contour map for the studied area was constructed (Fig.5).

The total uncertainty in the final Bouguer values (M_B) based on uncertainties in measured gravity basic stations (mg), observed gravity (mg), horizontal position (mγ), elevation (mh), terrain correction (mt) and density (σ), was estimated to be about ± 0.247 mgl, which also represents the mean square error of the Bouguer anomalies of individual gravity points, according to the following formula (Šutor and Odstrčil, 1977).

$$M_B = \pm \sqrt{mG^2 + mg^2 + m\gamma^2 + (0.3086 - 0.04185\sigma)mh^2 + mt^2}$$

From the above formula, it is clear that a contour interval of (0.5 – 1.0) mgl is generally reliable. While the magnetic measurements were performed according to the instruction mentioned in the instruction manual of push-button proton magnetometer, 1973 with maximum sensitivity of 1 gamma.

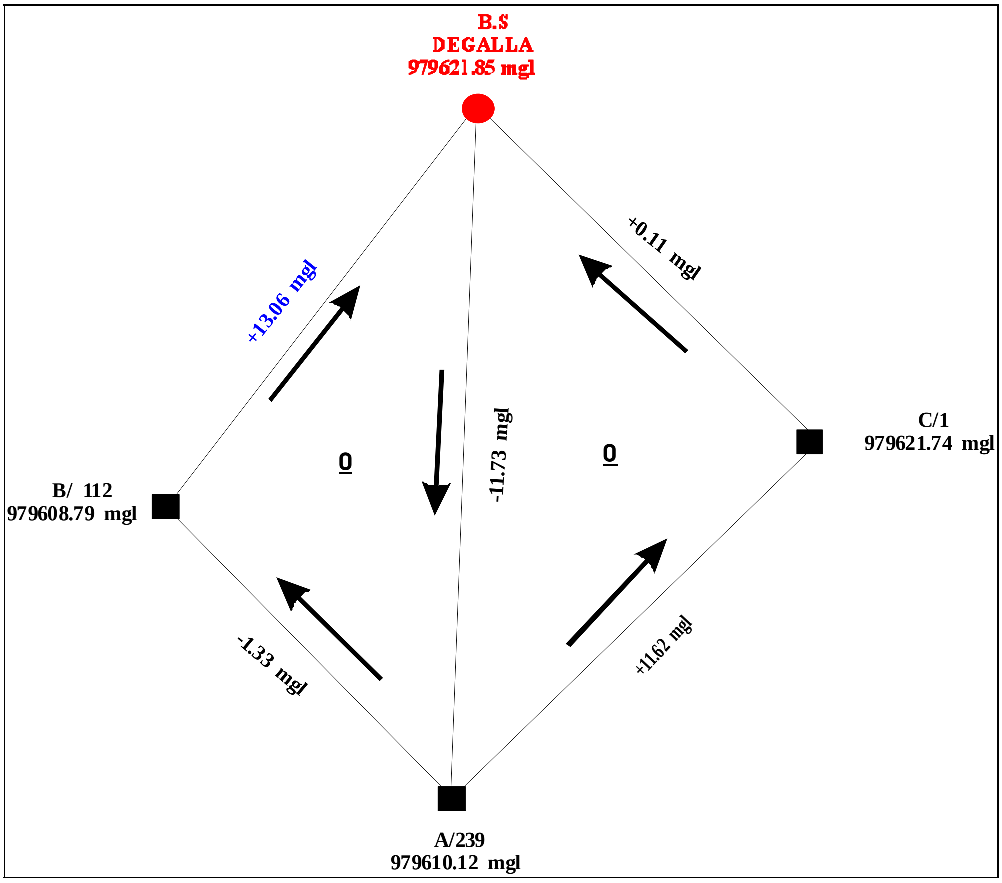

Fig.4: Sketch shows the ties between basic stations

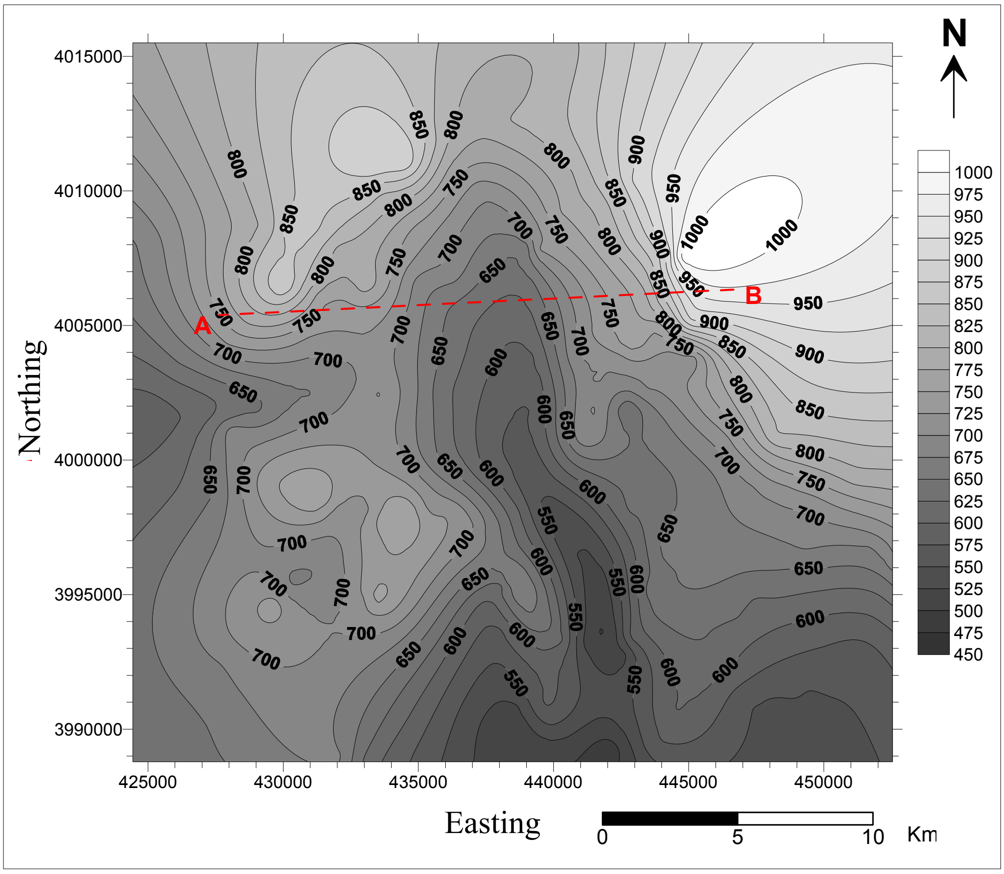

Fig.5: Topographic contour map of the studied area (C.I. = 25 m)

Gravity data were reduced using different corrections, which comprise drift curve correction, latitude correction, Bouguer and terrain corrections to remove all known gravitational effects that are not related to the subsurface density changes. While the magnetic data were fully corrected and reduced to their final form, using diurnal drift curve and normal field corrections.

Rock samples were gathered from outcrops, which are exposed in the studied area and near- by Bana Bawi area (Amin *et al.*, 2006), for density measurements, (Table1), these densities were weighted relative to thicknesses of formation and calculated to be 2.38 gm/ cm^3, this value was used in both Bouguer and terrain corrections.

▪ Interpretation of Gravity Data

Bouguer anomaly map (Fig.6) shows a smooth regional field increasing from SW to NE, having minimum and maximum contour values –84 mgl and –70 mgl, respectively. It can also be seen that the gravity contours become more densely spaced close to Wadi Shalghah, which trends N – S. An attempt to trace the trend of the residual anomalies was performed (Fig.7) and it shows the same N – S trend anomaly, which is found in Bouguer anomaly map indicating that the structure has not very deep origin. The regional gravity anomaly map (Fig.8) shows the same major trend of that in the Bouguer map with gradient of 1 mgl/ Km, increasing from SW to NE.

The residual Bouguer gravity map (Fig.7) exhibits clearly the effect of bordering gradient and the presence of disturbing feature (it could be a fault) in N – S direction along Wadi Shalghah. Considerable interpreted gravity anomaly was also outlined in the southeastern part of the studied area, having NW – SE trend and superimposed on the regional anomaly that has the same trend.

Profile AB (Fig.9) was performed perpendicular to the principle subsurface structure. The profile shows gradient anomaly, which may represent fault or contact, centered along Wadi Shalghah with its down thrown side to be towards NE.

Table 1: Interval density for samples gathered from the studied area

Ser. No.	Sample No.	General Description	Probable Fn.	Approximate Thickness (m)	Bulk Density (gm/cm^3)	Av. Bulk Density (gm/cm^3)	Weighted Density (gm/cm^3)
1	---	Valley fill, soil and slope sediments	Quaternary	1.6	2.0	2.0	0.00087
2	4	Sandstone	Bia Hassan	400	2.33	2.35	0.2562
3	5				2.30		
4	8				2.47		
5	11				2.66		
6	12				2.56		
7	17				2.11		
8	18				2.26		
9	22				2.39		
10	25				2.36		
11	10	Conglomerate	Bia Hassan	400	2.68	2.51	0.2737
12	13				2.48		
13	14				2.54		
14	15				2.41		
15	16				2.42		
16	24	Claystone	Bia Hassan	400	2.43	2.43	0.2654
17	3	Sandstone	Mukdadiya	300	2.21	2.32	0.1901
18	9				2.58		
19	20				2.33		
20	26				2.22		
21	27				2.41		
22	29				2.28		
23	6	Claystone	Mukdadiya	300	2.36	2.37	0.1942
24	30				2.39		
25	7	Claystone	Injana	80	2.32	2.32	0.0506
26	3	Red bed of sandstone	Gercus	40	2.29	2.29	0.0250
27	3′	Red bed of siltstone	Gercus	30	2.16	2.16	0.0176
28	13	Red bed of claystone	Gercus	30	2.46	2.46	0.0201
29	5	Black limestone with bitumen	Shiranish	100	2.25	2.25	0.0614
30	4	Black limestone	Shiranish	100	2.34	2.34	0.0638
31	2	Conglomerate and sandstone	Tanjero	200	2.61	2.61	0.1425
32	1	Marly limestone	Aqra – Bekhma	100	2.62	2.62	0.0715
33	7	Marly limestone	Aqra – Bekhma	80	2.63	2.63	0.0574
34	8	Marly limestone	Qamchuqua	400	2.58	2.85	0.2818
35	11	soft limestone	Khurmala	400	2.11	2.11	0.2304
36	12	Fossileferous limestone	---	200	2.39	2.39	0.1305
37	9	Sandstone	---	100	2.33	2.33	0.0636
Sum				3662			2.38

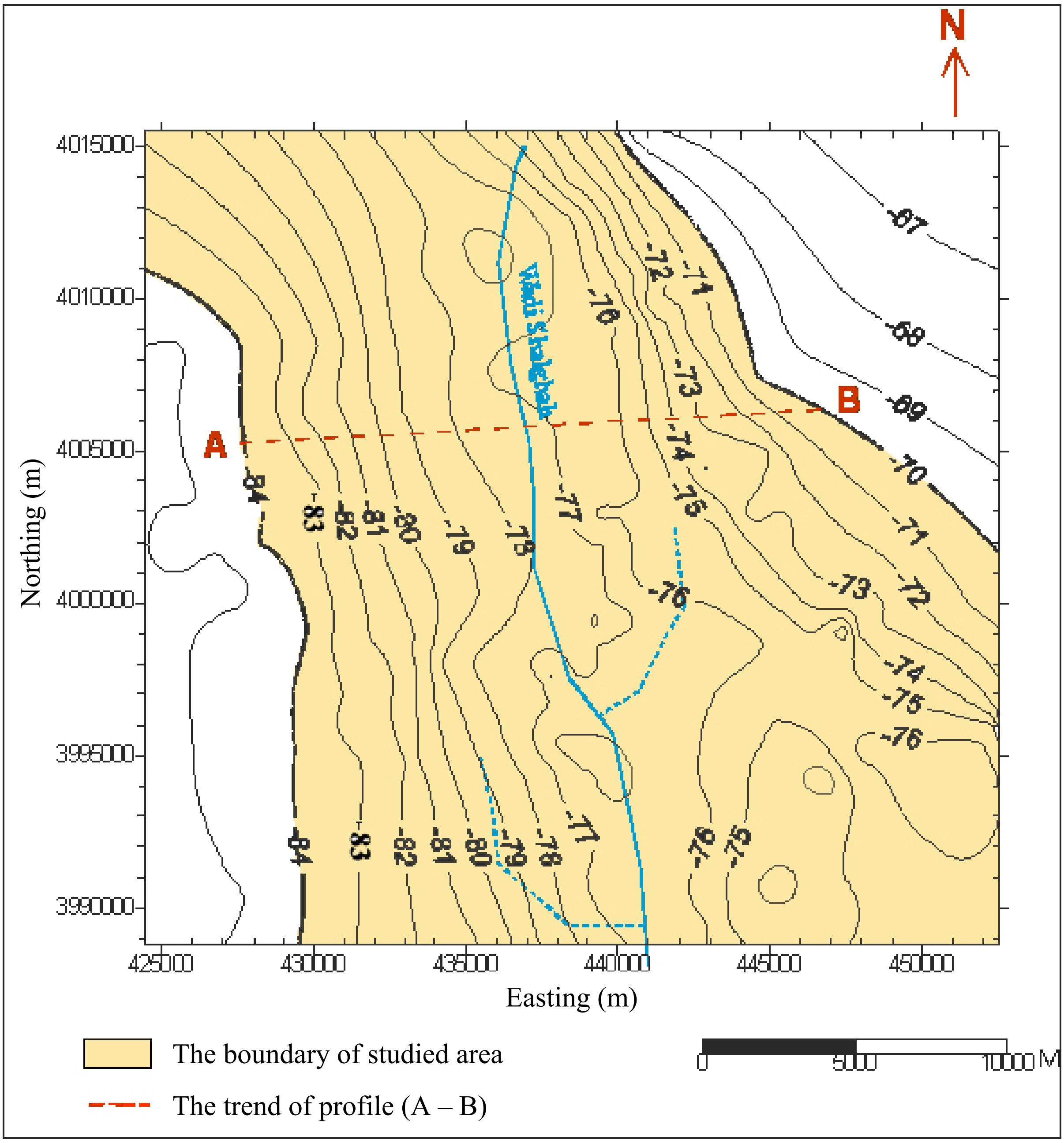

Fig.6: Bouguer anomaly map of the studied area (C.I = 1 mgl)

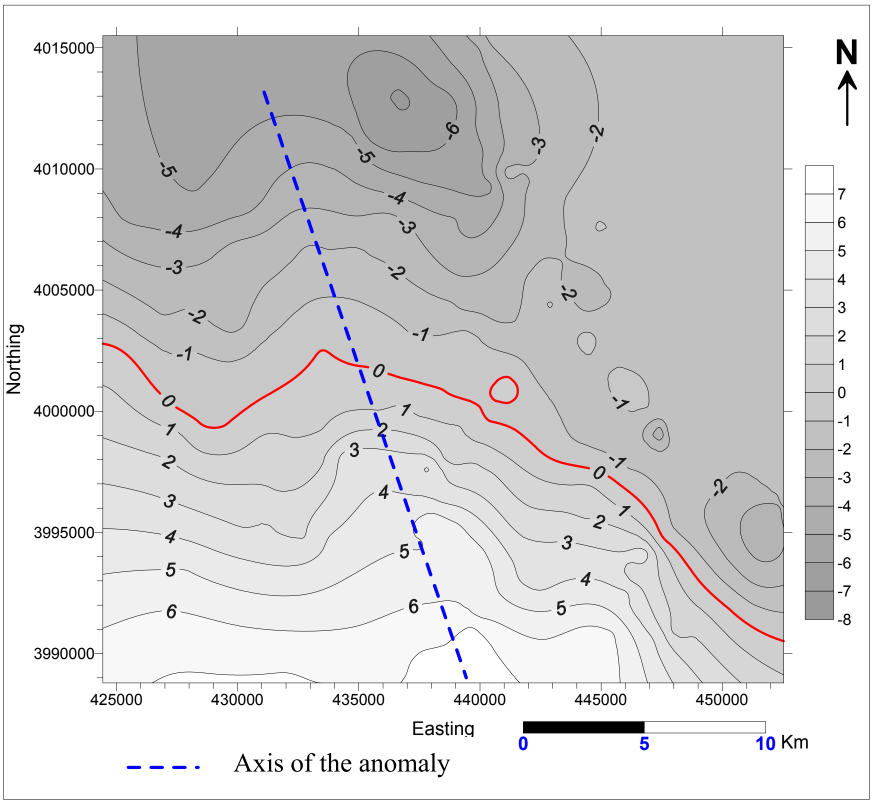

Fig.7: Residual Bouguer gravity map of the studied area using least square method by Agox (1951) (C.I. = 1 mgl)

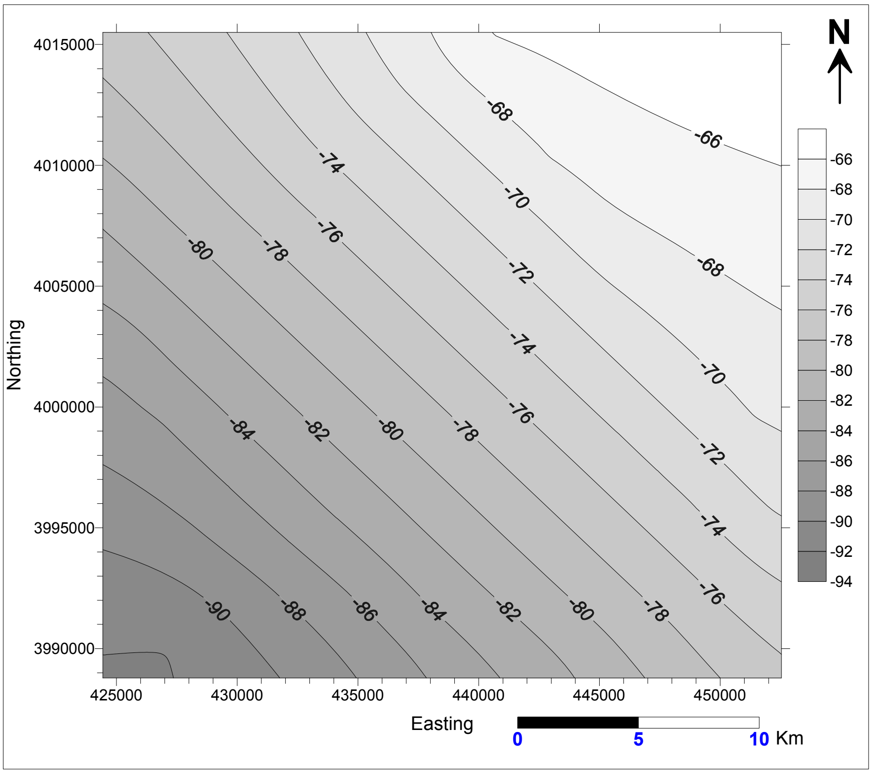

Fig.8: Regional Bouguer gravity map for studied area using least square method by Agox (1951) (C.I. = 2 mgl)

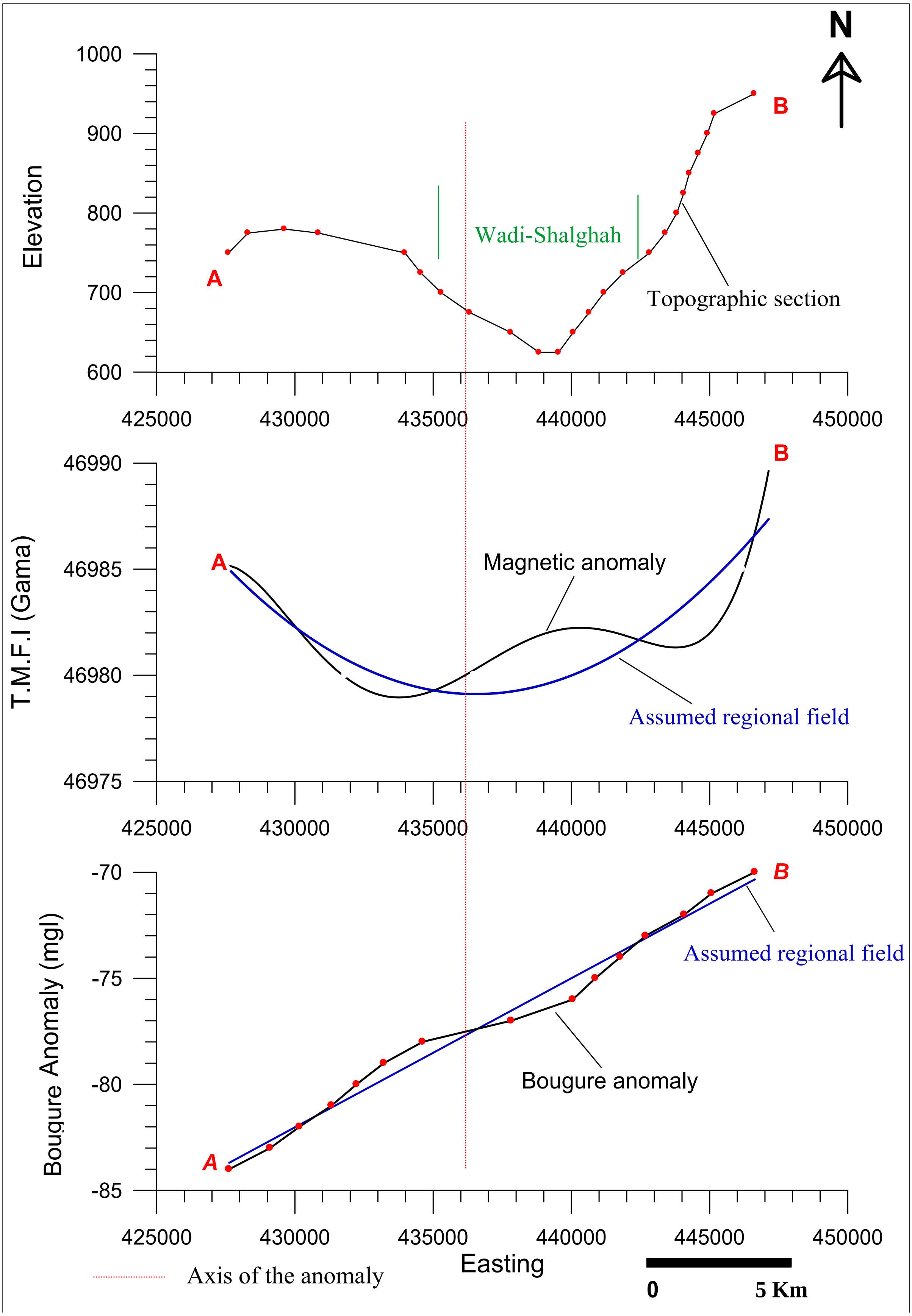

Fig.9: Comparison between gravity, magnetic and topographic data along profile AB

▪ **Quantitative Interpretation**

A profile AB of Fig. (6) was selected for quantitative interpretation. Fig. (10) shows gradient anomaly along profile AB with maximum amplitude of 2 mgl and wave length of 11 Km, this anomaly was assumed to be represented by model of normal fault at about 1000 m depth (Sharma, 1986).

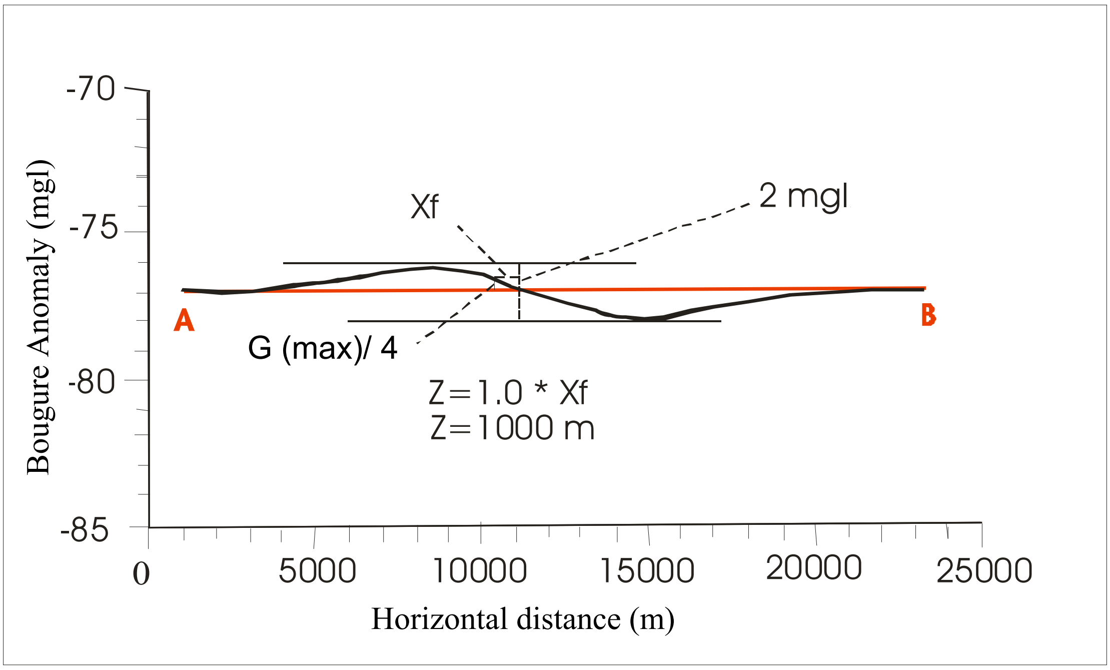

Fig.10: Quantitative interpretation of Bouguer anomaly along profile AB

▪ **Interpretation of Magnetic Data**

The total magnetic field intensity contour map (Fig.11) shows a principal anomaly covering most of the studied area and extends parallel to wadi Shalghah with maximum amplitude of 80 gamma. This local anomaly is supper imposed on a negative regional field, which might reflect the basement (Fig.9).

Relatively, high magnetic gradient is evidenced along the southwestern part of the studied area, such high gradient is indication of magnetic discontinuity, which might represent fault or contact. The residual magnetic anomaly map (Fig.12) shows that in the center of the studied area there is a local positive anomaly that trends NW – SE, parallel to the principal anomaly and flanked with negative anomalies on both sides.

The principle anomaly could be interpreted as a result of a subsurface fault, which affected the overlying sediments that are composed mainly of accumulation of clastics, which include detritus of igneous rocks along the branches of wadi Shalghah. The magnetic residual anomalies at shallow depth create mostly reverse anomaly, when compared with the gravity residual at the same depth, it is attributed to the fact that the susceptibility of the sedimentary cover is higher than that of limestone bedrocks. This small susceptibility contrast is probably caused by higher contents of igneous minerals in sediments (Reynolds, 1995). A regional magnetic anomaly contour map (Fig.13) shows regional trend increasing from SW to NE with gradient of 2.5 γ/ Km.

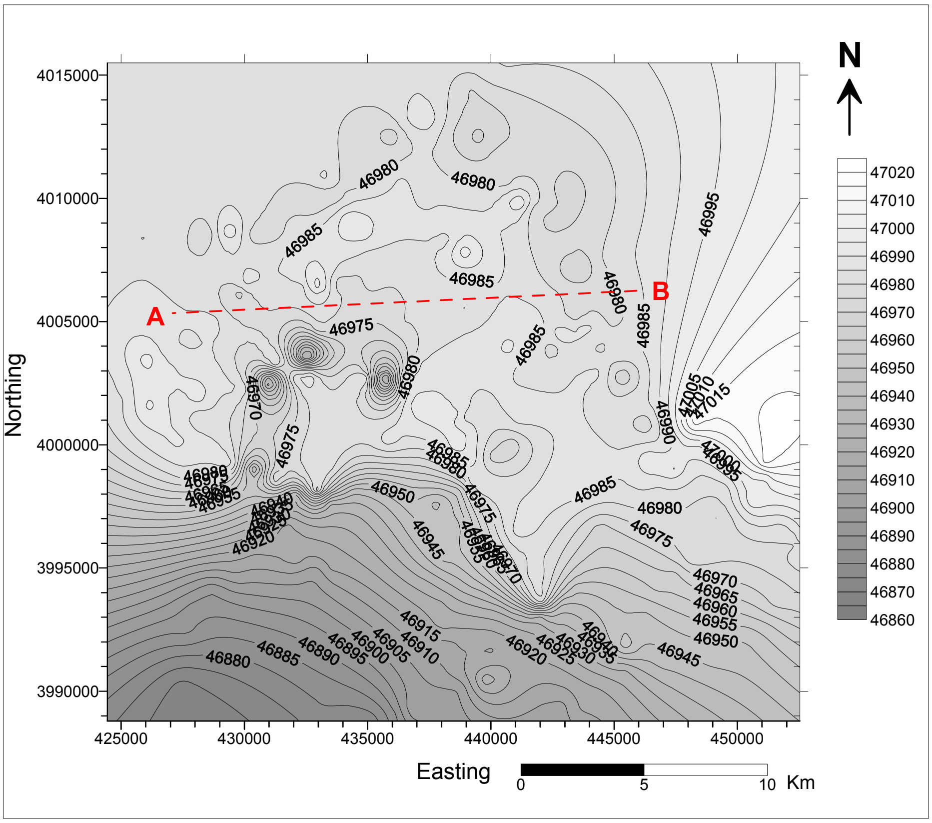

Fig.11: Total magnetic field intensity contour map of the studied area, (C.I. = 5γ)

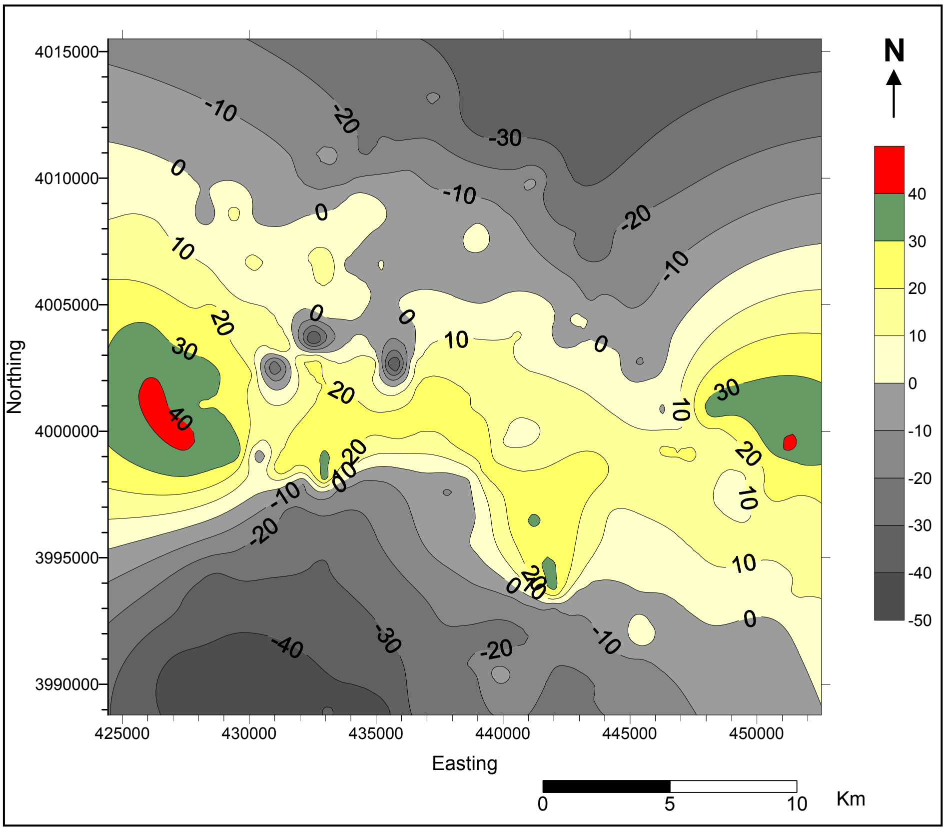

Fig.12: Residual magnetic contour map of the studied area (C.I. = 10 γ)

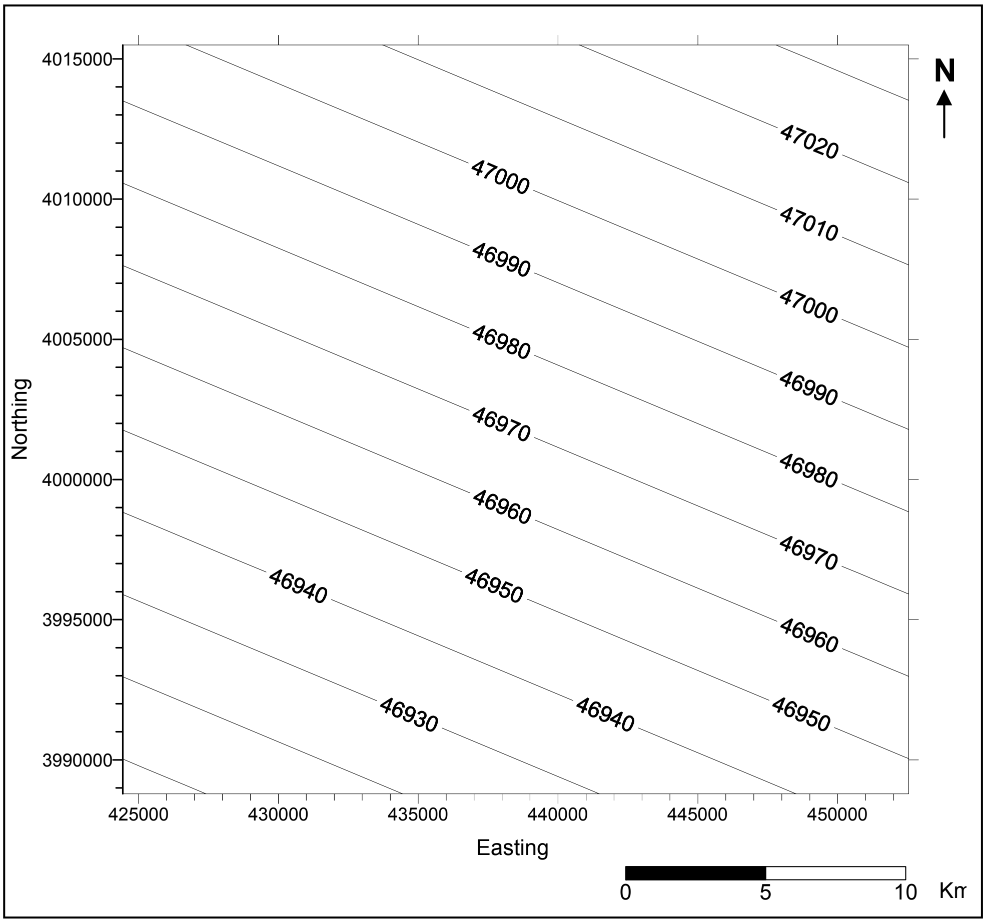

Fig.13: Regional total magnetic field intensity contour map of the studied area

- **Quantitative Interpretation**

In order to calculate the approximate depth to the top of the marker bed, which represents the subsurface structure, it is possible to obtain a very approximate estimate of the depth to a magnetic body, using the shape of anomaly by referring to simple sphere, slab or horizontal cylinder (Reynolds, 1995 and Sharma, 1986). Fig. (14) shows that the residual marker bed has depth of about 2 Km, where the regional anomaly has depth of about 8.5 Km. This depth could be confirmed with previously postulated basement depth for the same area by Jassim and Buday in Jassim and Goof (2006).

RESULTS AND DISCUSSION

Despite of the high variation in lithology within the sedimentary sequence, which is composed of alternation of a high and low density rocks that give some difficulties in the interpretation, the combined evaluation of the gravity and magnetic data, in the studied area revealed some information about the basement and subsurface structure. Magnetic information revealed that the basement depth in the studied area is about 8.5 Km and this is confirmed with previously postulated depth (Jassim and Buday in Jassim and Goff, 2006).

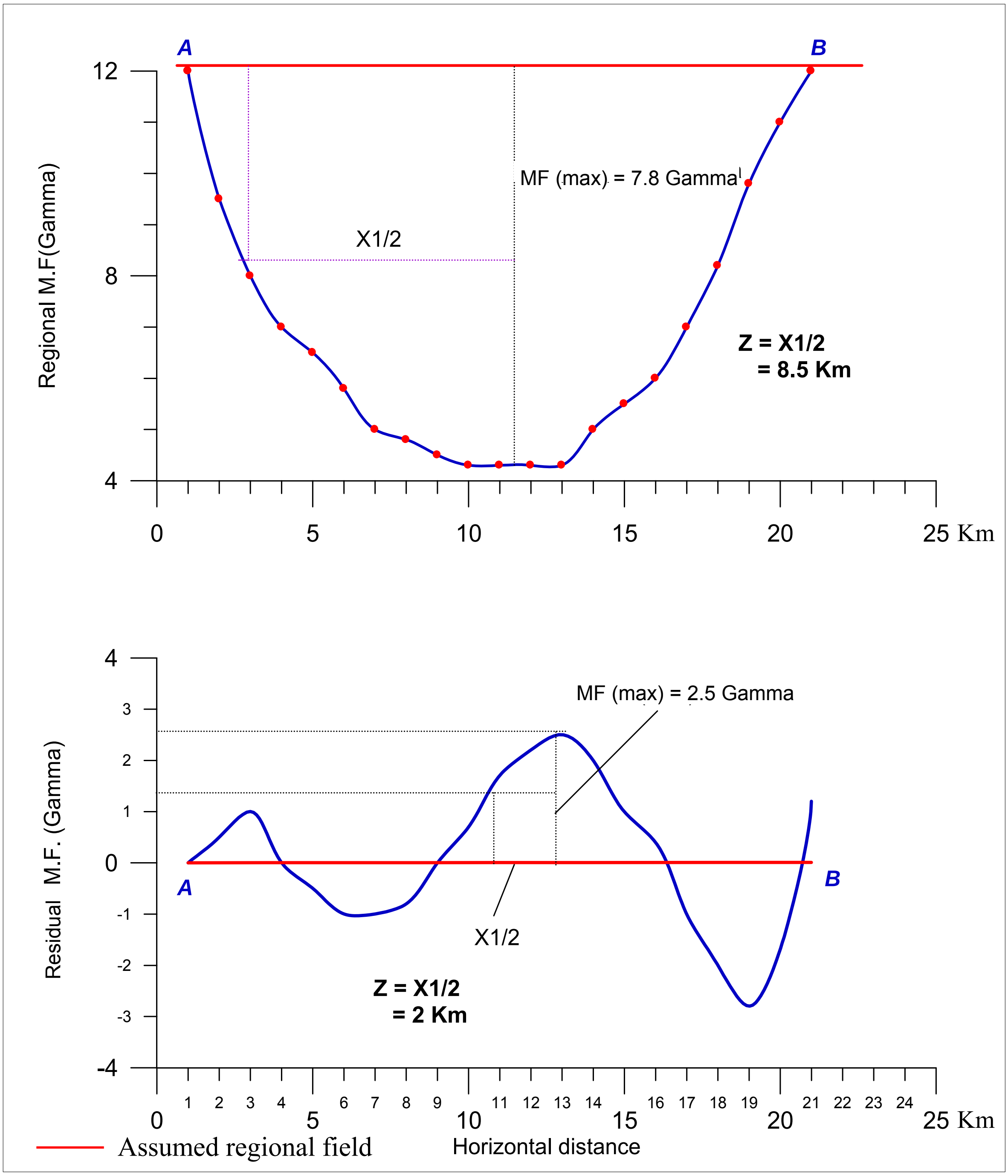

Fig.14: Quantitative interpretations of magnetic data along profile AB

From the interpretation of gravity data along profile AB, a model was assumed to represent a subsurface fault with 1.0 Km depth, which achieves an acceptable fit with the observed data. It was demonstrated from the interpretation of the data that there might be a subsided movement, which took place during the last Alpine folding and thrusting and affected the main body that is supposed to be within the basement, as well as the overlying sedimentary sequence. The effect of this subsided part was supposed to extend through the overlying sedimentary sequence and caused faulting within depth of (1 – 2) Km and it may extend down through the sedimentary sequence along wadi Shalghah. This effect was also detected by the magnetic data, which shows local positive anomaly superimposed on negative regional anomaly that extends along the same trend.

Generally, the idea of subsiding would coincide with the tectonic position of the studied area being a part of the Foothill Zone (Cham Chamal – Butma Subzone), which is characterized by faulting and folding (especially a very conspicuous long and deep synclines) associated with emerged and hidden structure (Jassim and Buday in Jassim and Goff, 2006).

Despite the poor correlation between the gravity and magnetic data, they show good coincidence with I.P.C. data, in delineating the presence of deep subsurface structure in the center of the studied area. A departure in the outline of the interpreted subsurface structure is obtained from the gravity and magnetic data. In gravity interpretation, the principle anomaly was found to trend N – S, along the studied area, while in the magnetic interpretation this anomaly was found to trend NNW – SSE. A possible explanation, as we thought for this departure in the trend, is that the structure that was detected by the gravity measurements may exhibit clock-wise turning, during its development.

Considerable interpreted gravity anomaly was also outlined in the southeastern part of the studied area, having NW – SE trend and super imposed on the regional anomaly that have the same trend. It is also found from the magnetic data that there are shallow positive anomalies, which follow the clastic material that are present within the sedimentary sequence that overlain the original subsurface structure.

CONCLUSIONS

- The interpretation of gravity and magnetic data concluded that the studied area is a zone of subsided area within the basement, along wadi Shalgah and forming submerged structure.
- Gravity and magnetic data show good coincidence with I.P.C. data in delineating the presence of deep subsurface structure in the center of the studied area.
- Magnetic information revealed that the basement depth is about 8.5 Km.
- Shallow positive magnetic anomaly follows the present clastic materials within the sedimentary sequence.
- Interpretation of gravity data revealed main subsurface structure that extends along wadi Shalgah.
- Considerable gravity anomaly was outlined in the southeastern part of the studied area, having NW – SE trend and superimposed on the regional anomaly that have the same trend.

ACKMOWLEDGMNET

The authors would like to express their thanks to the authorities of the ex-KPC for their permission in publishing of this article.

REFERENCES

Al-Kadhimi, J.A.M, Dawood, I. A., Al-Bana, A.S. and Amin, G.F., 1985. Gravity basic station net work of Iraq, GEOSURV, int. rep. no. 1551.

Al-Kadhimi, J. A M.., Sissakian, V.K., Fattah, A., A.S. and Deikran, D.B., 1996. Tectonic Map of Iraq, scale 1: 1000 000, 2nd edit., GEOSURV, Baghdad, Iraq.

Abdul Hassan, A.KH., Al-Musawi, H.A., Ajar, D., Zaini, M.T. and Khdhair, S.A., 2006. Detailed geological mapping of wadi Shalghah, east of Arbil, Iraq. GEOSURV, int. rep. no. 3038.

Amin, G.F., Yass, A.M., Musa, A.S. and Abdul Qader, S.O., 2006. Geophysical explorations of Bana Bawi mountain, Erbil, GEOSURV, int. rep. no. 2997.

Buday, T., 1980. The regional geology of Iraq, Vol.I. Stratigraphy and Paleography. Kassab, I. and Jassim, S.Z. (Eds.).GEOSURV, Baghdad, 445.

Blizkovsky, M., 1971. Geophysical measurements in the area of AL-UMM CHAIMIN topographic depression, GEOSURV, int. rep. no. 21G

Cooper, P.P., 1991.Two dimensional interactive magnetic and gravity modeling, ver. 1.3 Univ. of Witwater Sand, Johannesburg, South Africa.
Dunnington, H.V., 1959. Some problems of stratigraphy, structure and oil migration affecting search for oil in Iraq, I.P.C. Technical publication.
Grant, F.S., and West, G.F., 1965. Interpretation theory in applied geophysics. New York; McGraw Hill Co. 584pp.
Jassim, S.Z. and Goff, J., 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Brno, 341 pp.
Reynolds, J.M., 1995. An introduction to applied and environmental geophysics. John Wiley and Sons, 796pp.
Sharma, P.V., 1986. Geophysical Method in Geology, 2nd ed., Elsever Science Puplishing Co. Inc., 612pp.
Sissakian, V.K., 1979. Geological map of Erbil and Mahabad Quadrangeles, sheets NJ-38-14 and NJ-38-15, scale 1: 250 000. GEOSURV, Baghdad, Iraq.
Šutor, A. and Odstrčil, J., 1977. Gravity survey in the Western Desert of Iraq, Stojexport Praah-Geofysike, Brno, Czechoslovakia.