GEOPHYSICAL EXAMINATION OF THE CHRISTIAN ARCHAEOLOGICAL SITE EMMAUS-NICOPOLIS (CENTRAL ISRAEL)

L. V. Eppelbaum [a, *], S. E. Itkis[b]

[a]Dept. of Geophysics and Planetary Sciences, Raymond and Beverly Sackler of Exact Sciences, Tel Aviv University, Ramat Aviv 69978, Tel Aviv, Israel - lev@frodo.tau.ac.il
[b]Dept. of Geological and Environmental Sciences, Ben Gurion University of the Negev, Be'er-Sheva, Israel - itkis@bgumail.bgu.ac.il

KEY WORDS: Archaeology, Geophysics, Surveying, Application, Mathematics, Development, Interpretation, System

ABSTRACT:

Christian archaeological site Emmaus-Nicopolis is well known in the ancient and Biblical history. The site located halfway between Jerusalem and Tel Aviv, first built in the 5th century, over the site believed to be the place where Jesus appeared to two of his disciples after his resurrection. The Crusaders rebuilt it on a smaller scale in the 12th century. Two sites were examined by detailed magnetic investigations: (**A**) 25 x 40 m and (**B**) 10 x 24 m. Distance between the observation points was 1 meter, but not all points were accessible due to dense vegetation and rugged topography. Quantitative interpretation of magnetic anomalies was conducted using modern quantitative methods specially developed for complicated environments: oblique magnetization, rugged terrain relief and unknown level of the normal field. A distinct peculiarity of the survey was the fact that from these areas an upper part of soil (about two meters) containing modern contamination targets has been recently removed. A primary aim of this investigation was detection of buried ancient tunnels partially discovered at the eastern part of Emmaus-Nicoplis. However, performed survey allowing to revealing at least three high-intensive positive anomalies at the area A and one significant anomaly at the area B. Thus, all revealed anomalies (after removing 2m soil) must reflect some buried ancient remains. Determined depth of the upper edge of anomalous sources ranges from 0.7 to 1 m. Reliability of performed quantitative interpretation was successfully confirmed by 3-D modeling of magnetic field. The obtained results (they may have a great archaeological importance) were transmitted to archaeological group working at this site. The proposed ancient targets will be archaeologically inspected at the nearest time (apparently, until October 2003).

1. INTRODUCTION

The territory of Israel, in spite of comparatively small dimensions (21,000 km^2), is very attractive for archaeologists taking into account its dramatic ancient and Biblical history. It is undisputable fact that location of archaeological sites at Israeli territory is the densest in the world (for instance, Meyer, 1996; Reich, 1992). Christian remains consist of significant part of the total number of discovered archaeological objects. The Christian remains, according to the accomplished experience, occur in the subsurface layer at depth from 0 to 3 meters and often hold their initial correct (quasi-correct) geometrical form. Detailed magnetic survey is successfully applied to searching and localization of the remains, as rapid, effective and non-invasive tools for revealing a broad range of various targets: buried walls, columns, foundations, underground tunnels, chambers, water pipe systems and high temperature features (Dalan, and Banerjee, 1996; Eppelbaum, 2000; Frese and Noble, 1984; Herwanger et al., 2000; Weymouth, 1996). Geophysical surveys provide a ground plan of cultural remains before excavations or may be even used instead of excavations. Road and plant construction, selection of areas for various engineering and agricultural aims are usually accompanied by detailed geophysical (first of all, magnetic) investigations. Such investigations should help estimate the possible archaeological significance of the area under study. Rapid (first results may be obtained during a few hours − several days) and reliable interpretation of magnetic data should provide protection of archaeological remains from unpremeditated destruction.

Interpretation of magnetic surveys in Israel is complicated by a strong oblique magnetization of the Earth's magnetic field (about 42-44^o). The multi-layered and variable structure of the upper part of the geological section (Dan, 1988; Rabikovitz, 1992) often does not allow calculating the level of the normal magnetic field within the studied sites. Noise caused by industrial iron and iron-containing objects sometimes reaches high values. Rugged relief also disturbs the effect from the buried objects and complicates quantitative interpretation of magnetic anomalies (Eppelbaum and Khesin, 2001). The complicated conditions of the survey require application of sophisticated magnetic equipment, advanced methods of qualitative and quantitative interpretation as well 3-D modeling of magnetic field. The developed methods (Eppelbaum et al., 2000b; Khesin et al., 1996) allowed to eliminate noise, to reveal archaeological remains and calculate their depth and size, and to conduct an accurate 3-D modeling of magnetic fields.

Eppelbaum et al. (2003b) have shown an importance of correct mathematical formalization of geophysical/archaeological

* Corresponding author.

examination. The main role in the proposed algorithm plays a notion “information value”. Unfortunately, from the author’s experience follows that majority of geophysicists and archaeologists have troubles with accepting this approach.

Objects of archaeological study occur at a small depth and, consequently, the distance Δx between profile observation points usually varies from 20 cm to one meter. Distance Δy between profiles may not exceed Δx by more than three times and ideally Δy must equal to Δx. Selection of a magnetic sensor level (practically it ranges in interval of 0.1 - 3 meters) depends on the concrete archaeological/geological situation.

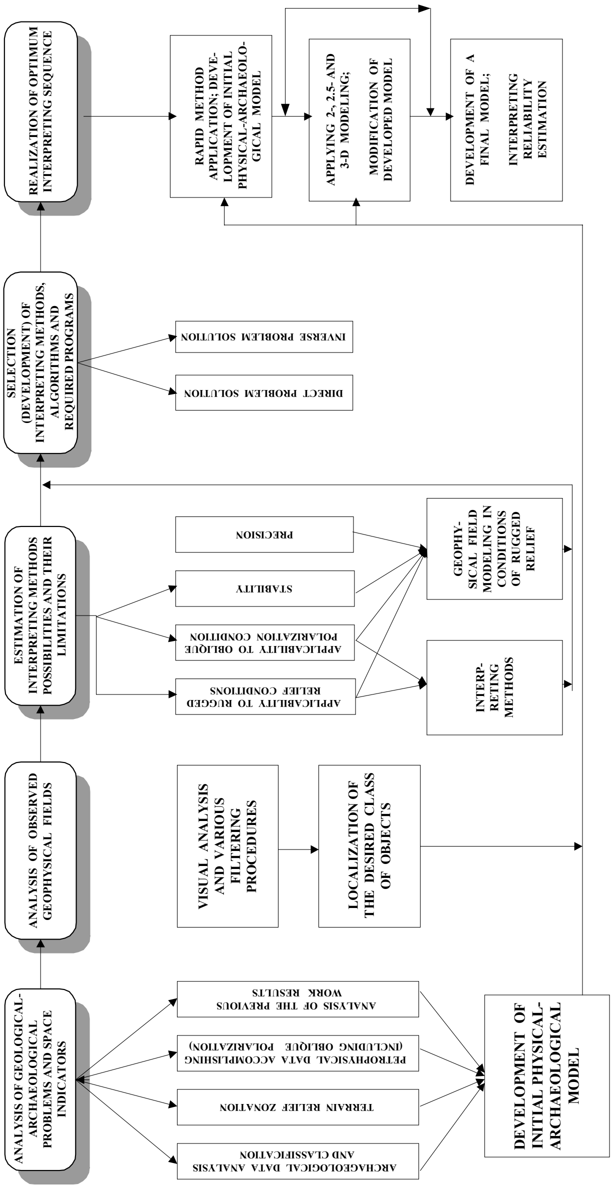

Figure 1. Flow-chart of geophysical data processing and interpretation at archaeological sites (after Khesin et al., 1996, with modifications)

According to our experience [Eppelbaum and Khesin, 2001; Eppelbaum et al., 2000a,2000b,2001,2003a] the general scheme of geophysical data processing and interpretation at archaeological sites may be composed using the following procedures presented in flow-chart (Figure 1).

Figure 2. Exposed remains of walls in the central part of Emmaus-Nicopolis site

2. BRIEF DESCRIPTION OF THE EMMAUS-NICOPOLIS ARCHAEOLOGICAL SITE

Christian archaeological site Emmaus-Nicopolis is well known in the ancient and Biblical history. The site (its fragment is shown in Figure 2) located halfway between Jerusalem and Tel Aviv, first built in the 5th century, over the site believed to be the place where Jesus appeared to two of his disciples after his resurrection. The Crusaders rebuilt it on a smaller scale in the 12th century (Mayer, 1996). Nicopolis is assumed in almost all Christian Pilgrim texts from the 4th century onward. In 221 C.E. the Emperor Elagabalus gave Emmaus the title of *city* and the name Nicopolis.

The primary aim of magnetic investigations at this site was detecting underground tunnels (caves) partially investigated at the eastern part of the area. However, purpose of our investigations was suddenly changed during the field exploration.

3. MAGNETIC EXAMINATION OF TWO SELECTED AREAS AT THE SITE OF EMMAUS-NICOPOLIS

3.1 Methodology of field magnetic observations

The magnetic survey at the site of Emmaus-Nicopolis have been carried out using following equipment:

- Proton Magnetometer MMP-203 (Era Assoc., Sankt-Petersburg, Russia), No. 206033 (it was used for field observations),
- Quantum Magnetometer MM-60 (Era Assoc., Sankt-Petersburg, Russia), No. 207001 (it was used for registering temporary magnetic variations at control point),
- Kappameter KT-5 (Scintrex, Canada) for magnetic susceptibility measurements.

Results of archaeological excavations and brief geological examination of the areas under study indicate that we have here two types of geological associations: soil (0 - 1.5 m) and underlying it limestone sometimes exposed at the earth's surface. A few tens performed measurements of magnetic susceptibility indicate that limestone is practically non-magnetic, and soil is characterized by magnetic susceptibility of 60-100 x 10^{-5} SI.

Detailed magnetic investigations were performed at two conjugated areas A and B (Figure 3). Unfortunately, small part of area A and significant part of area B have been not covered by magnetic survey (see Figure 3) due to zone of very dense vegetation (area A) and zone of rugged topography (area B).

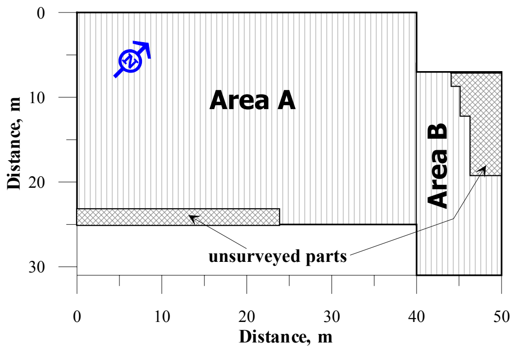

Figure 3. Location of two investigated areas

Magnetic sensor level, according to experience of previous works (Eppelbaum et al., 2000a, 2000b, 2003), was selected as 0.5 m above the earth's surface. Temporary magnetic variations were removed using conventional scheme (Telford et al., 1998).

Maps of the total magnetic fields over the areas A and B are presented in Figures 4 and 5, respectively. Mean-square error for magnetic observations at the area **A** was 1.85 nT and at the area **B** – 0.9 nT.

The most important peculiarity of this survey is that from the areas under study has been recently removed an upper part of soil (two meter thickness) containing all modern contamination. Thus, we can propose that three high-intensive anomalies observed at the area A (see Figure 4) and significant anomaly revealed at the area B (see Figure 5) are associated with the buried ancient remains.

3.2 Quantitative interpretation of magnetic anomalies

This stage involves application of methods for quantitative interpretation of magnetic anomalies for development of an initial physical/archaeological model. The developed methods

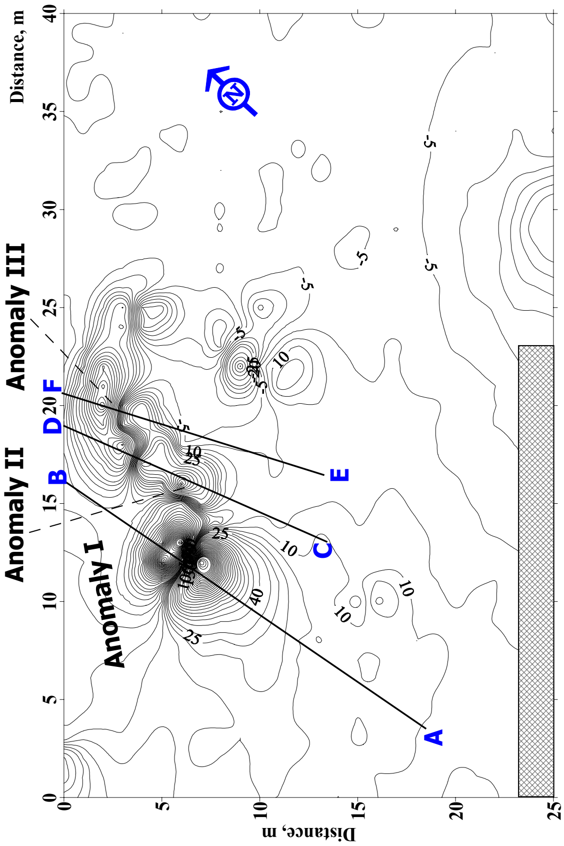

Figure 4. Map of the total magnetic field over area **A** at Emmaus-Nicopolis

(improved modifications of *characteristic point method* and *tangent method* are applicable in conditions of the rugged terrain topography, arbitrary direction of magnetization of the objects and unknown level of the normal magnetic field (Khesin et al., 1996). For quantitative interpretation of magnetic anomalies due to disturbing objects two geometric models were utilized: thin bed (Figures 6, 8 and 9) and horizontal circular cylinder (Figure 7). It should be noted that anomaly I (Figure 6) has a form close to ideal of theoretical anomaly due to a thin bed. By its interpreting was used so-called Reford's point (Reford and Sumner, 1964) showing a projection of the middle of anomalous object to the earth's surface. The disturbed upper part of anomaly II was smoothly reconstructed (dash line in Figure 7) for the more convenience interpretation. Anomaly III is also disturbed by some nearly occurred magnetoactive object(s). Anomaly IV of comparatively small intensity is registered in the vicinity of the proposed continuation of excavated underground tunnel. Determined depth of the upper edge of the targets ranges from 0.7 to 1 m.

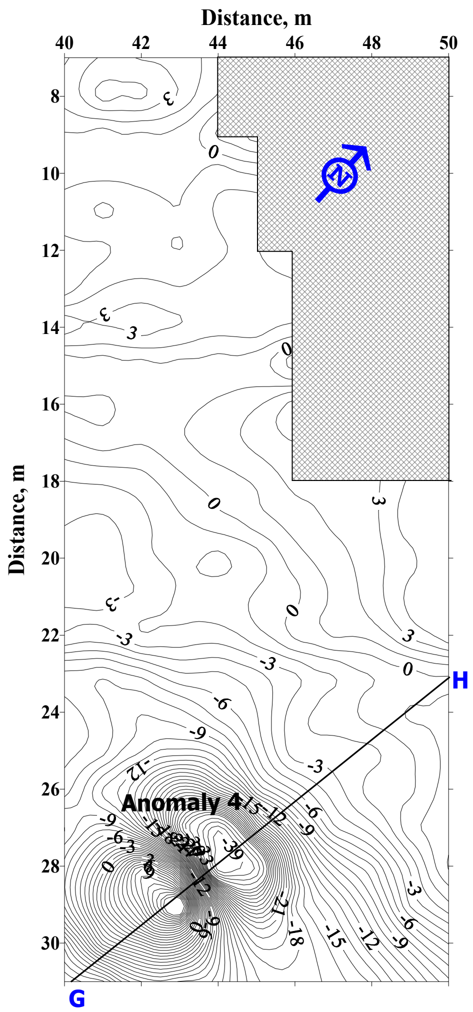

Figure 5. Map of the total magnetic field over area **B** at Emmaus-Nicopolis

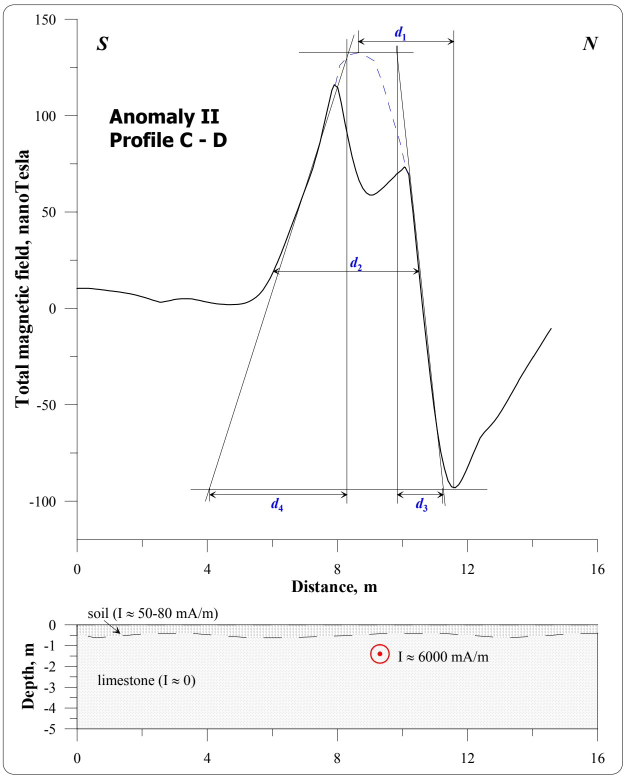

Figure 7. Quantitative interpretation of anomaly II (area A)

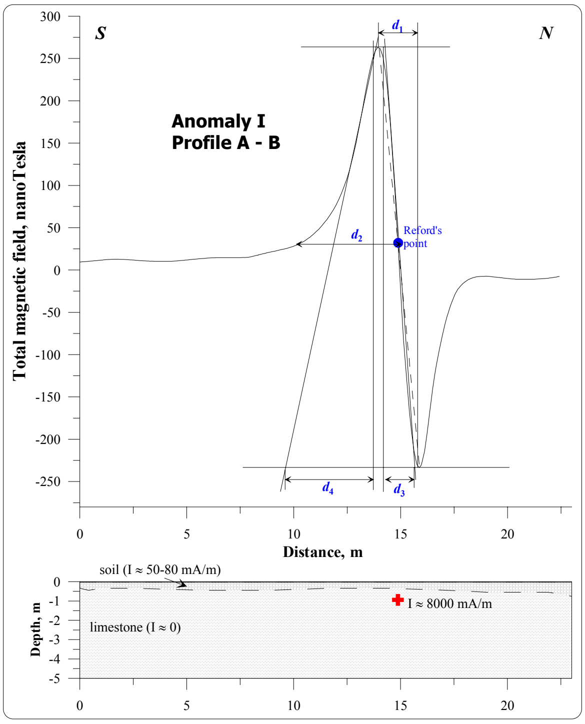

Figure 6. Quantitative interpretation of anomaly I (area A)

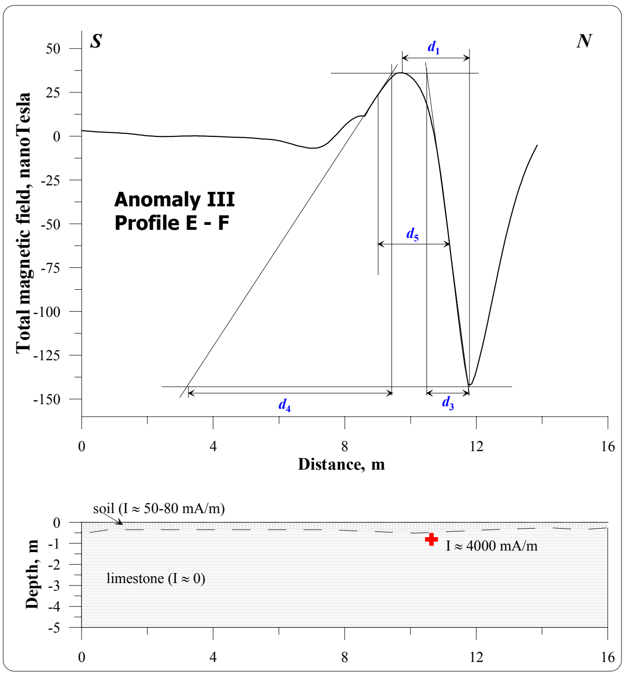

Figure 8. Quantitative interpretation of anomaly III (area A)

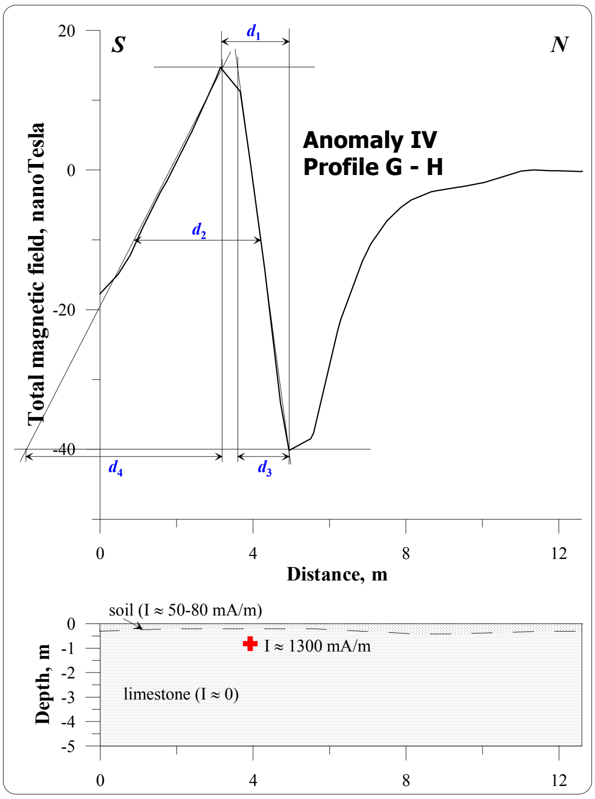

Figure 9. Quantitative interpretation of anomaly IV (area B)

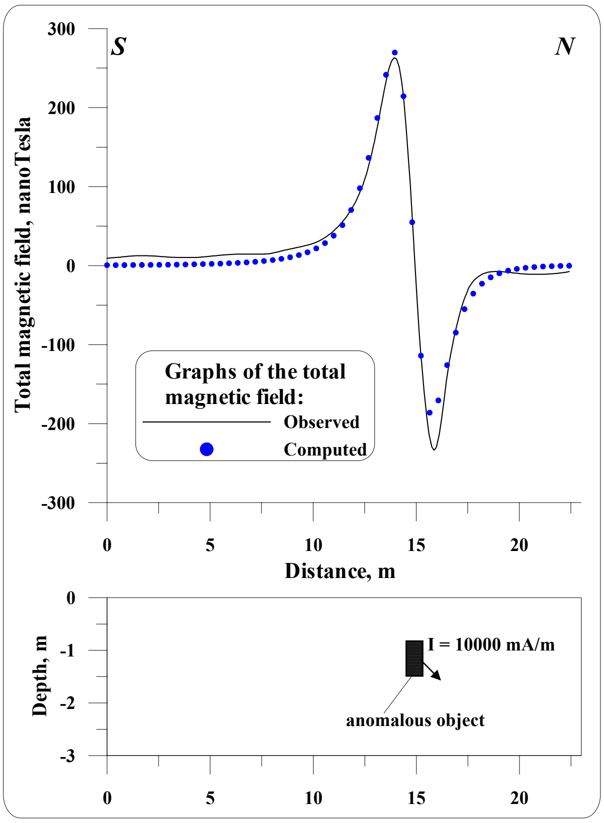

Figure 10. Results of 3-D modelling of magnetic field using *GSFC*-1 program. Arrow indicates the direction of magnetic vector

3.3 3-D modelling of magnetic anomalies

The GSFC-1 (*Geological Space Field Calculation*) program was developed for solving a direct 3-D gravity and magnetic prospecting problem under complicated geological conditions (Khesin et al., 1996; Eppelbaum, 2003). This program has been designed for computing the field of Δg (Bouguer, free-air or observed value anomalies), ΔZ, ΔX, ΔY, ΔT, as well as second derivatives of the gravitational potential under conditions of rugged relief and inclined magnetization. The geological space can be approximated by (1) three-dimensional, (2) semi-infinite bodies and (3) those infinite along the strike (closed, *L.H.* non-closed, *R.H.* non-closed and open). Geological bodies are approximated by horizontal polygonal prisms.

The basic algorithm realized in the *GSFC* program is the solution of the direct 3-D problem of gravimetric and magnetic prospecting for horizontal polygonal prism limited in the strike direction. In the presented algorithm integration over a volume is realized on the surface limiting the anomalous body.

Results of 3-D modelling of magnetic field produced by the buried target at area B have shown in Figure 10.

As initial model for the computing, the data obtained at the previous stage of quantitative interpretation (see Figure 6), were utilized. Figure 10 illustrates that observed and computed graphs gave an excellent agreement. Thus, good coinciding the observed and computed graphs proves the reliability of performed quantitative interpretation. Similar results were obtained and for anomalies II - IV.

Finally, Figure 11 shows an image of the examined area B at Emmaus-Nicopolis showing the projection of the upper edge of anomalous body to the earth's surface. On the basis of integrated analysis of geophysical and archaeological data we may suggest that this anomaly (see Figure 9) may be produced by some archaeological remain(s) containing in underground tunnel.

4. Conclusions

We can conclude that four analyzed magnetic anomalies with a high probability can correspond to buried archaeological remains. Despite of the fact that the recognized anomalies at the area A have more high intensity than the single anomaly at the area B, we propose that the last anomaly may have more important archaeological significance and it should be excavated for the first time.

Preferably, three magnetic anomalies displayed at the area A, must be examined also by conventional metal detector equipment.

The areas of geophysical examination must be extended to the west where also archaeological remains may be found.

References

Dalan, R.A. and Banerjee, S.K., 1996. Soil magnetism, an approach for examining archaeological landscapes. *Geophysical Research Letters*, **23** (2), pp. 185-188.

Dan, J., 1988. The soils of the land of Israel, *In: The zoogeography of Israel*, Y. Yom-Tov & E. Tchernov (Eds.), W. Junk Publishers, Dordrecht, pp. 95-128.

Eppelbaum, L.V., 2000. Applicability of geophysical methods for localization of archaeological targets: An introduction. *Geoinformatics*, **11**(1), pp. 19-28.

Eppelbaum, L.V., 2003. *Introduction to potential geophysical fields*. Handmanual for students, Tel Aviv University.

Eppelbaum, L.V., Itkis, S.E. and Petrov, A.V., 2000a. Physics and archaeology: magnetic field as a reliable tool for searching ancient remains in Israel. *Scientific Israel*, No.2, pp. 68-78.

Eppelbaum, L.V., Itkis, S.E. and Khesin, B.E., 2000b. Optimization of magnetic investigations in the archaeological sites in Israel. *Spec. Issue of Prospezioni Archeologiche, "Filtering, Modelling and Interpretation of Geophysical Fields at Archaeological Objects*", pp. 65-92.

Eppelbaum, L.V. and Khesin, B.E., 2001. Disturbing Factors in Geophysical Investigations at Archaeological Sites and Ways of Their Elimination. *Trans. of the **IV** Conf. on Archaeological Prospection*, Vienna, Austria, 99-101.

Eppelbaum, L.V., Khesin, B.E. and Itkis, S.E., 2001. Prompt magnetic investigations of archaeological remains in areas of infrastructure development: Israeli experience. *Archaeological Prospection*, **8**(3), 163-185.

Eppelbaum, L., Ben-Avraham, Z. and Itkis, S., 2003a. Ancient Roman Remains in Israel provide a challenge for physical-archaeological modelling techniques. *First Break*, **21** (2), pp. 51-61.

Eppelbaum, L., Eppelbaum V. and Ben-Avraham, Z., 2003b. Formalization and estimation of integrated geological investigations: Informational Approach. *Geoinformatics*, **14**, No.3, pp. 233-249.

Herwanger, J., Maurer, H., Green, A.G., and J. Leckebusch, 2000. 3-D inversions of magnetic gradiometer data in archaeological prospecting: possibilities and limitations. *Geophysics*, **65**, No. 3, pp. 849-860.

Khesin, B., Alexeyev, V. and Eppelbaum, L., 1996. *Interpretation of Geophysical Fields in Complicated Environments*. Kluwer Acad. Publisher, Ser.: Modern Geoph. Approaches, Dordrecht - London - Boston.

Meyer, E.M. (Ed.), 1996. *The Oxford Encyclopedia of Archaeology in the Near East*. 5 vols., Oxford University Press, Oxford.

Rabikovitz, S. 1992. *The Soils of Israel: Formation, Nature, and Properties*. Hakibbuts Hamehuchad Publishing House, Israel (in Hebrew), with 1:250,000 soil map of Israel (in Hebrew and English).

Reford, M.S. and Sumner, I.S., 1964. Aeromagnetics. *Geophysics*, **29**, No. 4, pp. 482-516.

Reich, R., 1992. *Architecture of ancient Israel*. Israel Exploration Society, Jerusalem.

Telford, W.M., Geldart, L.R. and Sheriff, R.E., 1998. *Applied Geophysics*. 5th ed. Cambridge University Press, Cambridge.

von Frese, R.R.B. and Noble, V.E., 1984. Magnetometry for archaeological exploration of historical sites. *Historical Archaeology*, **18** (2), pp. 38-53.

Weymouth, J.W., 1996. Digs without digging: exploring archaeological sites with geophysical techniques. *Geotimes*, Nov., pp. 16-19.

Figure 11. Photography of area B with projection of the proposed anomaly source to the earth's surface

Acknowledgements

The authors are grateful to Dr. K.-H. Fleckenstein and Mrs. L. Fleckenstein – working archaeological group at Emmaus-Nicopolis site – for very useful communications.