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Geophysical Investigation of Babylon archeological City, Iraq

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Abstract

A geophysical survey was carried out at old archeological Babylon City, which is located 90.0 km to the south of Baghdad. Three geophysical methods were applied in this survey. The VES resistivity method, for soil conductivity and layering testing. GPR and magnetic methods, for detecting subsurface archeological bodies. The resistivity results showed values lower than 5.0 ohm. m, and subsurface distortion, which are probably related to buried archeological ruins. Due to the low electrical resistivity of the top soil, the GPR method did not reach a good penetrating depth. Wide range of frequencies, 30 MHz, 250 MHz, 500 MHz, and 100MHz were applied. The high signal attenuation of the top soil resulted in distorted radar-grams with faint shallow anomalies. The GPR survey was conducted at different seasons hoping that the dry conditions of the hot summer could change the top soil electrical resistivity. Nevertheless, few GPR radar- grams show point reflections that related to small dense bodies at depths of 0.8 – 2.0, which could be archeological bricks walls. The magnetic survey was carried out in two stages using Cesium magnetometer of high sensitivity. An area of 140.0 m x 240.0 m was surveyed at the first stage, which is covered by twenty-eight N-S traverses. The preliminary results show the effects of the N-S profiling, which can be removed by directional first derivative filter. It showed indications of subsurface archeological features. In the second stage, an area of 40.0 x 40.0 meters was chosen for detailed survey. The survey is done a long 40 traverses in N-S direction and another 40.0 Traverses along W-E directions. The preliminary results of the both surveys show some differences. These differences were removed by using first derivative filter. They both showed subsurface geometric shapes that are probably related to buried archeological walls. The mathematical modeling results showed walls of widths 0.3-0.4 meters at depths around 0.8 meters. These walls continue down to 2.3-2.5 meters in depth. The magnetic survey also showed many circular high magnetic anomalies within an area of 1.0 – 2.0 meters only. The mathematical modeling suggested that these anomalies could be corresponding to building poles made of andesite or basaltic rocks or they are buried metals objects.

Keywords: Babylon Old City, Archeology Exploration, Geophysical Investigation, Iraq.

تحريـات جيوفيزيـائية في مدينة بـابـل الاثرية، الـعراق

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الخلاصة

أجري مسح جيوفيزيائي لموقع يمثل تلة اثرية في مدينة بابل الأثرية القديمة الواقعة على بعد 90.0 كم جنوب العاصمة بغداد. تم تطبيق ثلاث طرق استكشاف جيوفيزيائية في هذا المسح. طريقة المقاومة الكهربائية (VES) لاختبار توصلية التربة وطبقاتها. وطريقة الاختراق الراداري (GPR) والطريقة المغناطيسية للكشف عن الأجسام الأثرية الموجودة تحت السطح. أظهرت نتائج مسح المقاومة الكهربائية قيمًا أقل من 5.0 أوم.م للجزء العلوي من التربة في حين الجزء السفلي اظهر عدم تجانس في الغالب بسبب الاجسام الأثرية المدفونة. في حين طريقة الاستكشاف الراداري لم تحقق اختراق بأعماق جيدة بسبب المقاومة الكهربائية المنخفضة للتربة السطحية التي عملت على توهين اشارة الموجة الكهرومغناطيسية بشكل كبير. حيث تم تطبيق مدى واسع من الترددات، 500 ميجا هرتز، 250 ميجا هرتز، 100 ميجا هرتز و 30 ميجا هرتز ضمن

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عمل ميداني لعدة فترات في ظروف جوية مختلفة من الصيف الحار الى الربيع. ومع ذلك كانت هنالك بعض النتائج المحدودة التي تمثل انعكاسات نقطية تتعلق بأجسام كثيفة على أعماق تتراوح بين 0.8 م الى 2.0م، والتي يمكن أن تكون جدرانًا من الطوب الأثري. تم إجراء المسح المغناطيسي على مرحلتين باستخدام جهاز السيزيوم عالي الدقة. في المرحلة الاولى تم مسح موقع مختار من التلة الاثرية بأبعاد 140.0 م × 240.0 م والتي تم تغطيتها بثمانية وعشرين مسار باتجاه جنوب -شمال الذي أثر على النتائج الأولية للشواذ المغناطيسي علما ان مرشح المشتقة الأولى قلل كثيرا من ظاهرة اتجاه المسارات وتباعدها وتم الحصول على المؤشرات الأثرية تحت السطحية والتي على أساسها تم اختيار موقع المسح التفصيلي للمرحلة الثانية بمساحة 40.0 × 40.0 متر. وهنا المسح الميداني تم باتجاهين وهي جنوب - شمال وغرب - شرق وبتشبيك 1.0م في 1.0م. تظهر نتائج المسح بالاتجاهين تباين قليل تمت ازالته باستخدام مرشح المشتقة الأولى. أعطت نتائج المسح التفصيلي شواذا مغناطيسية بأشكال هندسية قد تكون مرتبطة بجدران أثرية مدفونة. استخدمت النمذجة الرياضية لحساب عمق وابعاد الاجسام المدفونة وهي اشبه بجدران مدفونة بعرض 0.3-0.4 متر وارتفاع 2.3 – 2.5 متر وأعماق تصل 0.8 متر من سطح الارض. كما ان نتائج المسح التفصيلي اظهرت شاذات مغناطسية دائرية وحادة ضمن مساحة 1.0 - 2.0 متر فقط. تشير النمذجة الرياضية إلى أن هذه الحالات الشاذة يمكن أن تتطابق مع أعمدة البناء المصنوعة من الصخور الصخور النارية القاعدية أو قد تكون اجسام معدنية مدفونة.

الكلمات المفتاحية: مدينة بابل الاثرية، استكشاف اثاري، استكشاف جيوفيزيائي، عراق.

Introduction

The well-known Babylon archeological City is located about 90 km to the south of the Baghdad City and about 10 km to the north of Hilla City [1]. It lies between longitude 44°24́ 40″ - 44°27́ 00E and latitudes 32°31́ 10″- 32° 33́ 00 N at Mesopotamian zone, in the stable shelf according to the physiographic subdivision of Iraq [2]. It is bounded from the west by Shatt Al-Hilla river, (a branch of the Euphrates River), and from the east by Babylon Canal, while from north and south by two artificial lakes. Geologically, Babylon area is covered by flood plain and Aeolian sediments of Quaternary age [3]. While Lithologically, the sediments are represented by gravels, sands, and prevalently silt. The thickness of Quaternary sediments reaches about (20-25m). The first meter of these sediments generally shows homogeneity and consists mainly of silty clay and sand of local artificial channels. The western part of the area consists mainly of flood plain sediments of Shatt Al-Hilla River [4, 5]. At Babylon archeological city, the second meter of sediments below ground surface proved some differences between the deposition outside the outer city wall and inside it. The area outside the wall composed of sandy deposits up to 1.5 m while the area within the wall composed mainly of silty clay. This means that the outer wall had acted as an embankment and protected the inner area from the floods.

In this study a site within Babylon archeological city is chosen mainly for geophysical research. It is located at a hill within the western part of the old city. It could be corresponded to a buried temple of Babylon archeological city.

Geophysical Investigations

No geophysical survey has been done for the archeological Babylon City. Parts of the archeological structures are existing above the ground surface. Some maintenances and manipulations had been done to these archeological structures. While, there are many areas have not investigated yet. They look like small isolated hills. In this study, however, one of these archeological hills is chosen figure 1. It is a low relief hills that is covered by fine sediments (mostly fine silt with clay). Underneath the soil, there are the old walls and unrecognized features. Some of these archeological features can be seen in the small wadi, which were developed by the rainy water. Three geophysical methods were applied; the electrical resistivity, GPR survey, and magnetic survey. The fieldwork was conducted on many field trips that continued for 14 months.

Electrical resistivity method

The main target of the resistivity survey [6, 7] was to detect the ground water table in the Babylon old city. Terrameter SAS 4000 equipment was used for this survey. Among the 18 VES points, only 8 points were considered as somehow reliable figure 1. This is due to the lateral non – homogeneity of subsurface conditions. The buried archeological features caused high distortion to the measured data. Furthermore, in some locations the top soil resistivity is too low. It is ranging from 1.0 to 4.0 ohm. m. Nevertheless, the eight VES data showed that the ground water table is around 8.0 meters in depth. This is only for the high-level areas of the old city.

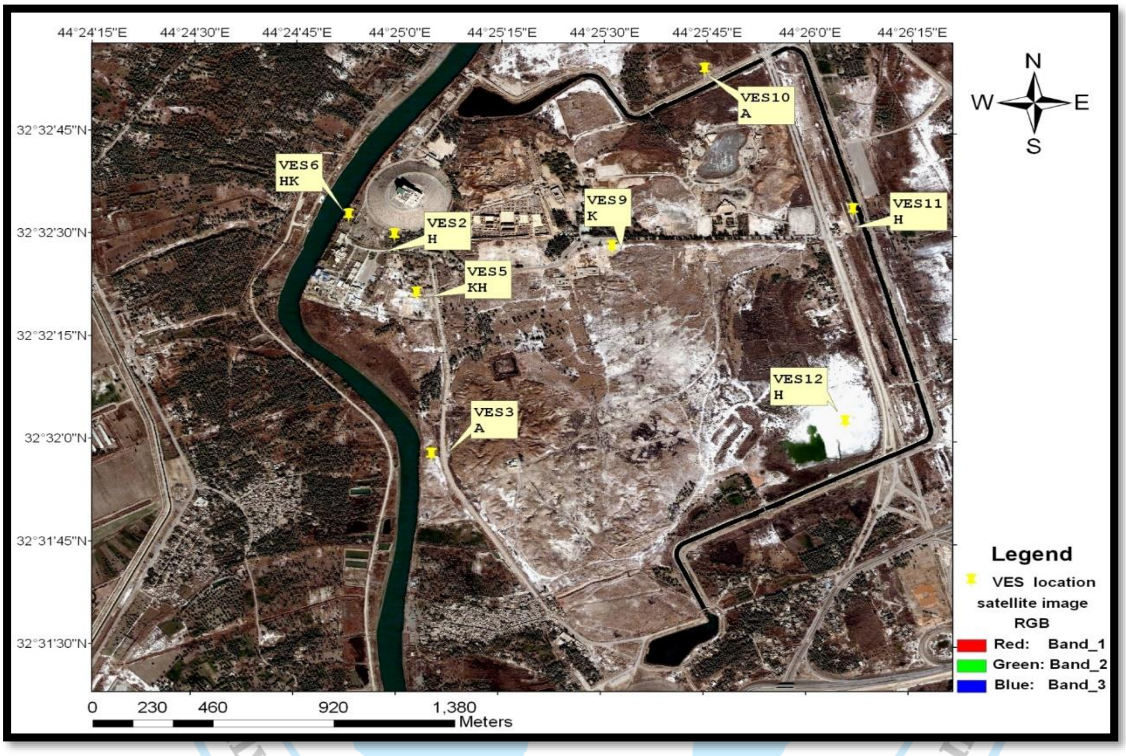

Figure 1: Locations of 8 VES points that were carried out at Babylon Old City.

Ground Penetrating Radar Method (GPR)

Ground penetrating radar (GPR) method was carried out for the chosen study site of 140.0 x 240.0 m figure 2. The low resistivity (less than 5.0 ohm. m) of the top soil makes the GPR method not workable in this area. Four different antenna frequencies (30MHz, 250MHz, 500MHz, and 100MHz) were used, and more than 80 traverses were carried out on different seasons (April, May, June, August, October, and December 2011) hoping to have a better condition for the soil resistivity. For this soil conditions the radar wave penetration is highly attenuated [8]. In most surveyed traverses, there are no real clear deep reflections. Only distortion shapes and shadows can be detected for depths not more than 2.0 m. However, few reflections, of point's types [9, 10], were noticed for some radar-grams. These could be related to small size (0.3 – 0.4 m) bodies at depths of around 0.8 -2.0 m figure 3, which could be composed of dense material (archeological buried walls). It should be noted that these negative GPR results are only corresponding to the chosen study area. The soil conditions at Babylon archeological city are quite variable from clay to silty sand, i.e., the GPR survey could be applicable at other locations. The archeological hill probably corresponds to a temple. It is covered by aeolian salty fine silt to clay soil. While the archeological walls are made of silty clay bricks, and with the low resistivity of the top soil the GPR method cannot clearly detect these subsurface features.

Figure 2: the chosen study area (hill site) at the Babylon old city. The area is marked by black rectangle

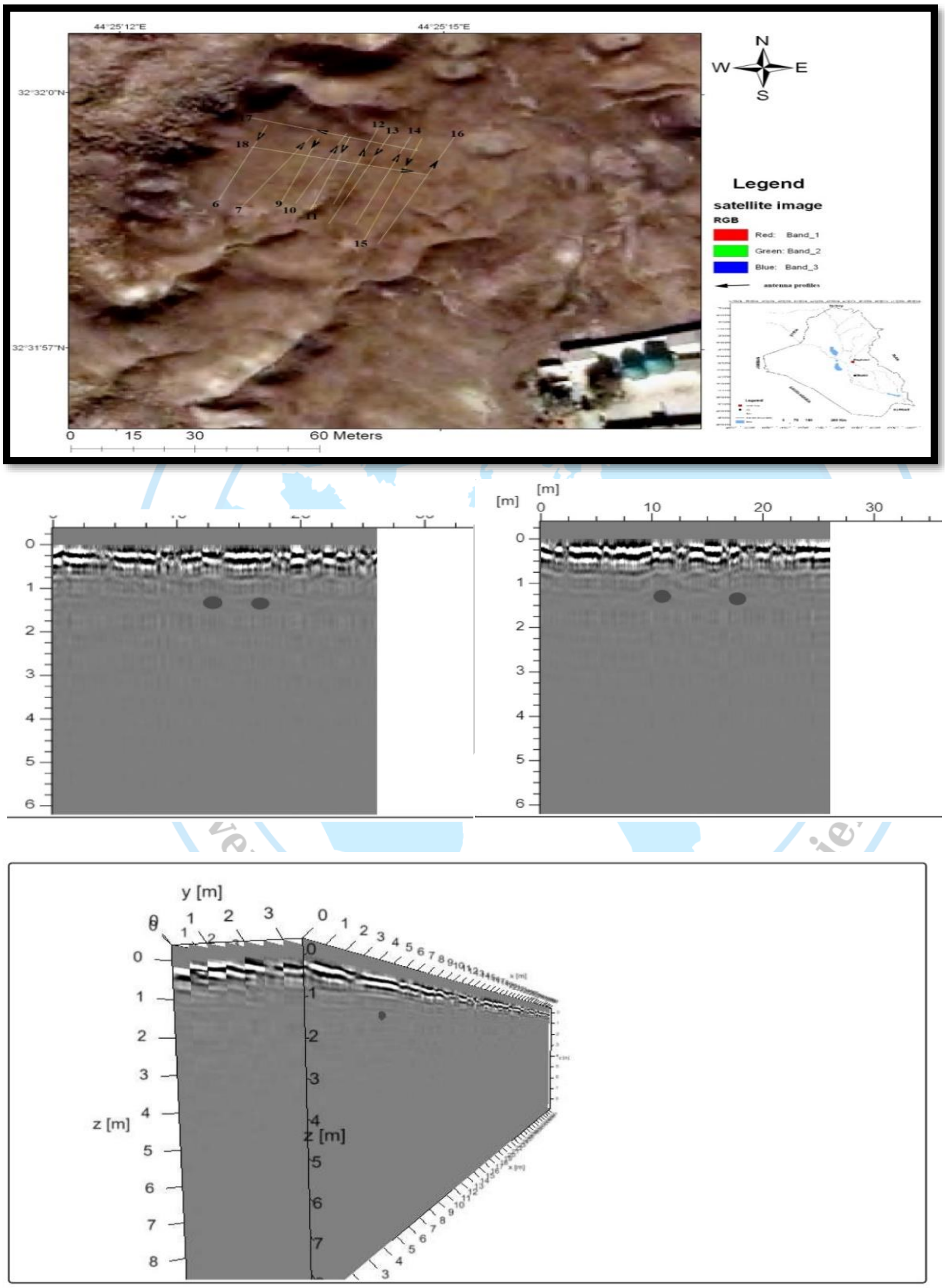

Figure 3: Locations of the surveyed GPR profiles using 250 MHz antenna(up), examples of the radar-grams (mid), and 3D view of few radar-grams (down). Note that the depth of investigation is less than 2.0 m.

Magnetic survey

Cesium magnetometer [11] was used for the field survey. Proton ENVI Pro magnetometer was used as a base station. The cesium magnetometer is capable of measuring the total magnetic field with a precision of 0.01 gammas. The point reading mode was used. The magnetometer sensor was kept at 0.6-meter elevation with an orientation parallel to the traverse trend, which is almost south-north, though Cesium magnetometer are not affected by the sensor orientation [11] as the proton magnetometer do.

The first magnetic survey was conduct on April 2011 and continued for 15 days. It was for an area of 240.0 X 140.0 m. Twenty-six traverses of 240.0 meters were surveyed. The inter-distance between profiles (traverse) is 5.0 meters, while the measuring point interval along each traverse is 1.0 meter. Periodical readings at a base station were done. This is for the diurnal magnetic variation's correction, which was done for all the magnetic measurements relative to the first day base station value.

A contour map was plotted for the corrected magnetic data of the study area, Figure 4. The first indications of this map are the longitudinal N-S features which could be buried archeological features or the effect of the profiling (measurements along S-N traverses), or the space between travers. For this reason, a small area (40.0 x 40.0 meters) was chosen, within the same surveyed area, for more detailed survey. This area was called here as "area B", figure 4. In this detailed magnetic survey eighty traverses were carried out (40 traverses in S-N direction and another 40 traverses in W-E direction). The distance between traverses was 1 meter, while the measuring point interval was 1 meter too, i.e., the survey was along a grid of 1.0 x 1.0 meter. One base station was chosen for this survey.

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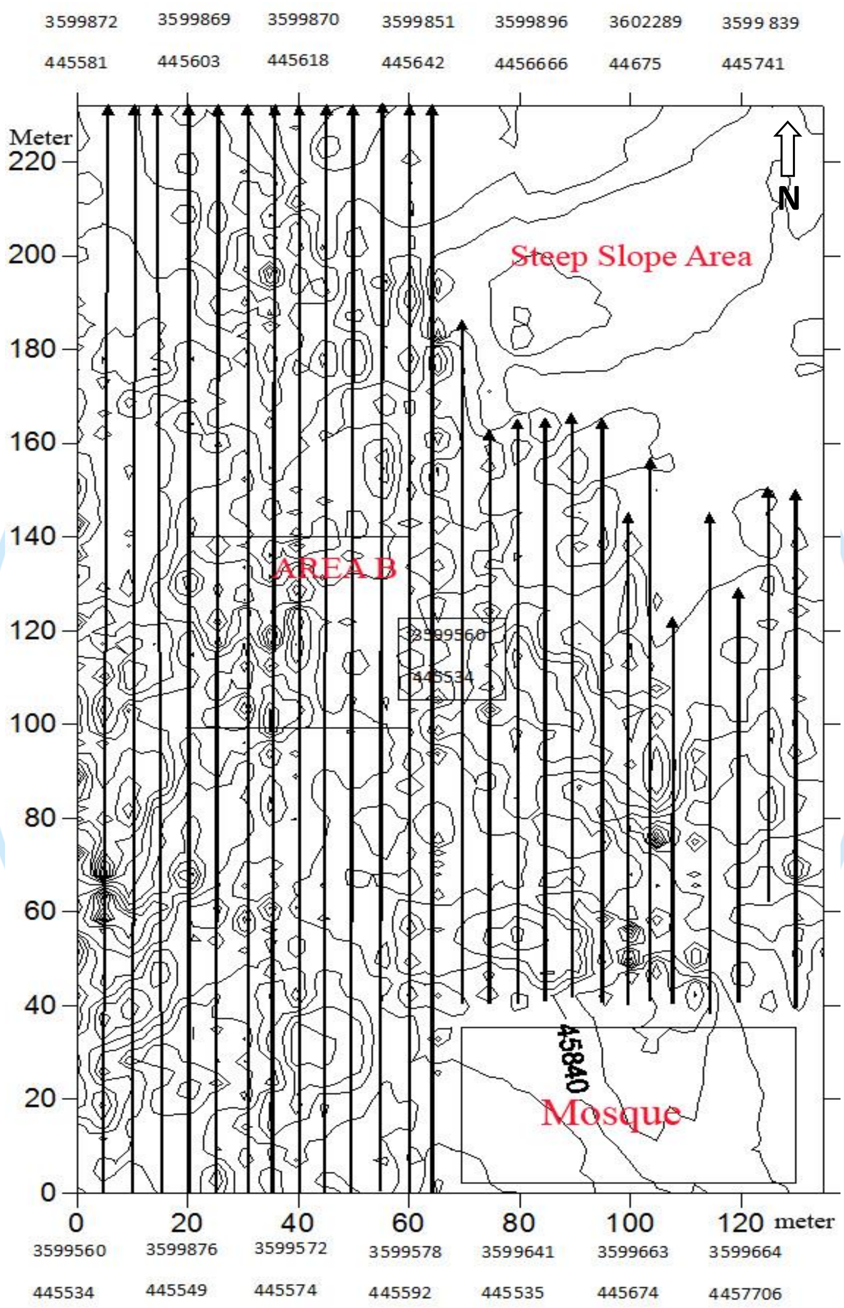

Figure 4: Magnetic anomaly map and the surveyed traverses' locations of the study area (140.0 x 240.0 meters). The location of Area B is shown here too. Northing and Easting coordinates are showing on the top and the bottom of the map.

Qualitative interpretation of magnetic data

The total magnetic field of the study area has been mapped using Surfer V.8 Software [12]. Figure 5 shows the map of the corrected magnetic field (relative to the main base station). It is clear from this map that the magnetic anomalies have north-south, northwest-southeast, and east–west trends. The maximum anomaly value reaches 180 gammas, while the minimum value reaches -220 gamma. Theses minimum values are restricted to one location at the southwest part of the surveyed area. It is indicated by white color on the map.

There is no obvious explanation for these strong negative anomalies. On the other hand, the other parts of the surveyed area show minimum values around -100 gammas. figure 6 shows the total magnetic maps of "area B" in N-S and E-W directions respectively. They are both showing almost the same anomalies, however, in the N-S surveyed magnetic map the north-south trending anomalies are clearer. While, in the E-W surveyed map the east-west trending anomalies are clearer.

Filtering of Magnetic Data "Area B" (40 x 40 m)

The first derivative filter, in general, plays a role in magnetic interpretation because they isolate contacts over which the field can be expected to change rapidly, therefore, it has large values for its derivatives [13]. It calculates the slope of the surface along a given direction. It can isolate and detect the short-wave anomalies, and particularly the one with high values. In this study, the first derivative was applied for "area B", and for both the N-S and E-W magnetic data. For the N-S surveyed data the directional first derivative was in 90^o trend, while for the E-W surveyed data the directional first derivative was in 0.0^o trend. Figure 7 shows both maps of the first derivative results. They are showing almost the same anomalies. This simply means that the first derivative or any filter that can be applied in 90^o can remove the effects of the surveying along N-S traverse direction.

The most interesting thing in the first derivative maps are the magnetic anomalies distribution. They show a distribution that probably reflects the archeological walls, rooms, or passageways.

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They show geometrical distribution that is probably corresponding to the buried archeological features. They show a general trending toward the northwest. There are many small rounded features in this map. These are corresponding to anomalies with high positive and negative values.

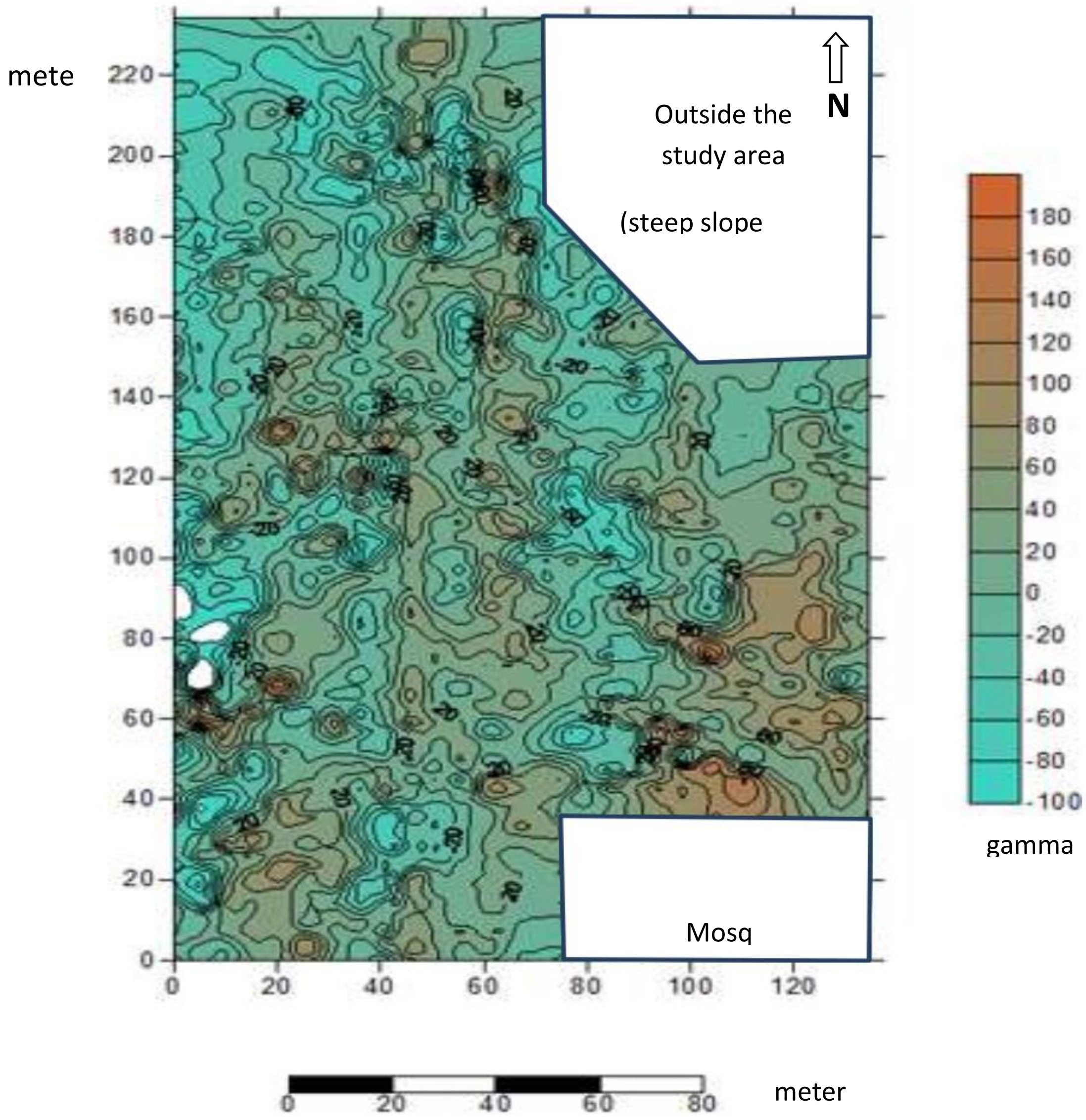

Figure 5: Magnetic anomalies of the study area relative to the base station. White spots on the lower left correspond to sharp negative and positive anomalies.

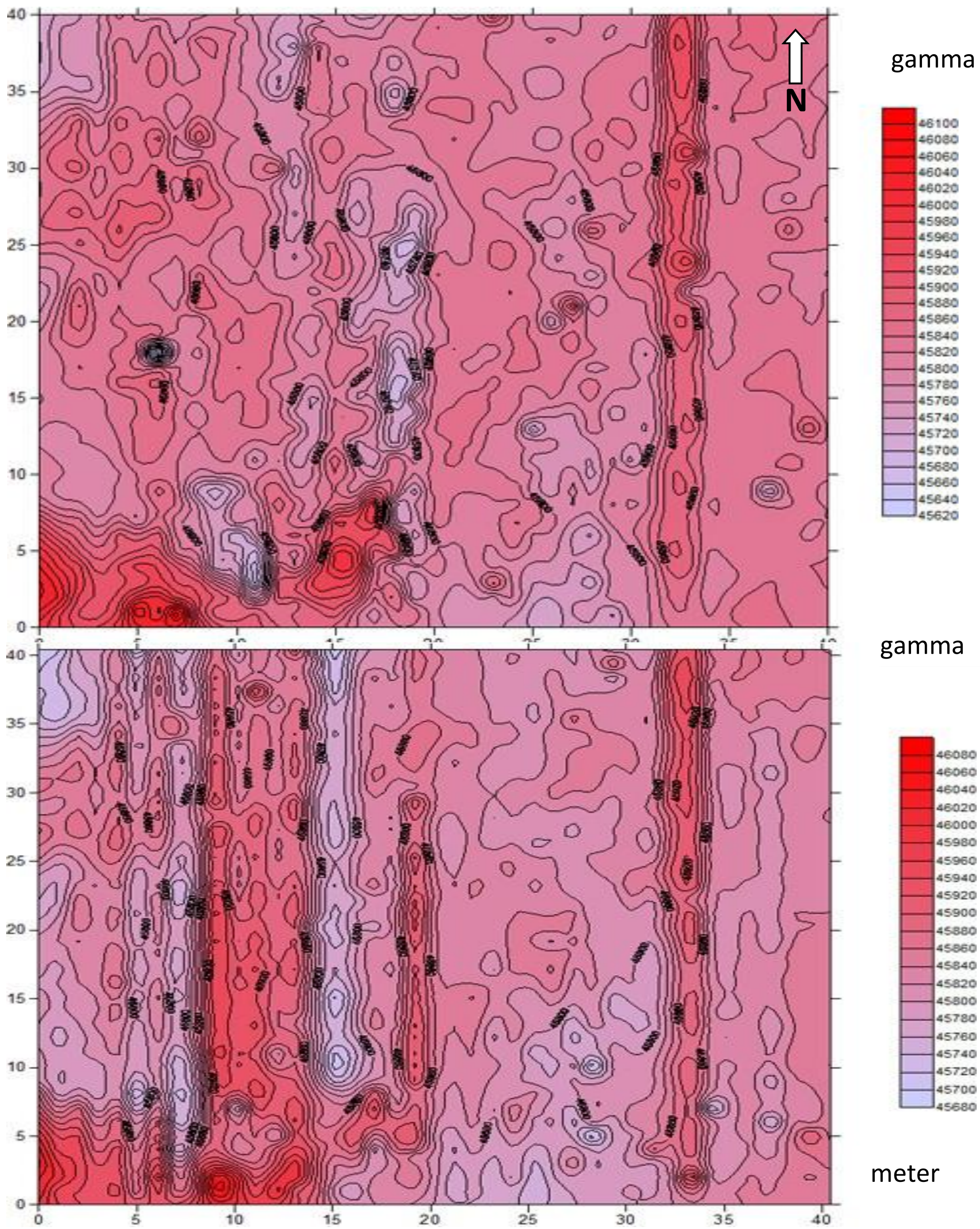

Figure 6: Total magnetic map of "area B". The survey traverses were along S-N direction (up) and were along W-E direction (down).

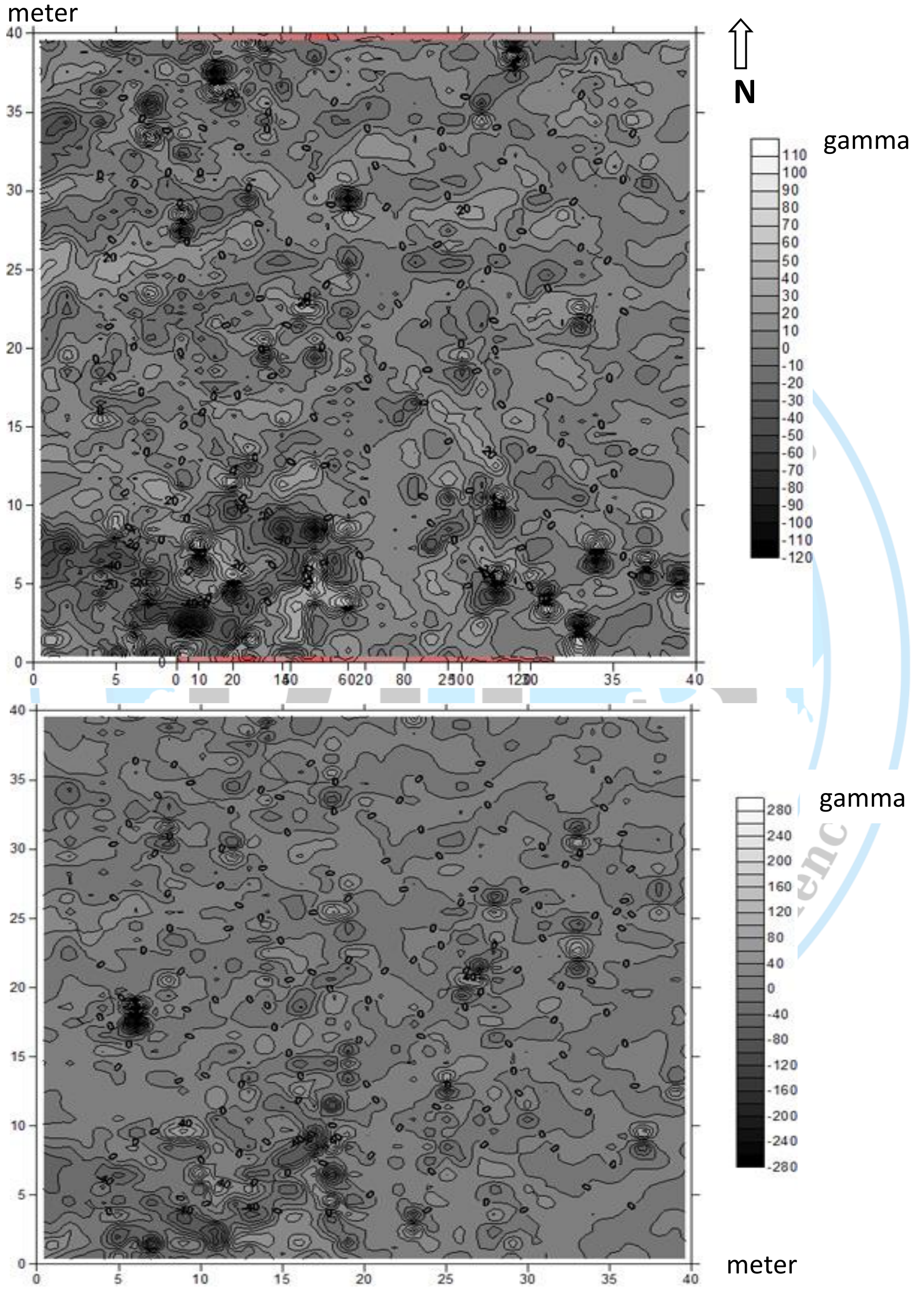

Figure 7: First derivative results of the magnetic data that were measured in S-N direction (up) and E-W direction (down) of area B.

Filtering of the Total Study Area (140 x 240 m)

The first derivative filtering is used for the total area magnetic data. Figure 8 shows the magnetic map for the 0.0^o trend, while Figure 9 shows the first derivative results with 90.0^o trend. Again, the N-S trend anomalies are clearer for the 0.0^o directional derivative, while the 90.0^o the east-west anomalies are more pronounced. In both maps the northwest-southeast trends anomalies are obvious.

Many filters were applied in this study, like the high pass, low pass, directional second derivative, reduction to the pole, upward and downward continuation and directional gradient filter. Some of these filters do not give real isolation of the residual from the regional anomalies. They give very general shape for the regional anomalies, as the case with the resulted pseudo gravity map, which suggests that the study area is an archeological hill. Apparently, the magnetic data of this study is self-explanatory, and the first derivative filter is quite enough.

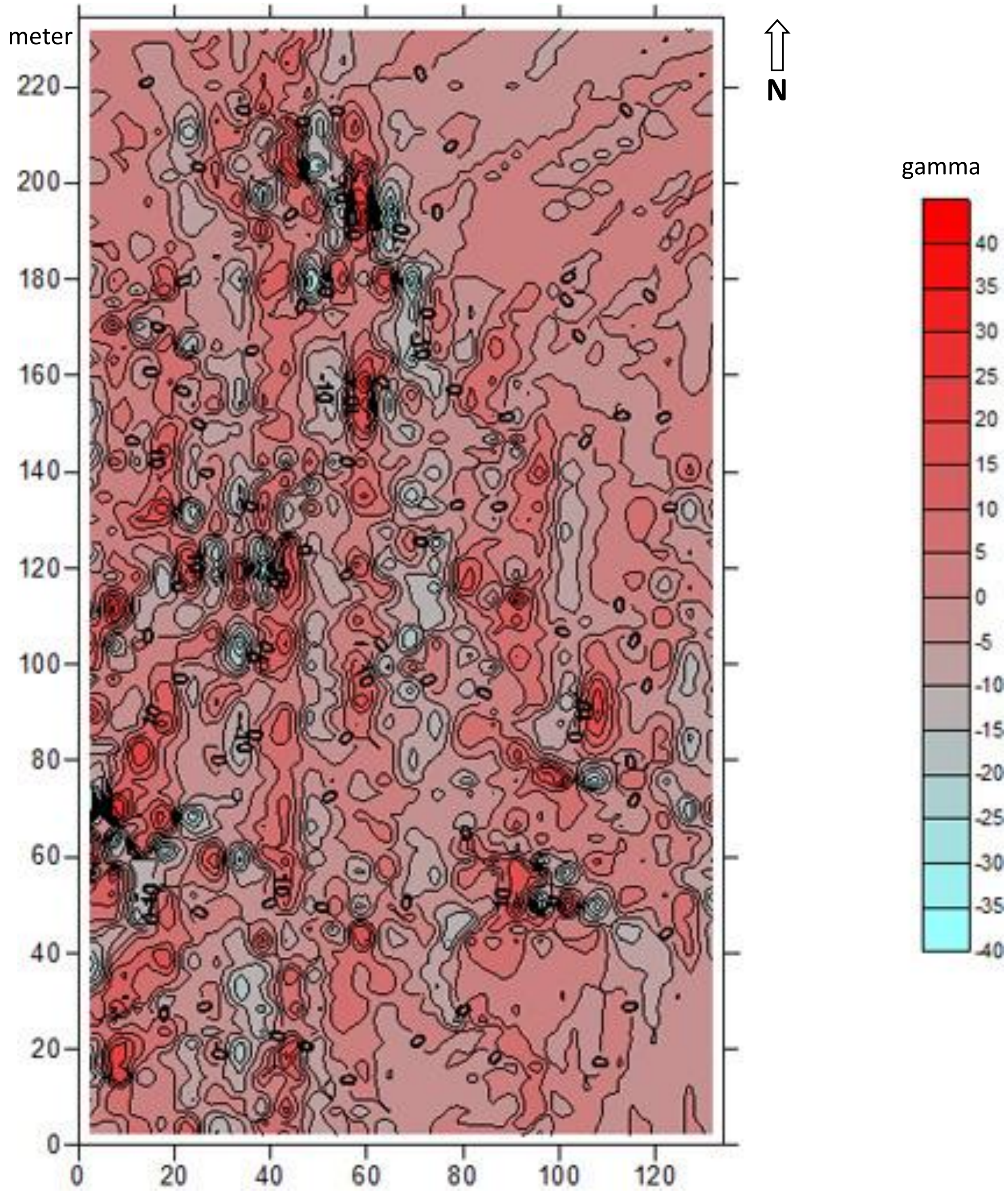

Figure 8: Results of the first directional derivative of the magnetic data. The derivative direction is 0.0°. The north-south features are more pronounced in this filter.

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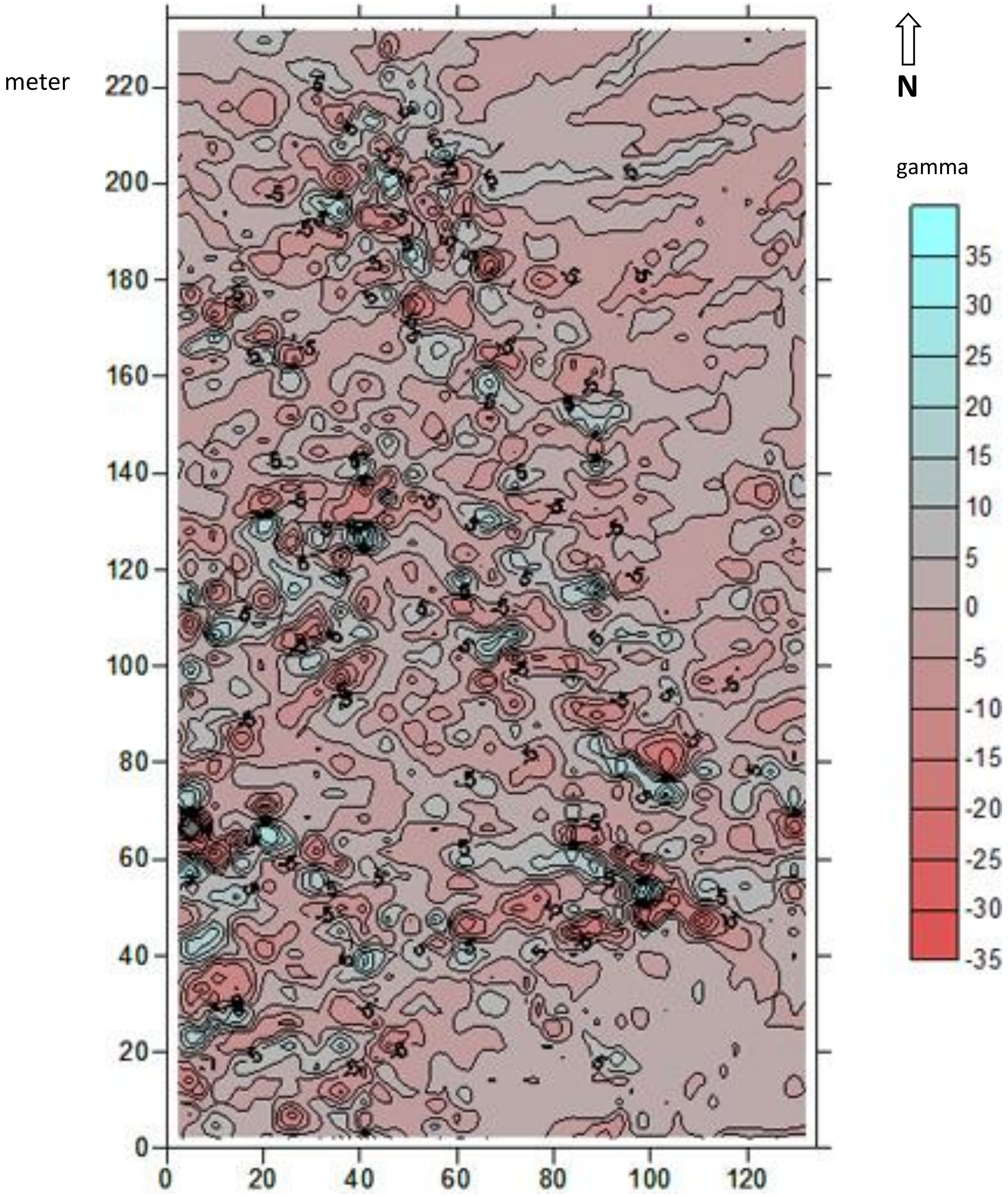

Figure 9: Results of the first directional derivative of the magnetic data. The derivative direction is 90.0°. This filter removes the effect of the north-south profiling. The geometric shapes are very clear, which probably correspond to the buried old walls.

Quantitative Interpretation and Modeling

In general, the magnetic anomalies that observed in archaeological sites are complex because of several factors. The sources that generate the anomalies are relatively shallow. Also, the various sources of magnetic anomalies from soils, near surface objects, and the clutter of ancient or modern human habitation, in addition to the objects of interest [13]. The "area B" with the detailed magnetic survey of 1.0 x 1.0 meter, can be the best for the quantitative interpretation. Each anomaly can be treated alone. Figure 10a shows the location of one of the magnetic anomalies that shows a value of more than 20 gamma between the maximum and minimum and within a distance of about 5 meters. The P Block model [14] for such anomaly suggest that the source is a body with a thickness of 0.3-0.4 meters and a height of 1.5 meters with its top at a depth of about 0.8 meter. The susceptibility contrast is about 0.009 in SI units (which is around 0.0007 c.g.s units). This value is acceptable for archeological materials.

The same modeling parameters are used for section C – C' (see Figure 10a for location). Only the traverse bearing is different from section A – A'. The mathematical model is shown in Figure 10b, which describe the observed anomaly in the shape and value. These two examples are suggesting archeological walls of 0.3 – 0.4 meters width of about 1.5 meters height. They are buried under 0.8 meter of soil. They represent many other similar anomalies in the magnetic anomalies map.

In the magnetic map of "area B", there are many sharp positive/negative anomalies. They can be noticed easily as black two spots with a distance of one meter. They are very sharp magnetic anomalies with maximum value reaches 100 gamma and minimum value reach – 30.0 gamma. Such sharp anomalies probably are related to small bodies with high susceptibility contrast and shallow depths. A mathematical model was done for one of these anomalies. P Block software was used figure 11, which clear suggest that the source of such anomalies probably are poles (Building columns) with a diameter of 0.3 meter, and a height of 2.0 meters. It is buried at depth of 0.8 meter with a susceptibility contrast of 0.3 SI unit. Basalt or Andesite rocks usually show such susceptibility values, i.e., these anomalies could be corresponding to basaltic poles, which

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usually are found at archeological castle or temple. Figure 12 shows shaded relief map of the area B magnetic anomalies. It is a method of representation that shows the possible buried archeological features.

-a-

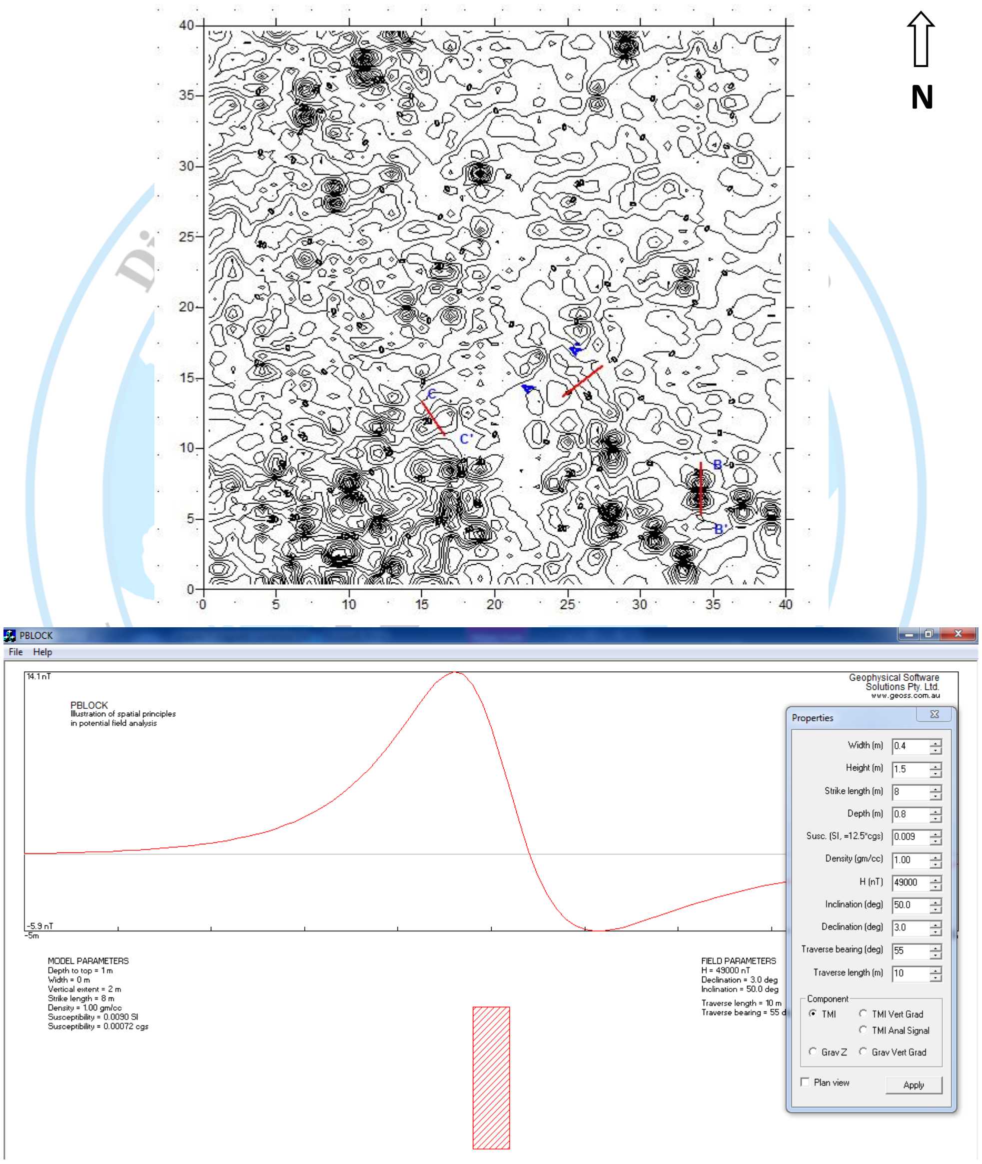

Figure 10 a: Location of the section A-A' of a magnetic anomaly (up), and shows the mathematical model of this anomaly (down).

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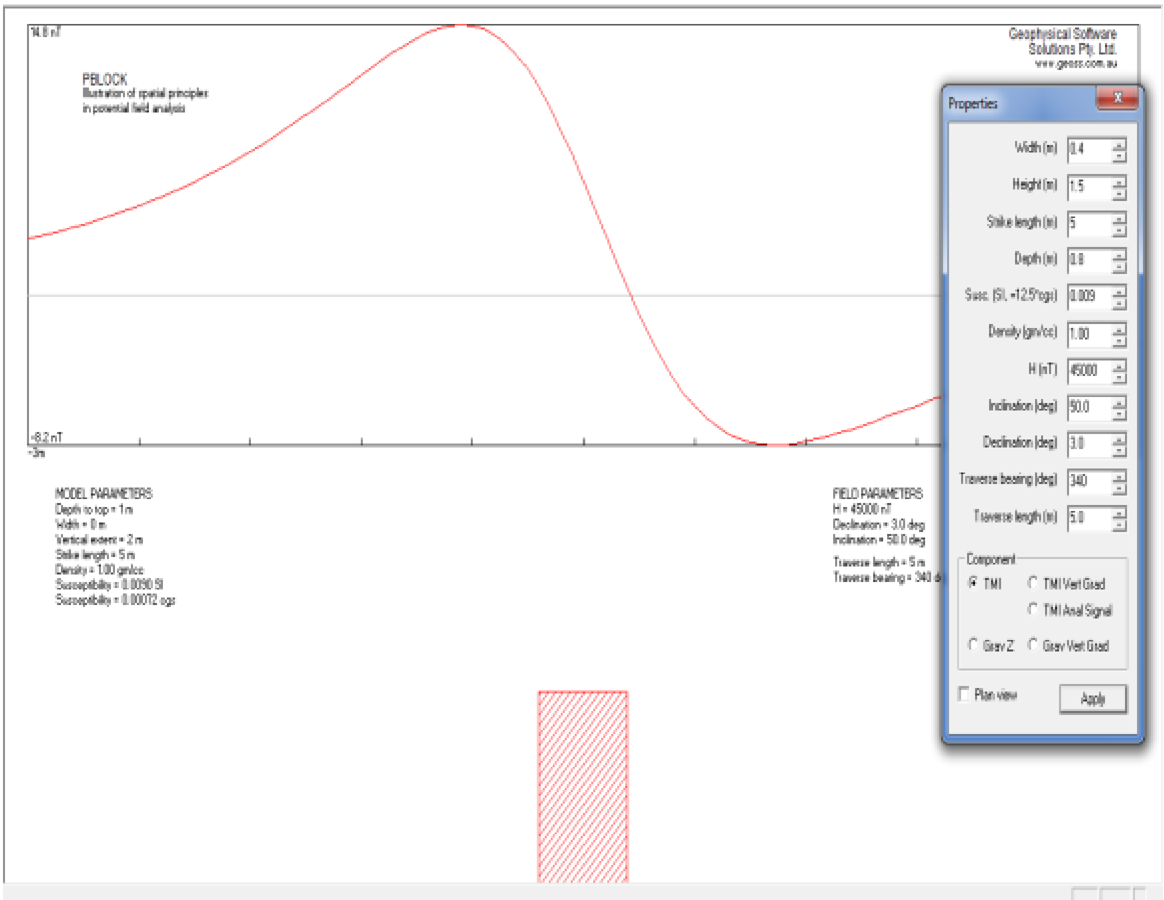

Figure 10b: Mathematical model of the magnetic anomaly along C – C' section. *The body thickness= 0.4 m; Depth= 0.8 m; Body height= 1.5m, strike length: 5.0 meters, Traverse length; 5.0m.*

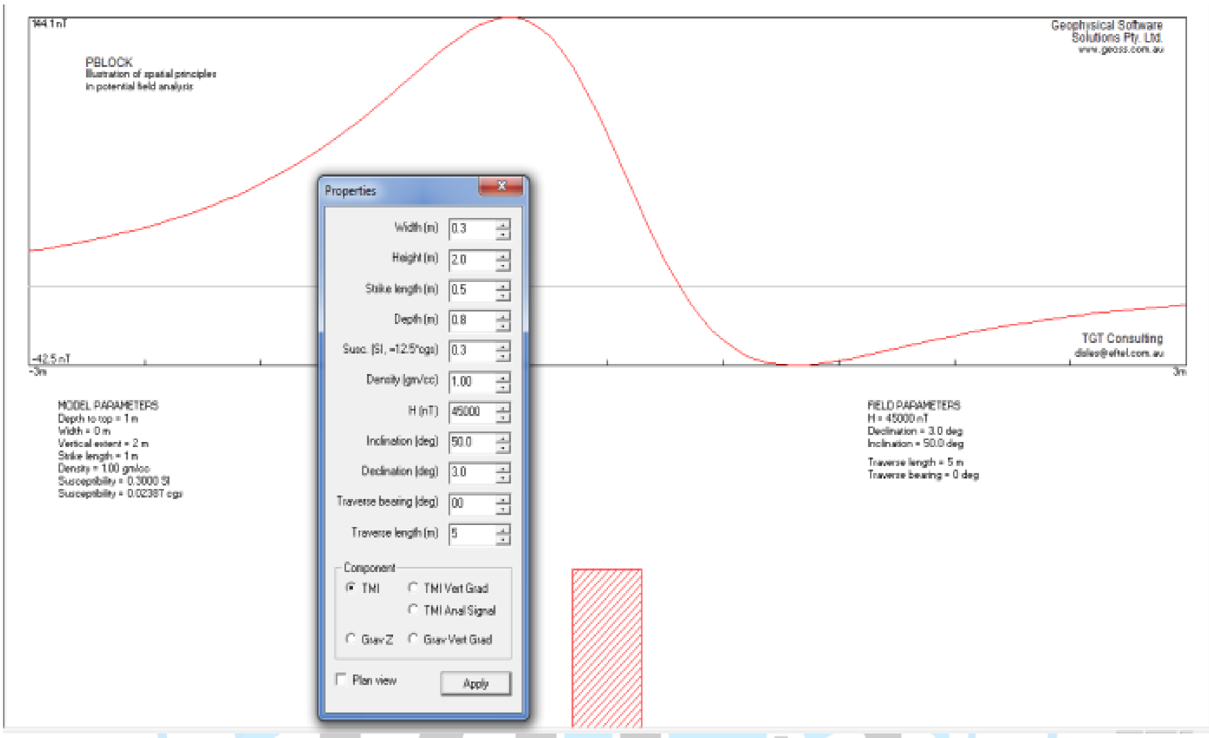

Figure 11 a: Mathematical model for a sharp magnetic anomaly (within a distance of 1.0 – 1.5 meters). The source body is possibly a basaltic pole of 2.0 meters in height and 0.3 meter in diameter and at depth of 0.8 meter.

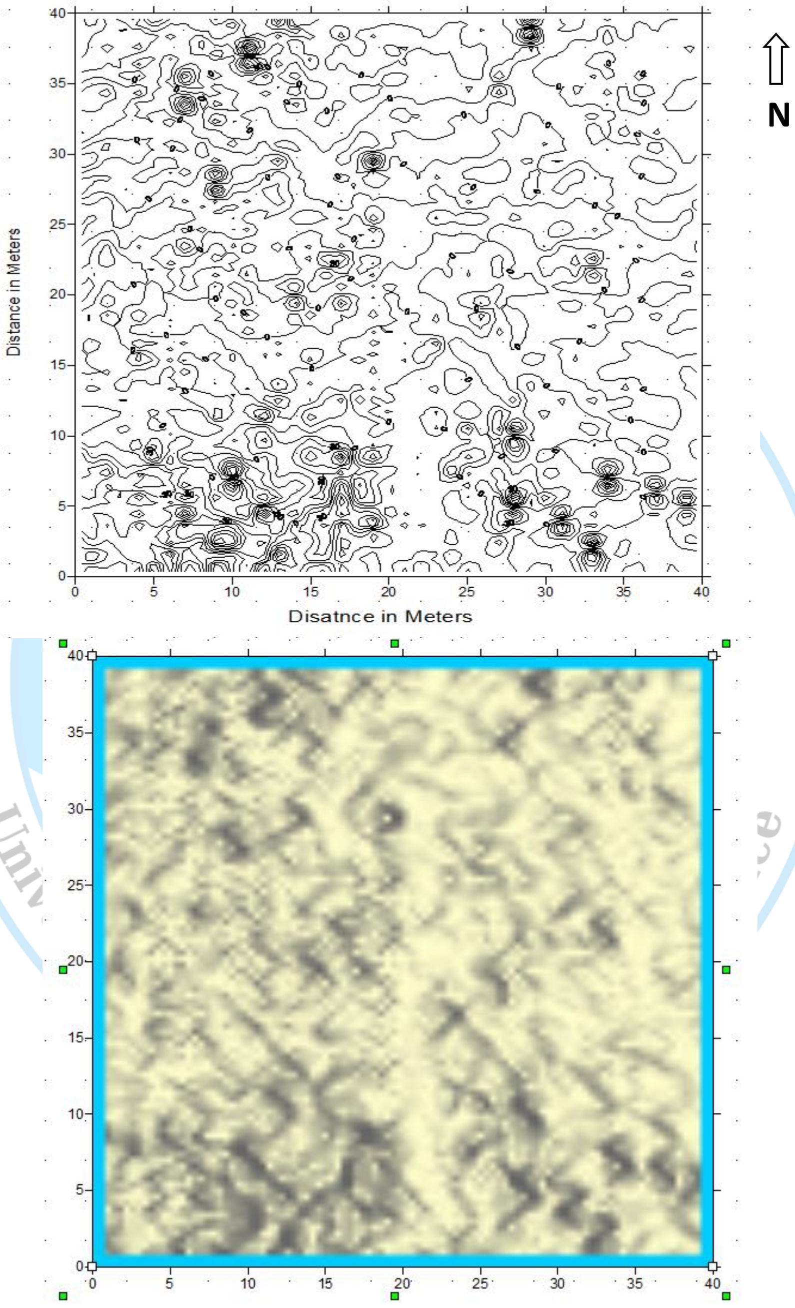

Figure 12: Magnetic anomaly map of area B (up) as a shaded relief map that shows the possible buried archeological features.

Conclusions

The geophysical studies of a chosen site at Babylon archeological city show the followings:

1. The electrical resistivity survey using VES methods is not suitable for detecting the ground water table in Babylon old city site. This is mainly due to lateral non-homogeneity of the soil and the near surface archeological ruins features.
2. The GPR survey method did not give a good penetrating depth at the chosen hill site. The survey was done using different frequencies and at different climate conditions within a year. The top soil resistivity is too low at the studied area, which resulted in high attenuation for the radar signals. On the other hand, the resistivity VES points that were distributed all around the Babylon old archeological city showed that the top soil resistivities are different from a place to another. Therefore, the GPR method may give a good result for those areas with high resistivity.
3. The magnetic survey that was carried out using cesium magnetometer of high sensitivity has showed interested results at Babylon old city. At the chosen hill site (140m x 240m) the effect of north-south traverses was noticed. A detailed magnetic survey of 1.0 x 1.0-meter grid was carried out for a small area (40.0 x 40.0 meters). The survey was done in two directions (S-N and W-E). Difference in the shape of the anomalies were noticed. These differences are removed by applying directional first derivative filter, i.e. the effect of the traverse's trends can be solved by the directional filters.
4. The magnetic anomalies map shows subsurface features that are probably corresponding to the buried walls. The mathematical modeling of some anomalies suggests buried walls of 0.3-0.4-meter thickness. The tops of these walls are at depth 0.8 meters. The height of these walls are around 1.5 meters. On the other hand, the mathematical models of the sharp magnetic anomalies suggest it could be corresponding to buried poles, which are constructed from basic igneous rocks.

5. The magnetic anomalies map of area B (40.0 x 40.0 meters) shows buried archeological walls of geometric distribution that could correspond to buried buildings, rooms and passageways.

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