

GROUND MAGNETIC SURVEY OF PLIOCENE – PLEISTOCENE SEDIMENTS IN BAHR AL-NAJAF DEPRESSION, CENTRAL IRAQ

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ABSTRACT

The present study aims to verify the aeromagnetic shallow source anomaly that appears at Bahr Al-Najaf Depression and to determine its source. The studied area is completely covered by Quaternary sediments, which are almost composed of sandy sediments. A ground magnetic survey includes 557 magnetic measuring points, distributed mainly on five profiles ranging in their lengths from (0.7 – 16) Km, have been measured in the area. The comparison between aeromagnetic profile and geomagnetic profile has shown a coincidence between them in the regional field. On the other hand, local magnetic anomalies (LMA) have been well recognizable on geomagnetic profiles. The combination of the effect of these LMA seems as similar as that of the aeromagnetic anomaly. Accordingly, the residual aeromagnetic anomaly of Bahr Al-Najaf Depression, which appears related to deep source, can be interpreted as due to accumulations of sediments containing little amounts of magnetic minerals. The source of the LMA has been defined by collecting samples from three separated sites. Results of XRD identifications and heavy minerals laboratory showed the presence of magnetite particles among the sandy sediments.

المسح المغناطيسي الأرضي لترسبات البلايوسين – البليستوسين الرملية في منطقة بحر النجف، وسط العراق

حيدر عدنان البهادلي و مناف عبد الجبار يوسف

المستخلص

تهدف الدراسة الحالية إلى متابعة الشاذة المغناطيسية الظاهرة في خرائط المسح المغناطيسي الجوي في منخفض بحر النجف، والتحقق من وجودها على الأرض وطبيعتها ومعرفة مصدرها. لتحقيق ذلك، فقد تم إجراء مسح مغناطيسي أرضي تضمن قياس 557 محطة قياس مغناطيسي موزعة على خمسة مسارات رئيسية بأطوال تراوحت بين (0.7 - 16) كم وبمسافة فاصلة مقدارها 50 م وباتجاه شمال شرق – جنوب غرب. تبين من خلال القياسات المغناطيسية الأرضية إن الشاذة المتحرى عنها، والتي من الممكن أن تفسر على إنها اندفاع لجسم مغناطيسي ضحل ضمن الغطاء الرسوبي، تعود إلى تجمعات الترسبات الرملية رصاصية اللون ذات عمر العصر الرباعي. إذ تتحد الشواذ المغناطيسية الناتجة عن هذه التجمعات المنتشرة والمتباعدة أحياناً لتظهر كشاذة واحدة في المسح المغناطيسي الجوي. ولغرض التعرف على طبيعة هذه الرمال بشكل دقيق فقد أجريت قياسات مغناطيسية تفصيلية، في عدة مواقع متفرقة، على شكل مسارات قصيرة نسبياً، تمر عبر هذه الترسبات تتراوح أطوالها من (70 - 600) م وبفاصلة قصيرة تصل إلى 5 م بين نقطة قياس وأخرى. تراوحت الشدة المغناطيسية لهذه الترسبات بين عدة نانوتسلا إلى ما يقارب 50 نانوتسلا. تم جمع أربع عينات، ثلاث منها لترسبات نهريّة والأخرى لصخور رملية، بغية التعرف على المصدر المسبب لهذه الشواذ. أظهرت نتائج كل من التشخيص المعدني بواسطة حيود الأشعة السينية وكذلك نتائج مختبر المعادن الثقيلة وجود كميات لا تتجاوز نسبتها 1% وزناً من معدني المغنيتايت والهيماتايت ضمن تلك الترسبات.

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INTRODUCTION

Aeromagnetic maps interpreted by the CGG (1974) mainly delineate the basement compositional and structural configuration. Intrasedimentary deep and shallow igneous intrusions, if present, are easy to be predicted. GEOSURV has adopted a non-systematic program for following-up shallow source anomalies scattered, especially, in the Western and Southern Deserts of Iraq, in order to verify and delineate them accurately on land (e.g. Sallomy *et al.*, 1982; Al-Bdaiwi *et al.*, 2005 and Al-Bahadily and Mussa, 2008). Apparently, the aeromagnetic map of south Al-Najaf city shows a shallow source magnetic anomaly, which could be interpreted as intrasedimentary igneous intrusion with relatively shallow depth. The length of this anomaly is more than 6 Km with positive magnetic amplitude of about 3 nT (Fig.1). The anomalous area is a part of Bahr Al-Najaf Depression and it was a target of a land magnetic survey by Al-Bahadily and Yousif (2010).

The sedimentary column in Iraq is practically not-magnetic; i.e. the sedimentary formations of this column did not contain appreciable magnetic minerals to create discernible anomalies, even if these formations were displaced vertically with considerable throw (Al-Bdaiwi, 2011). Generally, the magnetization of sedimentary rocks is small, it depends on their content of magnetic minerals, especially magnetite. Experimentally, a percentage of less than 5% of magnetite could give an anomaly value reaching several hundreds of nT.

AIM AND LOCATION

The aim of this study is to verify then delineate precisely the position of the magnetic anomaly that appears on the aeromagnetic map, by land magnetic survey. In addition, it aims to explain the source and the accurate characteristics (length, width, and amplitude) of this anomaly. Bahr Al-Najaf Depression is a closed topographic depression lies to the west and southwest of Al-Najaf city. It covers an area of about 360 Km². The location of the studied area is shown in Fig. (2).

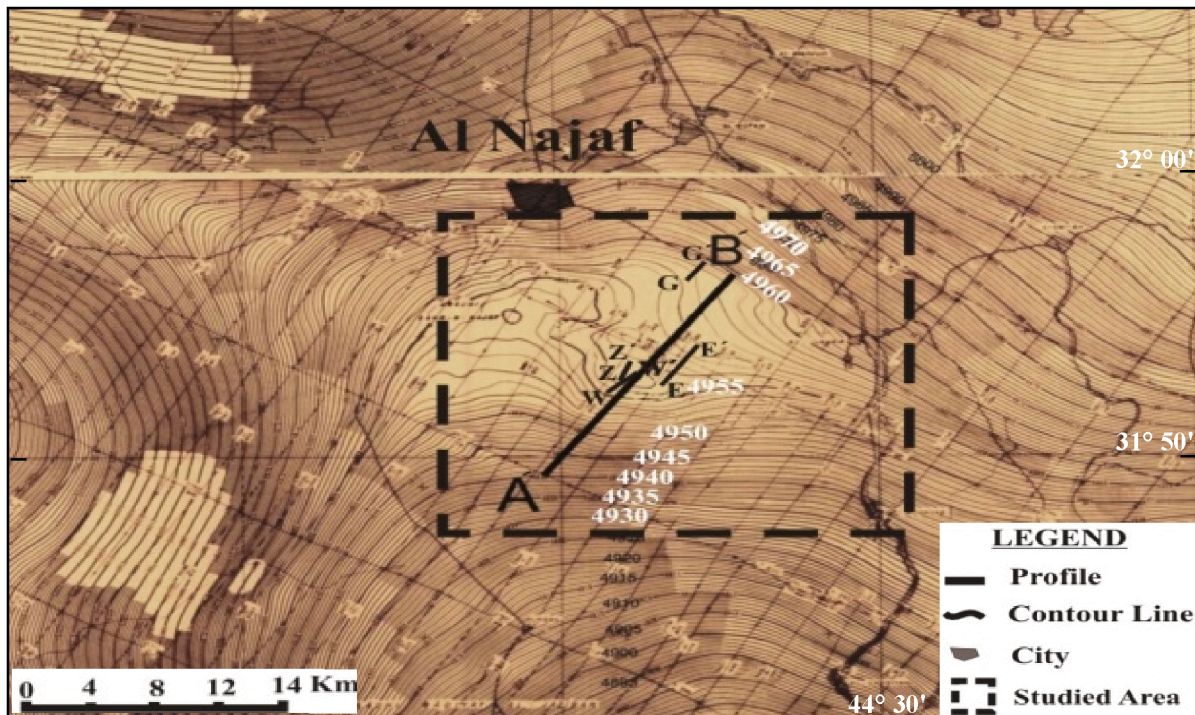


Fig.1: Aeromagnetic map of the studied area and surrounding
(after CGG, 1974)

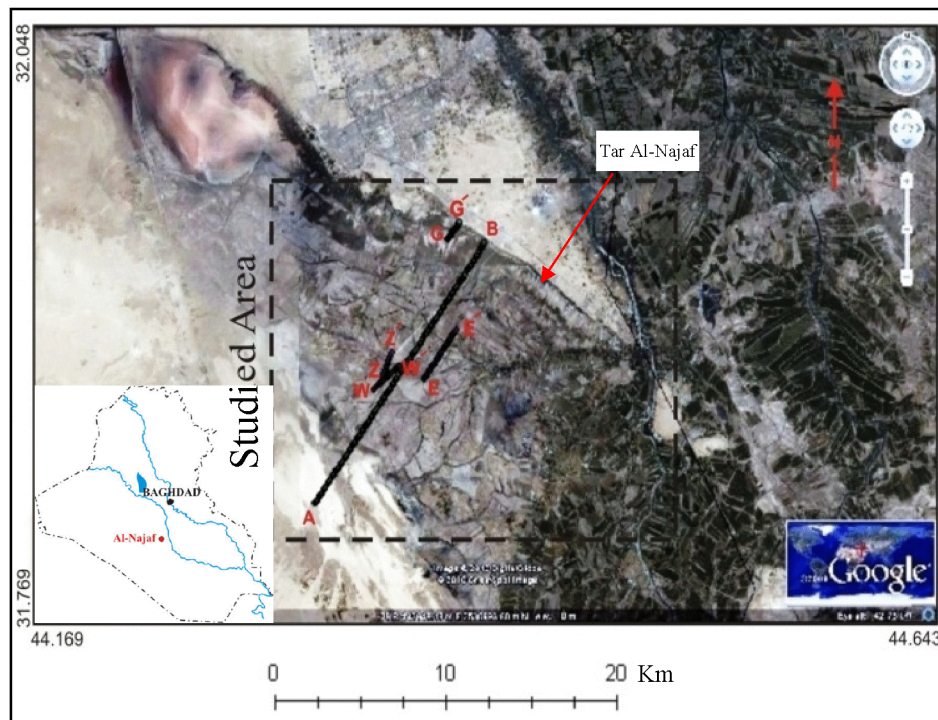


Fig.2: Location map of the studied area and surrounding
(after Google Earth, 2009)

GEOLOGICAL SETTING

The depression of Bahr Al-Najaf is completely covered by Quaternary sediments ranging in thickness between (10 – 20) m (Yacoub *et al.*, 1981 and Domas, 1983, in Benni, 2001). These sediments include flood plain sediments, at the eastern part, composed mostly of silty clays, sabkha, gypcrete, sand dunes and sand sheets. Tertiary formations represented by Dammam, Euphrates and are exposed outside the depression; whereas the exposures of Dibdibba and Injana formations are limited within Tar Al-Najaf in the north and northeastern part of the studied area (Barwary and Slewa, 1994) (Fig.3). The studied area, including Bahr Al-Najaf Depression, rises gradually southwards so it is drained by sub-parallel drainage pattern, mostly young and shallow, from the southwest towards northeast (Barwary and Slewa, 1994). Benni (2001) mentioned that Bahr Al-Najaf Depression includes marine sediments, according to marine organisms, and these sediments might be derived by drainage channels adjacent to the sea during early Holocene. Bahr Al-Najaf Depression has a tectonic importance; Fouad (2004) showed that Bahr Al-Najaf is a sag pond directly related to lateral movement of Abu Jir Fault Zone. In addition, Jassim and Goff (2006) referred that Bahr Al-Najaf Depression may be tectonically controlled by the NW – SE trending Euphrates Boundary Fault. The area lies near the boundary of two tectonic units, i.e. Mesopotamian Zone and Salman Zone; it belongs to the western part of Euphrates Subzone, which represents the westernmost part of the Mesopotamian Zone of the Stable Shelf (Jassim and Goff, 2006). Therefore, many authors believe that Bahr Al-Najaf Depression has a tectonic origin (Fouad, 2004; Jassim and Goff, 2006 and Ma'ala, 2009).

It is worth pointing out, herein, that the abovementioned formations are expected to be composed of non magnetic minerals so no magnetic anomalies could be expected from such materials. Moreover, such thicknesses of Quaternary sediments may be a good indication that Bahr Al-Najaf Depression is relatively recently formed.

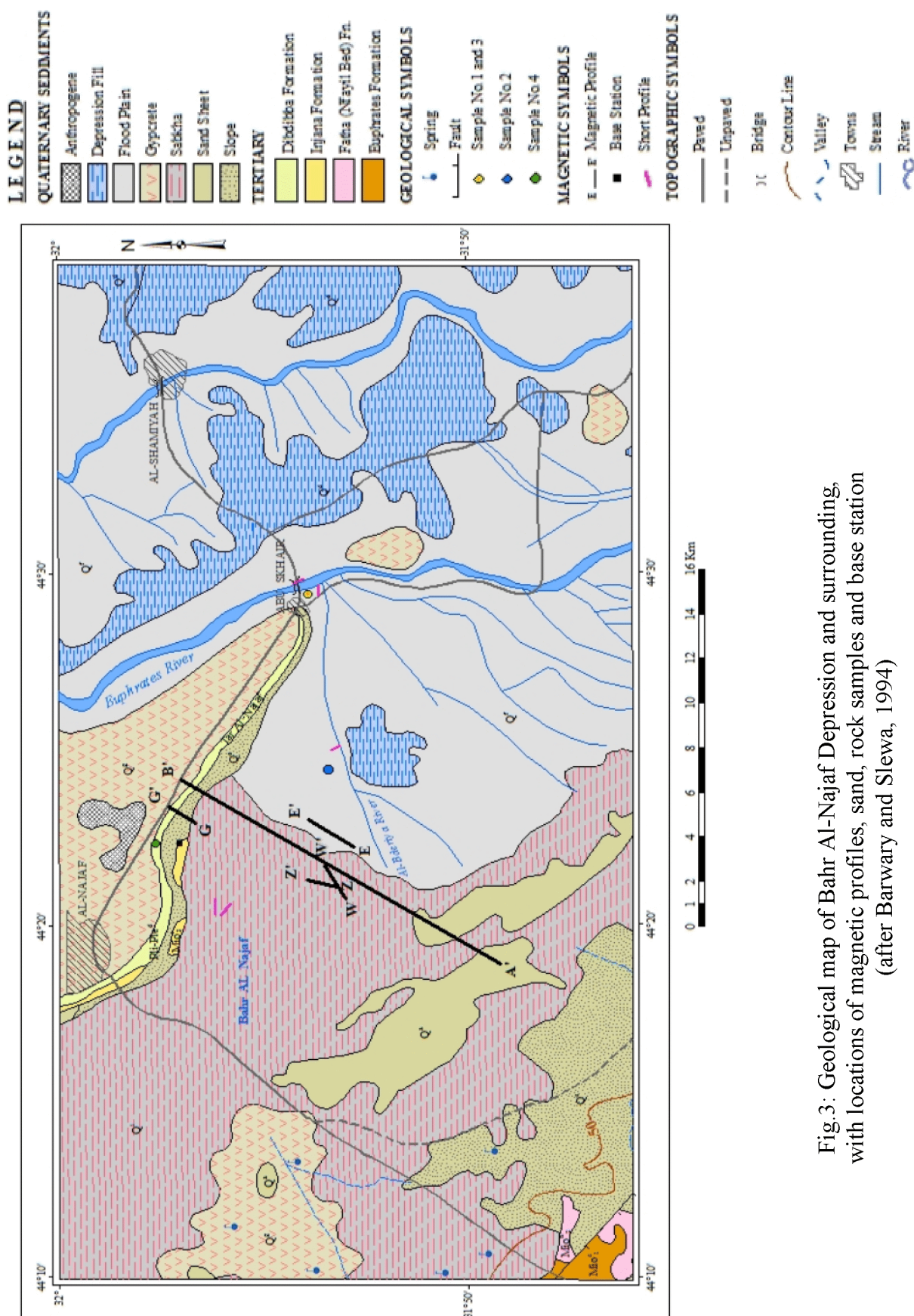


Fig.3: Geological map of Bahr Al-Najaf Depression and surrounding, with locations of magnetic profiles, sand, rock samples and base station (after Barwary and Slewa, 1994)

PREVIOUS GEOPHYSICAL WORKS

No particular geophysical studies have been carried out in the studied area, except gravity survey of regional nature. Bouguer gravity map shows that the area of Bahr Al-Najaf Depression is a part of regional gravity low extending N – S and bounded, from the northern and southern sides, by two gravity highs (Al-Kadhimi *et al.*, 1984). However, no evidence in this map refers to the presence of intrasedimentary magnetic body. Such bodies must have positive residual gravity anomaly due to relatively high density contrast.

On the other hand, land magnetic follow-up surveys could be reviewed, as follows:

- The magnetic survey carried out at Nehadain area, Western Desert. The geophysical staff measured shallow source magnetic anomalies that coincide with those, which appear in the aeromagnetic map. These anomalies have relatively low amplitude, as related to low magnetic bodies (Sallomy *et al.*, 1982).
- Magnetic follow-up measurements performed by Al-Bdaiwi *et al.* (2005) in Shuaib Al-Walage, Western Desert. They verified two magnetic anomalies with very low amplitude values, which were interpreted as a strip of pyroxene rocks intrusion. It is worth mentioning that their measured anomalies had the same value recorded in the aeromagnetic map.
- The reconnaissance magnetic surveys in Ga'ara Depression and nearby areas, Western Desert, in order to follow-up the shallow source magnetic anomalies that appear in six already chosen sites among the aeromagnetic maps (Al-Bahadily and Mussa, 2008). Out of these anomalies, only one anomaly was determined, which was at Wadi Al-Daya' site, where good correlation between the two anomalies (aeromagnetic anomaly with that measured on land) had been reported.

From the above mentioned geophysical works, the authors conclude the following:

- Not all the shallow source magnetic anomalies that appear in the aeromagnetic maps could be verified and determined on the land and that may be attributed to their very low amplitude values or to the poor matching between aeromagnetic and topographic maps as mentioned by Al-Bahadily and Mussa (2008), or to the combination between local magnetic anomalies to have a similar appearance of one magnetic anomaly, when measured by airborne measuring techniques, as will be shown in the present work. The authors believe that there is another reason for this discrepancy and it is connected with low accuracy of the land survey, which usually uses the proton magnetometer of a sensitivity ± 1 nT, in comparison with airborne survey (the CGG, 1974) that used a Cesium Vapor Instrument, which is specified to measure the variations in the earth's magnetic field with sensitivity of up to ± 0.01 nT.
- All the residual aeromagnetic anomalies that could be verified by ground magnetic measurements have the same amplitude values as that appear on the aeromagnetic map.

FIELD WORK, DATA ACQUISITION AND PROCESSING

Two proton magnetometers of Geometrics G-816 type with sensitivity of ± 1 nT were used in this survey. The first one was used for magnetic data collection (portable magnetometer), whereas the second was used as a base station (fixed magnetometer). The height of the sensor was 4 m in order to avoid the affect of the near surface objects (to eliminate or diminish noise).

According to the characteristic of the magnetic anomaly that appear in the aeromagnetic map of CGG, five profiles (A'B', EE', WW', ZZ' and GG') mostly, in NE – SW direction, have been performed on land. The lengths of these profiles are A'B' = 15.8 Km, EE' = 3 Km, WW' = 1.75 Km, ZZ' = 1.5 Km and GG' = 0.7 Km and the spacing interval is 50 m, which is

in accordance with the aim of the current magnetic survey. The survey includes measuring of 557 magnetic stations distributed on the abovementioned profiles. The locations of these profiles are explained in Figs. (1, 2 and 3).

The accuracy of magnetic survey measurements was ± 1.5 nT. Diurnal and normal corrections have been applied on the raw data. The value used for removing the magnetic gradient was $- 3.75$ nT/Km in the direction of profile 'AB' (from the south west towards northeast). Magnetic sections with local field are constructed after applying the corrections (Figs.4 and 5).

QUALITATIVE INTERPRETATION

By the comparison between the magnetic profiles AB and A'B' that represent airborne measurements and land measurements, respectively (Fig.4), it is clearly shown that there is a coincidence between them, as far as the regional field is concerned. On the other hand, there are many peaks with different values on profile A'B' (geomagnetic profile) only. In fact, they represent local magnetic anomalies (LMA) scattered along the profile, which are characterized by short wavelength with amplitudes ranging in their values between (+ 10 and $- 8$) nT. The LMA have normal polarization expressed in this figure by the negative part of the anomaly towards the north. Similarly, such anomalies can be noticed along some parts of profiles EE', ZZ', WW' and GG' (Fig.5).

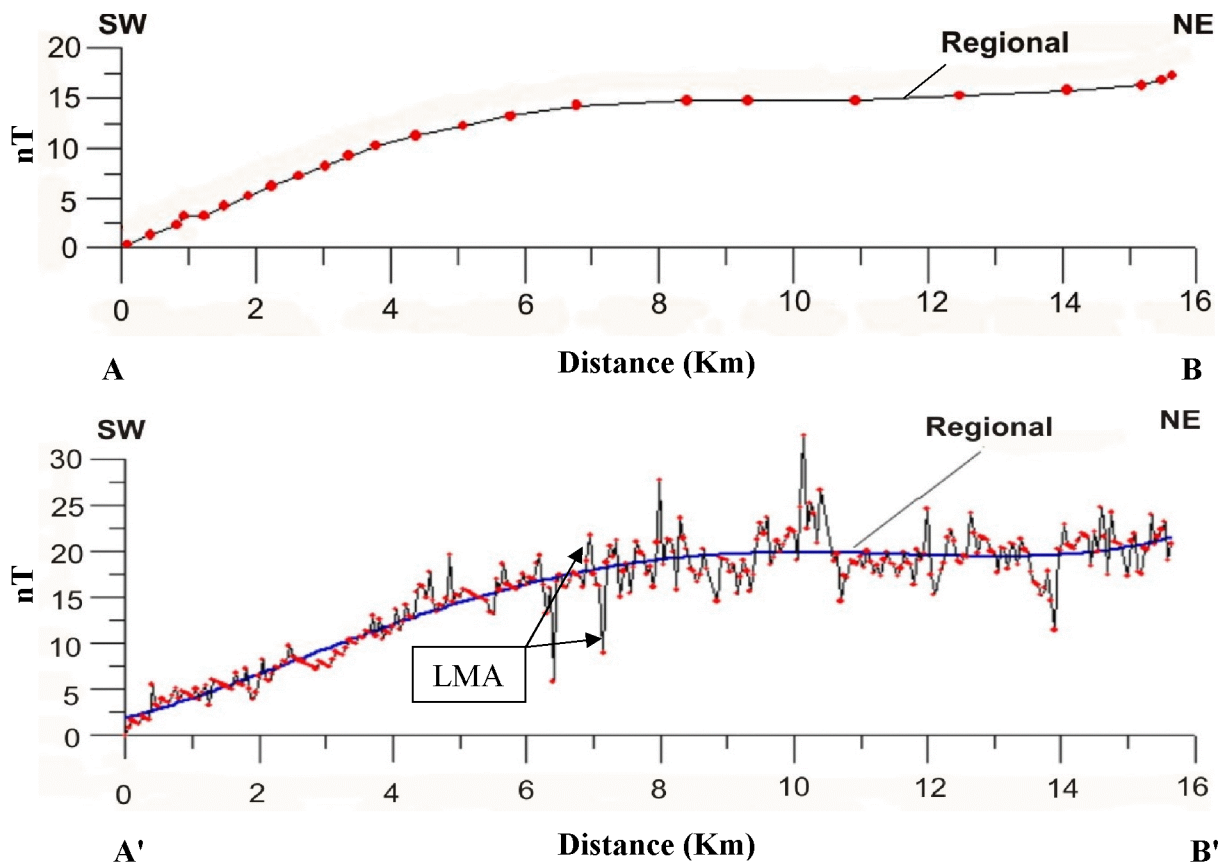


Fig.4: The aeromagnetic profile (the uppermost) and geomagnetic profile (the lowermost).

The comparison between the two profiles shows a complete matching between them, moreover, the lower profile shows local magnetic anomalies (LMA), the envelope ranges from (+ 10) to ($- 8$) nT

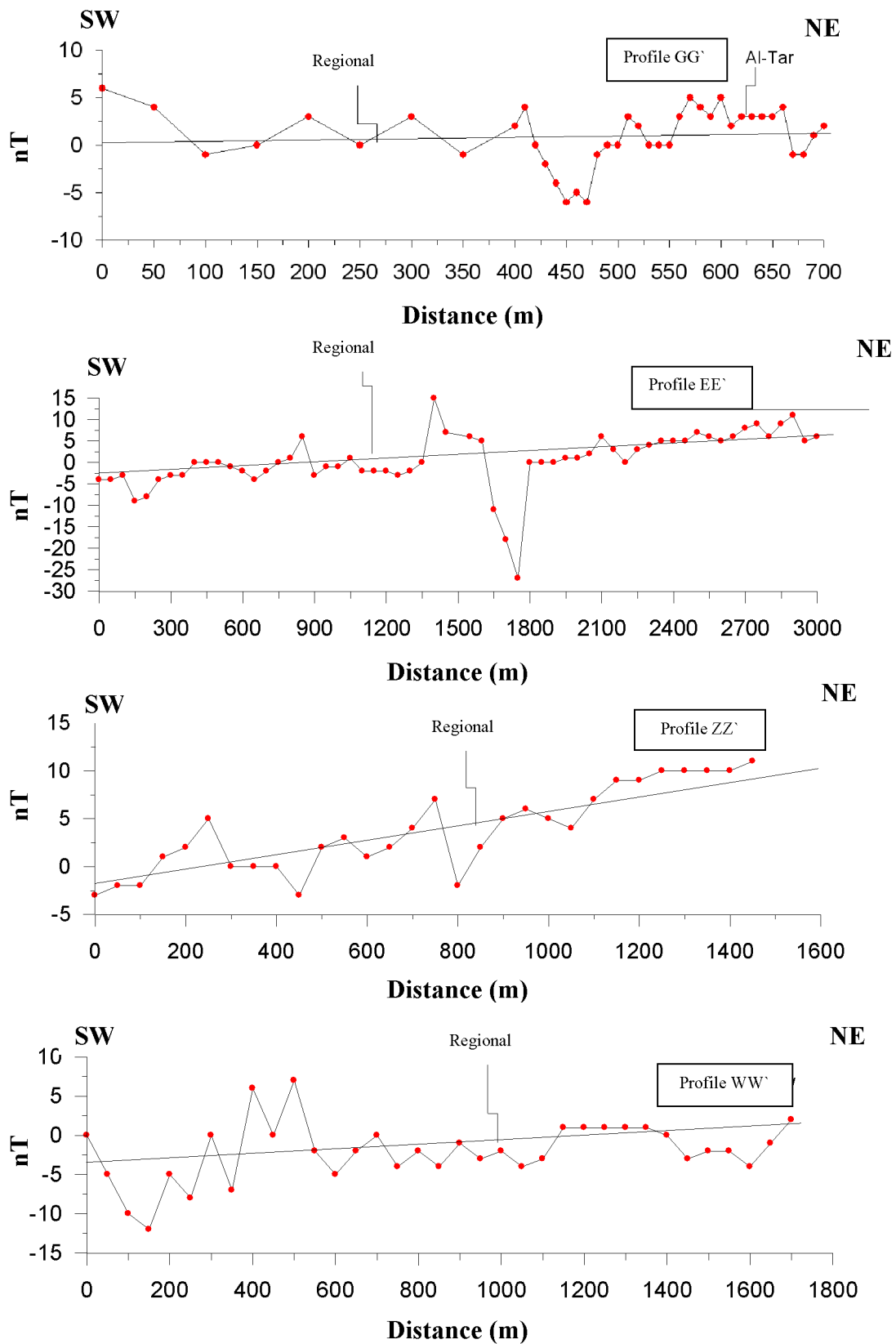


Fig.5: Magnetic profiles (GG', EE', ZZ' and WW') performed in Bahr Al-Najaf Depression. The spacing interval is 50 m. Many LMA with different values and shapes could be noticed on these profiles. The locations of these profiles on map are explained in Figs. (2 and 3)

The two profiles A'B' and GG' pass across Tar Al-Najaf, the eastern edge of Bahr Al-Najaf Depression, and immediately end beside it. Pliocene – Pleistocene rocks are exposed in this part of the Tar Al-Najaf represented by Dibdibba Formation, which is composed mainly of white color sandstone. No significant shallow source magnetic anomaly, which could be related to the differences in lithologies between the Quaternary sediments; inside the depression and exposed Tertiary formations outside the depression, has been recorded in this part of the area (i.e. the edge of the depression).

It is worth to mention that during the field work survey it was noticed that some of the LMA were directly situated over areas, which composed of gray sand sediments and the readings of the magnetometer were higher, while passing over these areas. Therefore, it was decided to follow-up and concern such sediments by executing short magnetic profiles with relatively close spacing intervals on them.

SHORT PROFILES

In order to study, in detail, the LMA, which have a source-relation with gray-sand sediments, several short magnetic profiles ranging in their lengths between (70 – 600) m with close spacing intervals reached to 5 m, were executed along these LMA and the surroundings. The locations of these profiles are shown in Fig. (3). Three profiles S5, S6 and S7 are shown in Fig. (6), they have different lengths and directions, but the same spacing intervals.

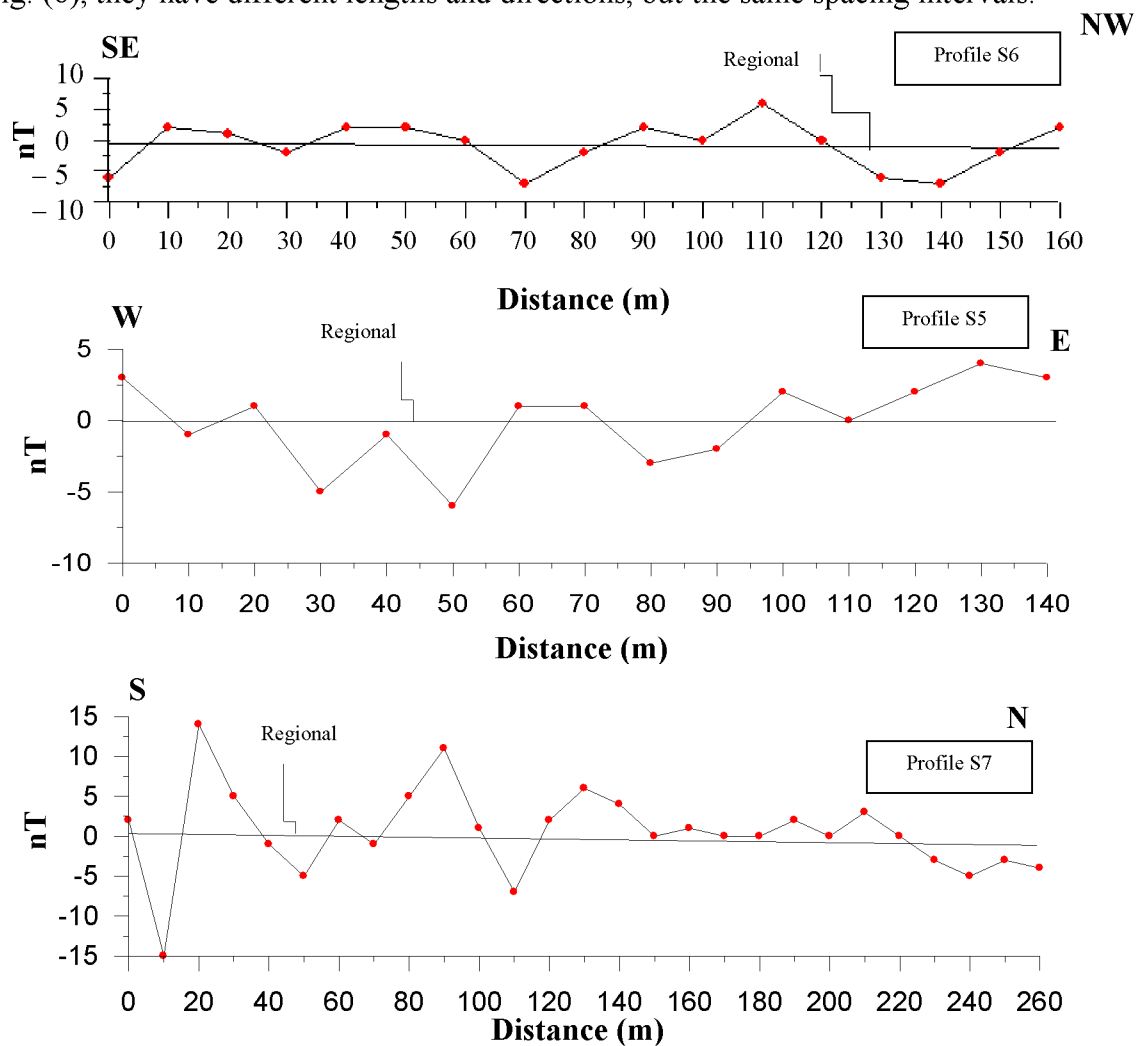


Fig.6: Short profiles S4, S5 and S7 were performed over sand sediments

The results showed the presence of anomalies, with different magnetic characters (shape, amplitude and wavelength) and these are related to gray sand sediments (locally widespread). Additional magnetic measurements have been carried out beside Euphrates River, the extreme eastern part of the studied area, and nearby. They aimed to know whether there are any changes in the LMA values towards the river. The results are explained in Fig. (7).

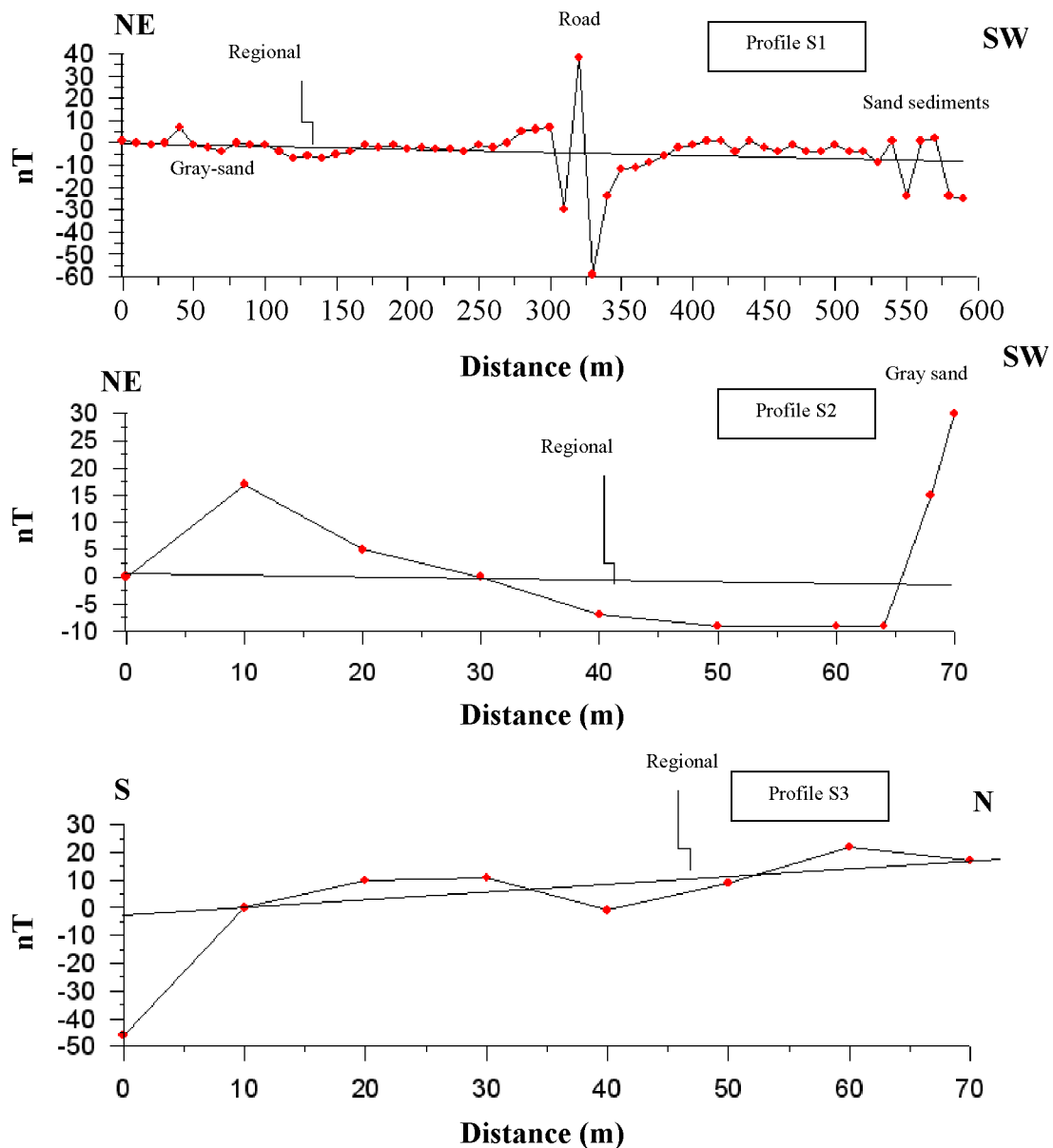


Fig.7: Magnetic profiles measured on the bank of Euphrates River (profile S3) and nearby agricultural area (profiles S1 and S2)

The middle part of profile S1 shown in Fig. (7) represents noise attributed to a paved road, which underlying by irrigation pipes that commonly extend across the paved roads. The anomalous part is confined in the beginning (5 nT) and the end (about 20 nT) of the profile, is related to gray-sandy sediments, which appeared by excavation of the irrigation canal. Profile S2 represents magnetic measurements carried out over accumulations of gray-sand sediments in an agricultural area, where sample No.1 was taken (Fig.8). Profile S3 was carried out at the

western bank of Euphrates River immediately at the intersection area between the Euphrates and Bdairiya Rivers, in the eastern part of the studied area (Fig.3). A relatively small (about 5 nT), but broad anomaly was recorded in this area. Obviously, there is a considerable difference in amplitude and shape of the observed anomaly of S3 (covered sand) and that observed in profile S1 (uncovered sand).

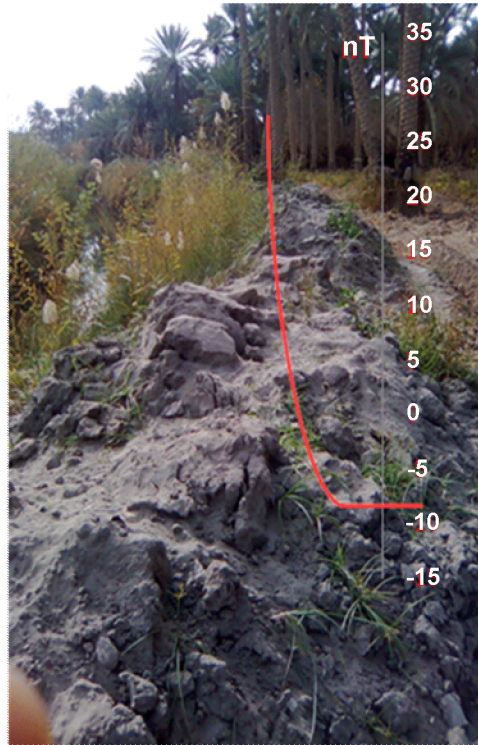


Fig.8: Gray-sand accumulations appeared due to excavation of the irrigation canal. A reasonable magnetic anomaly has been observed during passing across these sediments

SOURCE DETERMINATION OF THE LMA

For the purpose of determining the source of the LMA, four samples of sediments and rock collected from three separated sites. Samples No.1 and 3 were collected from the same site, whereas sample No.4 belongs to Dibdibba Formation, that exposed at Tar Al-Najaf. The locations of the samples are shown in Fig. (3). Ages and brief descriptions for each sample are explained in Table (1).

Table 1: Ages and descriptions of the samples

Sample No.	Age	Description
1	Quaternary	Gray loose sand
2	Quaternary	Gray loose sand
3	Quaternary	soil
4	Pliocene – Pleistocene	White poorly sorted sandstone

These samples were sent to the X-Ray Diffraction (XRD) and heavy minerals laboratories for mineral identification and heavy mineral analyses, respectively. The process and its results are explained as follows.

▪ Mineral Identification by XRD

The primary results of XRD showed no magnetic minerals identified in the four samples. This is attributed to the very low percentage of magnetic minerals (less than 1% as will be shown in heavy mineral separation section), therefore, the XRD device is unable to detect them. Therefore, an attempt to increase these percentages has been carried out by separating the magnetic minerals with the aid of magnetic separator device. The process could be applied on loose sands only (i.e. samples No.1 and 2). XRD results after separation are represented in Table (2).

Table 2: XRD identifications of the samples No.1 and No.2 after magnetic separation

Sample No.	XRD	Description
1	Feldspar, Quartz, Magnetite, Hematite, Calcite	Gray loose sand
2	Quartz, Feldspar, Magnetite, Hematite	Gray loose sand

The magnetic minerals that appear in Table (2) are Magnetite (Fe_3O_4) and Hematite (Fe_2O_3). Their percentages, though are below 1%, cause anomalies in the local field. Such percentage is usually enough to disturb the earth's magnetic field, especially, it is so close to the ground surface, and accordingly, causes a good magnetic anomaly.

▪ Heavy Mineral Separation

In order to specify the amount of heavy minerals, which include magnetic minerals, for each sample, a heavy minerals separation process has been used. The results of this process are shown in Table (3).

Table 3: Results of heavy minerals identification

Sample No.	Weight %			Count %												Description	
	H.F*	L.F**	Magnetic Opaque	Opaque	Alterite	Zeosite – Epidote	Horneblend	Ortho – pyroxene	Clinopyroxene	Zircon	Garnet	Tourmaline	Chlorite	Tremolite – Actinolite	Cellestite		Others
1	8.03	91.24	0.73	20.80	6.4	4	15.2	4.8	6.4	4.8	3.2	2.4	8.8	6.4	15.2	Staurolite (0.8) brown Hornblende (0.8)	Gray loose sand
2	0.76	99.14	0.1	58.28	1.74	1.74	7.39	3.91	3.48	3.04	2.61	1.3	1.74	6.52	6.52	Rutile (0.43) Staurolite (0.43) brown Hornblende (0.87)	Gray loose sand
3	3.26	96.4	0.33	45.43	2.9	0.97	7.73	6.28	8.69	1.93	3.86	0.97	3.38	12.56	3.38	Rutile (0.48) Staurolite (0.48) Kyanite (0.48) brown Hornblende (0.48)	Soil
4	0.56	99.44	0.003	7.17	1.30	0.33	0.33	–	0.33	–	–	3.58	–	–	86.97	–	White poorly sorted sandstone

* H.F= heavy fractions

** L.F= light fractions

Table (3) shows that sample No.1 (gray sand) and sample No.3 (soil), which have been collected from the same site (the distance between them is about 20 m), have the largest amount of heavy minerals (8.03%) and (3.26%) and magnetic minerals (0.73%) and (0.33%), respectively. Therefore, this amount of magnetic minerals could interpret the magnetic anomalies that already appeared in the site (Fig.7, profile S2, and Fig.8). Sample No.2 (gray sand) has adequate amount of magnetic minerals (0.10%) to give a measurable magnetic anomaly. Sample No.4 (sandstone of Dibdibba Formation), which has been collected from Tar Al-Najaf, has the lowest amount of heavy minerals (0.56%) and magnetic minerals (0.003%). Similar results of heavy minerals identifications, in Tar Al-Najaf area, were concluded by Al-Mukhtar and Abid Al-Rahman (2008).

It is worth mentioning that the aforementioned percentages of heavy minerals could be attributed to the erosion process by water agent on the exposed formations, which as a result, concentrates the magnetic minerals from the clastic sediments of these formations. However, the presence of heavy minerals like Epidote, Garnet and Chlorite suggests that the source rocks of these sediments (samples No.1, 2 and 3) are metamorphic rocks. Metamorphic rock outcrops exist at the northern and northeastern part of Iraq and also exist in the Arabian Shield.

RESULTS AND DISCUSSION

This work shows that the residual magnetic anomalies obtained by ground magnetic survey did not match with those appearing in the aeromagnetic map of Bahr Al-Najaf Depression. However, a perfect coincidence has been observed in the regional field.

The resolution of individual anomalies from separate buried sources depends on the height of the flight line above the level of the sources (Dobrin, 1978). Therefore, the total magnetic effects of the dispersed sand sediments have appeared as combined anomaly, when measured by airborne magnetic survey. However, the resultant magnetic anomaly will have another characteristic (shape, width and amplitude) due to elevation, i.e. the individual magnetic anomalies (represented by the LMA) merge into one at a higher elevation.

The source of LMA anomalies that appear at Bahr Al-Najaf Depression has been determined by collecting samples from magnetically anomalous and non anomalous sites for comparison in mineral composition between the white sandstone of Dibdibba Formation (non magnetic) and gray sand of flood plain sediments (magnetic). XRD identifications, as well as heavy minerals analyses have shown that magnetite and hematite, with weight percentage less than 1%, are the causative source of the above mentioned LMA. However, the differences in amplitudes and shapes of the LMA along the studied profiles refer that the percentage of the magnetic minerals could slightly differ from one place to another. Keen inspection of the aforementioned profiles shows that the type of the magnetization is induced magnetization. The negative parts of the anomalies occur at the northern side of the anomalies.

CONCLUSIONS

The following conclusions could be revealed from the present work:

- Geomagnetic survey in Bahr Al-Najaf Depression provided the geophysicists by a new outlook to the shallow-sources of magnetic anomalies that appear at the aeromagnetic maps interpreted by CGG (1974). It is "The shallow source aeromagnetic anomaly, which appears at Bahr Al-Najaf Depression, could be separated into many locally extended anomalies when measured on land".

- The residual aeromagnetic anomaly of Bahr Al-Najaf Depression that was believed to be related to intrasedimentary magnetic body, represents scattered locally extended anomalies related to gray-sand sediments, which contain small amount of magnetic minerals, which can interpret the observed LMA.
- The magnetic source that causes the LMA has been accurately determined by collecting rock and loose (sediments) samples from four different sites. The results of XRD and heavy minerals for the samples have shown the presence of magnetite and hematite with a weight percentage of less than 1%.
- The amount of the magnetic minerals (magnetite and hematite) may be variable from place to another, throughout the studied area.
- Depending on the thicknesses and lateral extents of these lenses, as well as on the presence of magnetic minerals, the observed magnetic anomaly is changed. Therefore, anomalies with different amplitudes and shapes have been recognized along the studied profiles.
- Basically, heavy minerals, including magnetite particles, exist among gray-sand sediments, which had been transported and then concentrated by river action affecting on the exposed formations.
- The metamorphic rocks are the source rocks of magnetite and other heavy minerals. However, heavy minerals are derived mainly from Injana and Dibdibba formations as inferred from the presence of minerals like epidote, garnet and chlorite that appeared in heavy mineral analysis.

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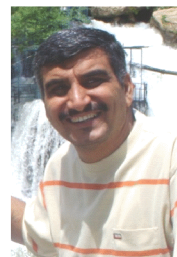
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