

MAGNETIC SURVEY FOR DETECTION OF BURIED ARCHAEOLOGICAL FEATURES IN AL-MADAI'N AREA, SOUTHEAST OF BAGHDAD, IRAQ

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ABSTRACT

A detailed magnetic survey has been carried out in Taq-Kisra Archaeological Site, situated in Al-Mada'in city; about 32 Km southeast of Baghdad. The aim of this survey is to delineate the locations and extensions of the buried archaeological structures. The area was covered by (2×2) m net of magnetic measurements, with 5262 stations measured with an accuracy of up to ± 1.8 nT. Residual magnetic intensity map of the site has been constructed after applying the necessary corrections on the raw data. Generally, the map shows linear magnetic anomalies that have archaeological meaning. The range of the achieved magnetic anomalies is $(15 - 24)$ nT. Location of ten trenches, depending on the magnetic map, have been suggested for checking the obtained magnetic anomalies. The results of the excavations showed good relations between the observed magnetic anomalies and the causative sources, represented by archaeological features. The archaeological features that appeared through excavations are: the main mure, walls, floor, base of column and other archaeological remains. These have depths ranging between $(0.25 - 2)$ m and they were built with clayey burned bricks, which have red and yellow colors. A map showing the suggested tracks and areas for future excavations in the site is prepared, too.

المسح المغناطيسي لاكتشاف التراكيب الأثرية المغمورة في منطقة المدائن، جنوب شرق بغداد، العراق

حيدر عدنان البهادلي و مناف عبد الجبار يوسف

المستخلص

بهدف التحري عن التراكيب الأثرية المغمورة في موقع طاق كسرى (المدائن) المؤرخ 400 سنة بعد الميلاد والواقع على بعد 32 كم إلى الجنوب الشرقي من العاصمة بغداد، فقد تم إجراء مسح جيوفيزيائي مغناطيسي تفصيلي في هذا الموقع. شمل المسح 5262 محطة قياس توزعت على شبكة كثيفة من القياسات بأبعاد (2×2) م. تم إعداد خريطة للشواذ المغناطيسية المتبقية وذلك بعد إجراء التصحيحات اللازمة للقراءات الأولية. بينت الخريطة وجود العديد من الشواذ المغناطيسية الخطية وغير الخطية ذات المعالم الواضحة، تراوح معدل سعات الشواذ المغناطيسية بين $(15 - 24)$ نانوتسلا، والتي من الممكن أن تعود إلى التراكيب الأثرية المغمورة، كما وتعتبر الشواذ المغناطيسية ذات السعتين 6 و 42 نانوتسلا هي اصغر واكبر السعات للشواذ المغناطيسية المسجلة في الموقع، على التوالي. تم حفر عشرة خنادق في مواقع مختلفة، تم اختيارها وتأشيرها مسبقا على الخريطة لاعتبارات فنية، وذلك لغرض تدقيق نتائج هذه القياسات. أعطت عملية الحفر نتائج جيدة، في جميع الخنادق المحفورة، إذ أثبتت وجود تطابق كبير بين الشواذ المغناطيسية المستحصلة والتراكيب الأثرية المسببة لها (مصادر تلك الشواذ). تمثلت التراكيب الأثرية المستخرجة

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بالحفر السور الرئيسي، الجدران الداخلية، أرضية من الطابوق الفخاري (لإحدى الغرف)، تراكيب دائرية الشكل قريبة من شكل قواعد أعمدة لأبنية قديمة، مضافاً إلى تراكيب أثرية غير واضحة المعالم التي ربما تحتاج للاستمرار والتوسع في عملية الحفر، أو أنها تمثل بقايا أبنية تعرضت إلى عمليات التجوية التي ساهمت في إخفاء بعض معالمها. تراوحت أعماق هذه التراكيب بين (0.25 - 2) م. كما أعدت خريطة تتضمن المسارات والأماكن المقترحة لعمليات الحفر المستقبلي في الموقع.

INTRODUCTION

Magnetic method is usually used in archaeological exploration to detect features, such as buried walls and structures, pottery, bricks, fire pits, buried pathways, tombs and other numerous objects. The features are detected and mapped as a result of they are more magnetic than surrounding material (Patella, 1991 in Urbini *et al.*, 2006).

According to the cooperation between Iraq Geological Survey (GEOSURV) and the State Board of Antiquities and Heritage, the latter suggested an area of about 2000 m², which lies in Al-Mada'in Archaeological Site, for magnetic survey (Al-Bahadily *et al.*, 2010). The site is located about 32 Km southeast of Baghdad and less than 1 Km to the east of the Tigris River (Fig.1). The studied area is delineated in the Google Earth image and it is covered completely by soil.

The Archaeologists believe that there are many subsurface archaeological structures covered by soil. Therefore, the present work aims in detecting the locations and extensions of the subsurface archaeological structures, which according to field observations are probably less than 3 m in depth. The aim was deduced using magnetic survey technique. Accordingly, this will aid and guide the excavation program for the archaeologists in the undiscovered part of the site.

The only visible remain left in this site is the great arch (Taq-Kisra), which represents the ruins of what was for seven centuries the capital of Parthian and Sassanid Empires of Persia; Tisfun, known to the Romans as Ctesiphon. It was built in 400 A.D. and it is the largest brick built arch in the world (Iraqi Historic Sites, 2008).

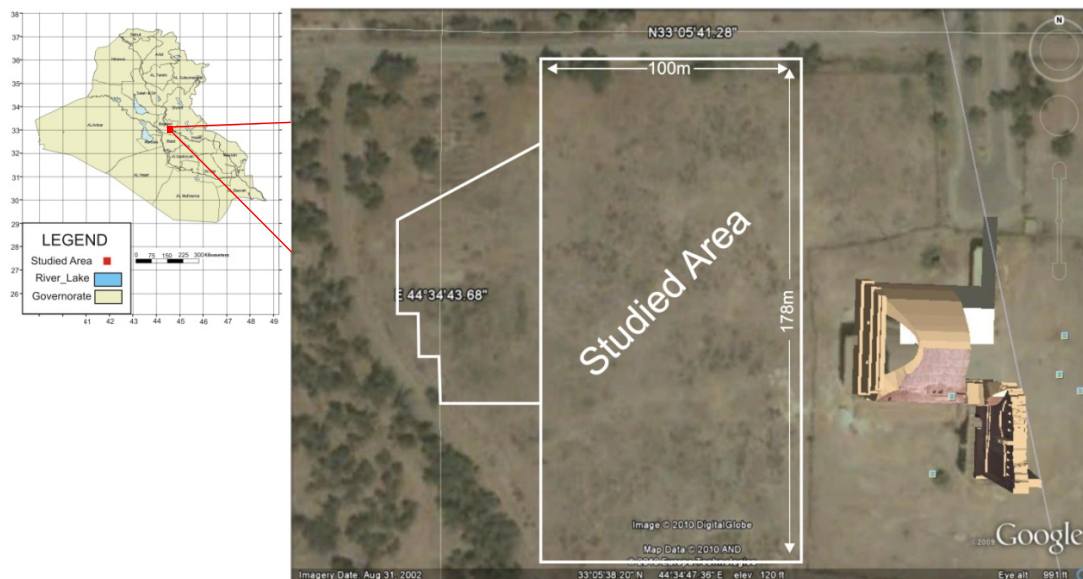


Fig.1: Location map of Taq-Kisra Archaeological Site, the arch appears on the right side of the image (after Google Earth, dated Aug 31, 2002)

PREVIOUS WORK

Two similar studies have been documented in GEOSURV's library, those are:

- Magnetic survey in 'Tel Kutha' Archaeological Site, situated in Babylon Province and related to the Sumerian Period, it dealt with archaeological structures (represented by walls), which were covered by (0.8 – 3.6) m of soil. The area has relatively high topographic variations, which in turns have obvious effects on magnetic measurements. It was covered by a grid of (2 x 2) m. The resultant magnetic anomalies have been interpreted qualitatively and quantitatively, where good coincidence between the anomalies and objects of interest had been clearly noticed. The highest and lowest recorded values of magnetic anomalies were + 40 and – 70 nT, respectively (Salumy *et al.*, 1978).
- Magnetic survey performed in partially discovered site; so called 'Tal Harmal' Archaeological Site, located to the southeast of Baghdad, dealing with subsurface archaeological remains. Although, the site had high background level of magnetic noise; the excavation that followed the field work showed the presence of well and wall at a depth of 1.2 m. The achieved anomaly value of the archaeological structures was about 20 nT. The building materials of the structures were clayey bricks (Al-Bahadily *et al.*, 2009).

Other studies may be reviewed hereinafter.

- Hamo (1977) used the magnetic method in two separated archaeological sites, Sippar and Abu-Skhair. Maps of the total magnetic field have been presented and the obtained magnetic anomalies were interpreted with the aid of susceptibility measurements that applied on samples of soils and bricks. She mentioned that some of the magnetic anomalies were interfered due to interference in magnetic sources related to successive periods.
- Ahmad (1979) carried out a magnetic survey in Ctesiphon archaeological site. The acquired data have been filtered by using Griffin and Forier methods for separation purposes and the resulting residual anomalies were interpreted quantitatively by modeling.

From the aforementioned geophysical works and also from authors' experience, two types of magnetic anomalies could be encountered through the field work: The first source (non-archaeological) gives anomalies characterized by short-wavelength, high-amplitude, and dipolar in its nature. This source is created by debris on or near to the ground surface. The second source (archaeological) gives anomalies characterized by relatively low amplitude, usually not exceed several tens of nT, and long-wavelength anomalies.

FIELD WORK AND DATA PROCESSING

Eighty two magnetic profiles of lengths ranging from (40 – 170) m separated with a distance of 2 m were defined in N – S direction and the spacing interval between measuring points was 2 m, i.e. a regular grid of (2 × 2) m of measuring points.

In this investigation, two types of proton magnetometers were used for measuring earth's total magnetic field. The first one was the magnetic measurement system (portable and base station) ENVI PRO, manufactured by Canadian Scintrex Limited Company, with magnetic sensitivity of ± 0.1 nT. The second proton magnetometer was Geometrics G-816, with magnetic sensitivity of ± 1 nT. The latter instrument was used due to a fault that affected the first instrument, which had already completed some 50% of the survey. The sensor was set to a fixed distance equal to 2.40 m from the ground surface. A point near the studied site was the base station, for ENVI PRO magnetometer, another base station was chosen (point no. 60 on line no. 30), used for proton magnetometer G-816. Readings obtained from the two magnetometers have been compared together and the differences between them, which

resulted from the sensitivity and location of base stations, have been subtracted so that the final total magnetic map of the whole site was achieved. These differences have been determined by overlapping the measurements of the two magnetometers.

In quiet magnetic field days, the rate of readings for each measuring point was 2 readings per point. However, more than 4 readings per point; in areas of strong noise were recorded. Sometimes, the magnetic survey has been completely stopped when the magnetic field was highly disturbed. However, the rate of base station; automatically recorded readings was taken every 30 seconds, so a semi-continuous and accurate diurnal magnetic field was recorded.

Five thousand and two hundred sixty two points of measurements were carried out along 148 profiles. Among them, 790 measuring points were carried out as repeated points (15% of the total measuring points), and 525 measurements as control points (10% of the total measuring points). The repeated and control points were used later for accuracy calculation purpose; the accuracy of the current magnetic survey measurements was ± 1.8 nT, it was calculated according to control points, which are useful for tying between profiles as well.

Finally, the resulted data, and after applying the diurnal correction were performed in grid form by Kriging method; using the program Surfer 8. Accordingly, total magnetic intensity map for the site of interest has been constructed to achieve residual magnetic anomalies map (Fig.2). Many non-archaeological anomalies, characterized by short-wavelength, high-amplitude and dipolar in the total field magnetic intensity map have been recognized, especially in the southwestern part of the site. These have been processed by removing them as dummy values. The main sources of the non-magnetic anomalies were debris, which have ferromagnetic properties, and the outer steel fence that surrounds the site. However, these noisy sources were easily recognized and isolated.

QUALITATIVE INTERPRETATION

Obviously, Taq-Kisra Archaeological Site is rich with archaeological structures that could be noticed from the first sight of the magnetic map. They are represented by the nature of magnetic anomalies that appear in the map (Fig.2).

The minimum and maximum recorded values, of magnetic field that have an archaeological meaning for the entire site, are 45931 nT and 45982 nT, respectively. The average value of magnetic amplitudes of the anomalies associated with buried archaeological remains is about (15 – 24) nT, whereas the lowest and highest magnetic amplitudes encountered in the site are 6 and 42 nT, respectively.

Evidently, the most important features (anomalies) are those, which have linear trends and regular dimensions and extensions (geometrical shapes), for example the magnetic anomalies that appears in the area A, which is the most remarkable feature in the magnetic map (Fig.2). Mostly, these anomalies could reflect linear subsurface structures; like walls in N – S and E – W directions. Moreover, the linear anomalies range in their lengths between (20 – 50) m.

It is worth mentioning that N – S and E – W directions were the preferable directions in most of archaeological buildings in that time, which are in accordance with sunshine and sunset directions (Baqir, 1951). In addition, area A (Fig.2), which appears as a rectangular shape, has 22 m width and lies directly opposite to the main gate of the arch, in the west direction and about 40 m away from the gate. The relatively high negative anomalies that appear in area A may be attributed to the influence of chemical processes on magnetic minerals, from which the building materials (bricks) were made, where these processes could change the magnetic behavior of magnetic minerals.

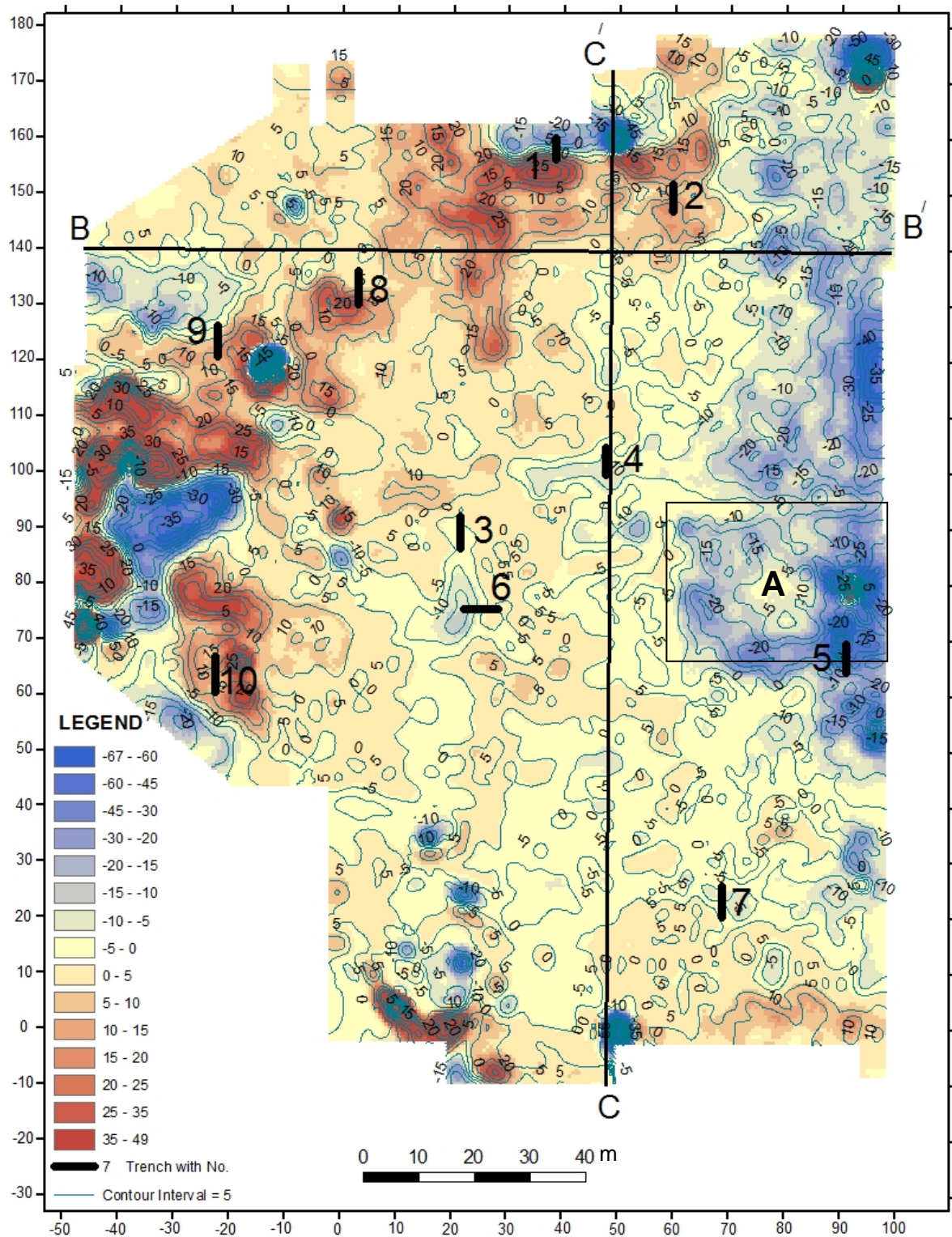


Fig.2: Residual magnetic anomalies map of Taq-Kisra Archaeological Site.
X and y axes represent line and point numbers, respectively

For the purpose of enhancement of the magnetic anomalies, a viewshed map, which is derived from the total magnetic intensity map with contour interval of 3 nT, has been constructed (Fig.3). The map is very useful when looking at these linear anomalies. It is achieved by using line density technique involved in ArcGIS Program. It expresses excellently the subsurface structures delineated by the area of the dense contour lines. Some of these linear anomalies appear weak; in some parts. The weakness and strength could be related to the differential effects of weathering on the causative sources of these anomalies (subsurface structures). In addition, the differences in the shapes and the amplitudes of the anomalies throughout the area reflect the differences in depth and size of the causative sources of these anomalies. This is assured by the trench excavations that followed the field work.

The effect of the outer steel fence can be easily seen on the eastern side of the total magnetic intensity map, where it added a negative effect (blue color) on lines 96 and 98 that started from point number 46 to point number 140 (Fig.2).

RESULTS AND DISCUSSION

In order to check the appeared anomalies (Fig.2) and to get a better idea about the causative sources, their depths and lateral extensions, ten trenches with 6 m length, 2 m width and variable depths, and three pits with depth that didn't exceed 1 m, have been excavated after finishing the field work. The locations of the trenches are shown in Fig. (2). These locations have been chosen according to changes in shapes and amplitudes of the anomalies acquired throughout the investigated site.

The results of the aforementioned ten trenches are successful. Many archaeological structures (approved by archaeologist) with different sizes, shapes and depths have been verified. However, the three pits were dug to assure the extensions and the presence of some archaeological structures. The depths of the discovered archaeological features ranged from (0.25 – 2) m, and included features like: main mure (trenches number 1 and 2, Fig.4), floor with almost threshold and intersections of surrounding walls (trench no.3, Fig.5), an archaeological feature; was not well recognized, which could be a weathered part of a wall (derived from the shape of inherent magnetic anomaly) (trench no.4, Fig.6), a cracked wall due to compaction of the overburden soil (trench no.5, Fig.7), a circular shape; like a base of column (trench No.6, Fig.8), a wall (trench No.9, Fig.9), and unknown features (trenches no.7 and 8).

Two magnetic sections have been plotted in NS and EW directions (C C' and B B', in Fig.11). Clearly, some of the anomalies appeared in C C' section show normal polarization (the relatively low negative part towards the north direction), which reflects induced magnetization; others appear so complicated to determine whether the magnetization is induced or remnant. The complications may be related to interference from adjacent anomalies that may have different causative sources. The anomalies in section B B' seem to be broader, because they, almost, run along linear anomalies. Figure (11) shows that the highest magnetic amplitude does not exceed 20 nT; for both negative and positive parts. However, amplitudes of several nT are also frequent.

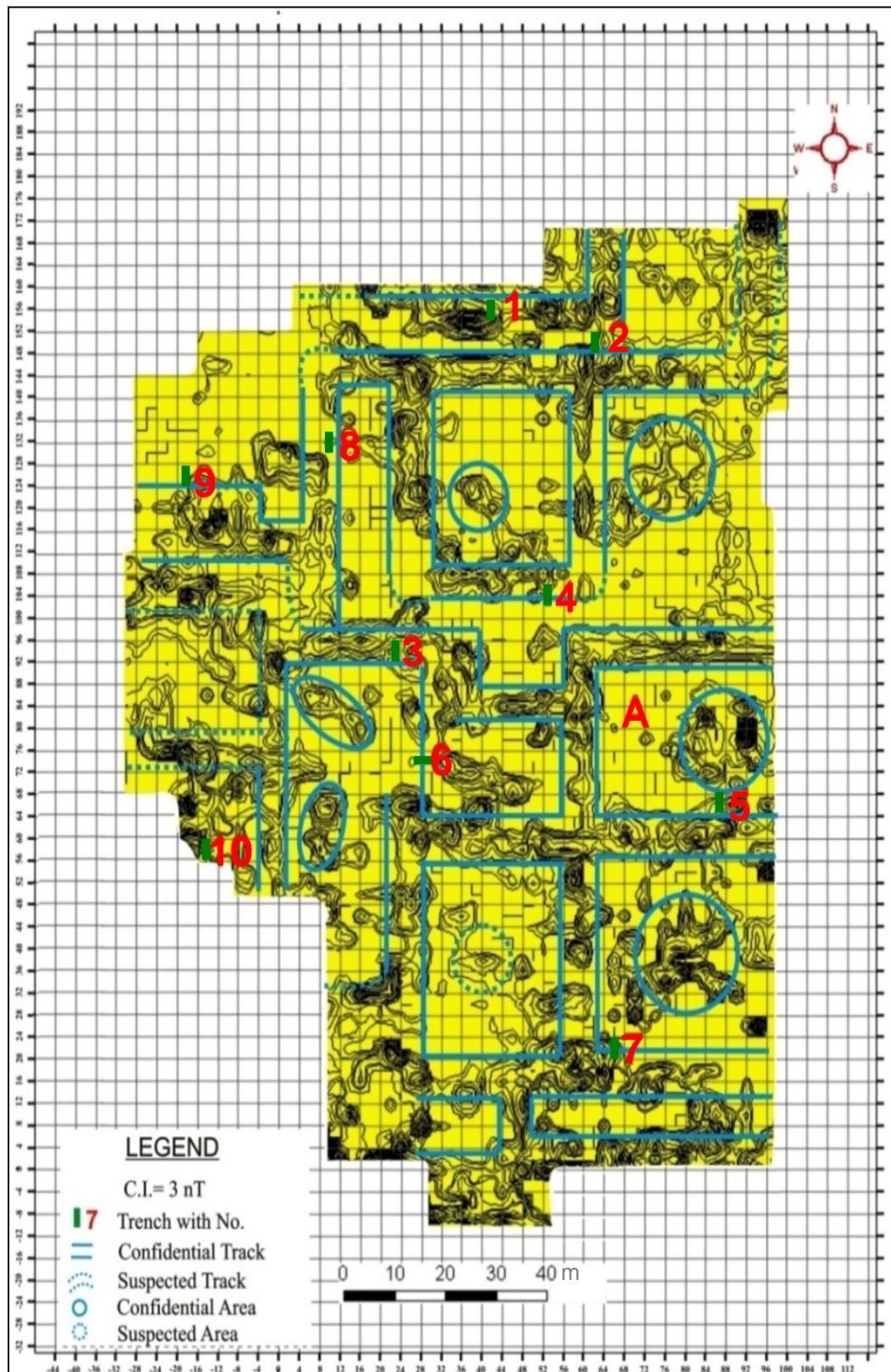


Fig.3: Viewshed map derived from total magnetic intensity map.
The density of contour lines determines the subsurface archaeological structures.
Tracks and areas suggested for future excavations are presented as well



Fig.4: The main mure which appeared in trenches No.1 and 2.
Partially weathered bricks have been assigned by arrows



Fig.5: Bricks collocates as a floor (the outlined area),
appeared in trench No.3



Fig.6: An archaeological feature could be a part of a weathered wall, appeared in trench No.4

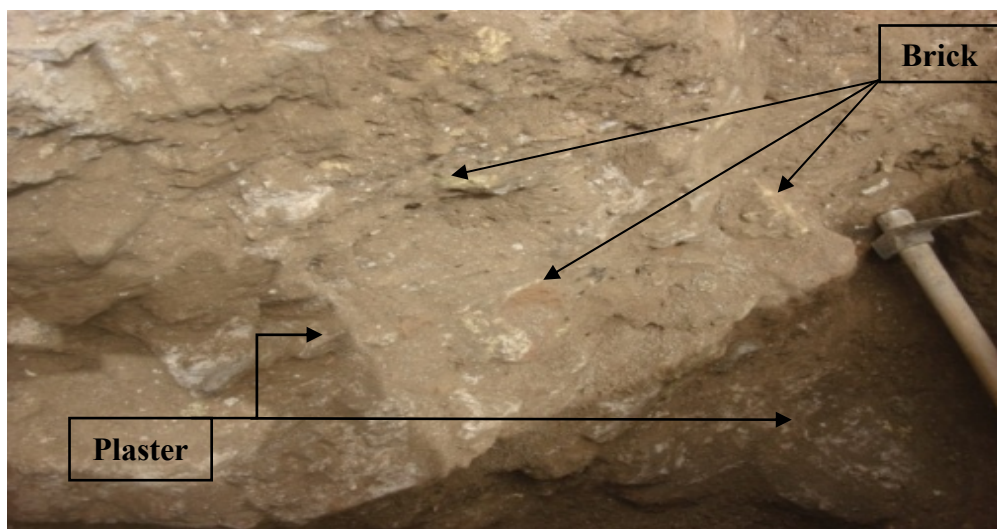


Fig.7: A cracked wall due to compaction of the overburden soil.
White color materials like gypsum as a cemented material appear and cover the bricks (trench No.5)



Fig.8: A circular shape; like a base of column, appeared in trench No.6



Fig.9: A wall in good preservation condition, encountered in trench No.9

The near surface archaeological structures (only few tens centimeters in depth) have their influence on the ground surface; directly lying above them. That's because the effect of capillary action, where the near surface water dissolves the building materials and takes them up to the surface causing an area that differs from the neighboring areas, in its nature and also its color. This could be easily noticed on the upper surface (Fig.10). This is a great tool for investigations of archaeological remains, which are very shallow in depth.



Fig.10: Capillary action effect on near surface archaeological structures. The outlined area by red color represents the area, where archaeological structure is buried (few centimeters in depth). The differences in color and the surface nature between the marked area and the nearby is due to the effect of capillary action

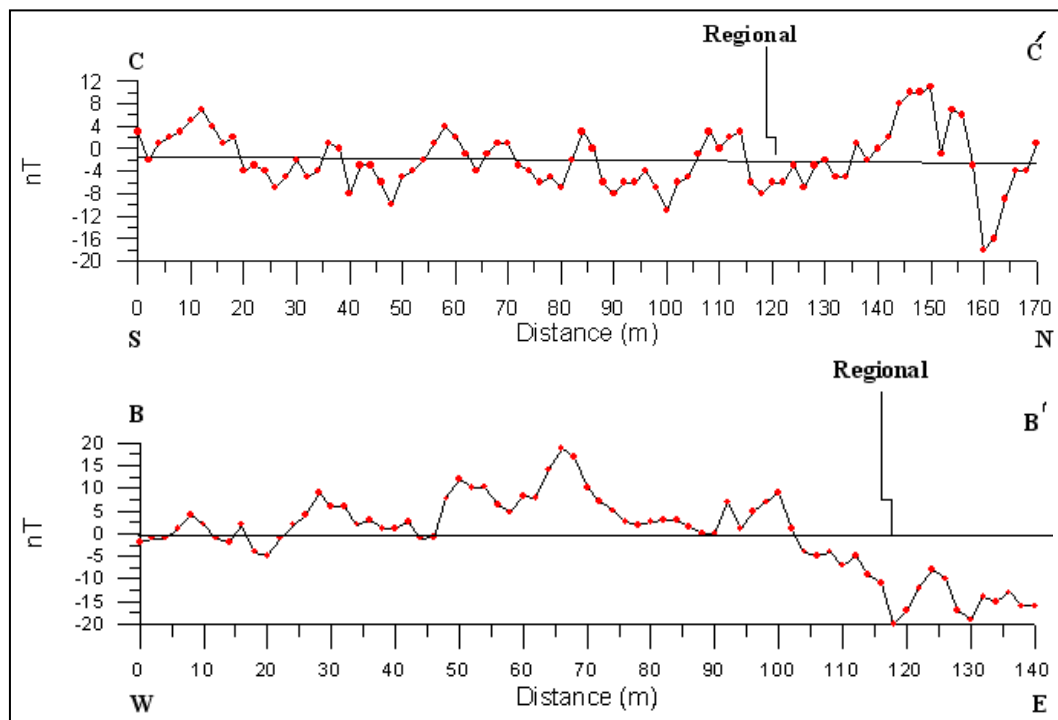


Fig.11: Magnetic sections in N – S and E – W directions (C C' and B B', respectively).
 For the locations of these sections see Fig. (2)

CONCLUSIONS AND RECOMMENDATIONS

The magnetic survey in "Taq-Kisra" Archaeological Site has successfully provided important information to the archaeological research in the site. Summarizing the obtained results; it is worth pointing out the following aspects:

- Taq-Kisra Archaeological Site is rich with many subsurface archaeological features. This is proved by the nature of the obtained magnetic anomalies, which have archaeological meaning; as it was shown thereafter by excavations.
- The highlighted anomalies appeared in the residual anomaly map and assigned by trenches had full archaeological feedbacks represented by mure, walls, base of column, floor, and other archaeological remains proved by the excavation that followed the field work. The features have depths ranging from (0.25 – 2) m. Accordingly, the areas appeared in the viewshed map (Fig.3) are suggested as archaeologically meaningful areas for future excavations.
- The structures discovered by the excavation are mostly constructed of burned bricks with dimensions of (25; length × 25; width × 7.5; thickness) cm, with two colors red and yellow and white color materials like plaster; as a cementing material. These are hosted by soil.
- The highest the magnetic anomalies are, the nearest from the ground surface the archeological structures are. Moreover, some high anomalies may reflect places of intersections between internal walls, where good amount of building materials are present to give such anomalies.
- The near surface archaeological structures (only few tens of centimeters in depth) have their influence on the ground surface, which directly lies above them. Due to the effect of capillary action, where the near surface water dissolves the building materials and takes them up to the surface causing an area that differs from the neighboring areas, in its nature

and color. This could be easily noticed on the upper surface (Fig.10). This is a great tool for investigations of archaeological remains, which are very shallow in depth.

- Definitely, magnetic survey has proved to be quite an effective tool in locating buried archaeological structures and guiding excavations with great saving of money and time.

According to the aforementioned excavation results that followed the magnetic survey, the present work recommends to expand the excavation process to cover all the appeared anomalies in the viewshed map (Fig.3); starting from the already excavated trenches in order to follow up the archaeological features that are exposed by trenches excavation. Figure (3) represents the suggested tracks and areas for future excavations in the site.

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