

A Large-scale Magnetic Survey in Makrygialos (Pieria), Greece

G. N. TSOKAS^{1,*}, A. SARRIS², M. PAPPA³, M. BESSIOS³,
C. B. PAPAACHOS⁴, P. TSOURLOS¹ AND A. GIANNOPOULOS¹

¹University of Thessaloniki, Geophysical Laboratory, P.O. Box 352-1, Thessaloniki 54006, Greece; ²National Airforce Academy, Dekelia Airbase, Tatoi, Athens 10000, Greece; ³Archaeological Museum of Thessaloniki, 6 Manolis Andronikos Street, Thessaloniki 54621, Greece; and ⁴Institute of Engineering Seismology and Earthquake Engineering, P.O. Box 53, 55102 Finikas, Thessaloniki, Greece

ABSTRACT A large-scale magnetic survey was conducted in the archaeological area of Makrygialos. The site was threatened due to the construction activities carried out in the area, as part of the national highway re-route project. Geophysical prospection contributed to the archaeological evaluation of the site, which was based mainly on the salvage excavations that took place prior to and after the geophysical survey.

Magnetic prospecting was applied on a routine base, in order to cover a large area in a short period of time. Also, magnetic susceptibility was used to acquire detailed information of the stratigraphy of the ditches revealed by the excavations. The Le Borgne contrast was calculated and was used as an index of the magnitude of the magnetic anomalies.

Geophysical data were processed by a number of filtering techniques, including the removal of regional trends and Hanning smoothing. Fourier transformation was applied and bandpass filtering procedure was based on the examination of the power spectrum of the data. In addition, two-dimensional inversion filtering was performed at specific parts of the data set, in an effort to rectify the significant geophysical anomalies of the site and obtain more information about their width and magnetization.

The results of the geophysical survey were able to highlight a system of three curvilinear ditches, which excavation data suggested were probably dug during the Neolithic period. Various linear and geometrical anomalies, related to subsurface structures, are included among the other geophysical features encountered at the site.

The geophysical prospecting techniques were able to map more than 60,000 m² of the site, a large portion of which has now been destroyed by the construction activities for the national road. In this way, geophysical maps can be used as a valuable source of information for the future study of the site. The present case study illustrates the impact of geophysical exploration in the management of archaeological sites threatened by large-scale construction projects.
© 1997 John Wiley & Sons, Ltd.

Archaeol. Prospect. 4: 123–137, 1997.

No. of Figures: 11. No. of Tables: 0. No. of Refs: 31.

Key words: magnetic survey; Fourier transform; bandpass filtering; Neolithic; Makrygialos

Introduction

A large-scale magnetic survey was conducted in the archaeological area of Makrygialos. The

archaeological evaluation of the site was based mainly on the salvage excavations that took place prior to and after the geophysical survey. The results presented in this paper enable the tracing of features discovered previously. Also, several other features were spotted and thus a contribution to the archaeological evaluation was possible. The area of Makrygialos constitutes one of the

*Correspondence to: G. N. Tsokas, Geophysical Laboratory, University of Thessaloniki, P.O. Box 352-1, Thessaloniki 54006, Greece.

most active regions in Greece in terms of archaeological excavations that have taken place for the past 20 years. The location of the site is shown in Figure 1(A and B). The city of ancient Pydna is the predominant site of interest in the area. Pydna used to be the most important port of the Macedonian Kingdom during the fifth century BC (Bessios, 1989, 1990, 1995a). The site lies in the middle of the road connecting the Thessalian and Macedonian plains, and the current archaeological and geophysical research have shown a multiple occupation of the site spanning from the Late Neolithic Period to the Byzantine Era.

The fortified settlement of the ancient city lies south of the modern village of Makrygialos (Bessios, 1988, 1995b). A number of large-scale rescue excavations have been conducted in the area as the construction of the new railroad, the new highway connecting Thessaloniki to Katerini and the construction of the natural gas pipe comprised an enormous threat to the cultural monuments (Bessios, 1992). South of Korinos, the natural gas pipe crossed the settlement of the Late Classical/Early Hellenistic Period. The second re-route of the national road coincides with a Roman cemetery site at the entrance of Katerini and a Bronze Age cemetery site at Korinos. The railway line also coincided with a Late Bronze Age–Roman Period settlement site north of Korinos and also sites of Classical, Hellenistic, Roman cemeteries and a Neolithic settlement site in Makrygialos (Bessios, 1987, 1988, 1991, 1992).

Some of the rescue excavations were financed by the construction companies and brought to light a number of important archaeological finds. A large-scale excavation was carried out in the area west from the Makrygialos village and yielded an extended late Neolithic settlement, the largest one of this period ever discovered in Greece (Bessios, 1995b; Bessios and Pappa, 1993, 1994, 1995, 1997; Pappa, 1996; Pappa and Bessios, 1997). The excavation of the prehistoric settlement covered about 10 per cent of the estimated size of the settlement. The settlement is badly preserved due to processes of erosion.

The geophysical search was concentrated along the path of the second re-route of the national highway, which passes tangential to Makrygialos village (Figure 2). The search was expanded in

the area between the new and the old national roads in order to investigate the limits of the site (Tsokas, 1993; Sarris and Jones, 1998). Finally, more areas were covered in the region east of the new highway and near the construction works of the railway route, with the goal of adding more information on the remnants of the prehistoric settlement.

Data acquisition

Magnetic prospecting was applied in a systematic way, in order to cover a large area in a short period of time. Two proton magnetometers (SCINTREX MP-2 and Geometrics G856, both with resolution of 1 nT) were used for the measurement of the total magnetic field. The increased levels of noise due to the traffic nearby limited the use of magnetic techniques along the direction of the new re-route. Nevertheless, magnetic techniques were used successfully in the area between the new re-route and the old national road, as well as in the area extending to the east of the first re-route (Figure 2).

Magnetic measurements were carried out using a base station magnetometer, which kept track of the Earth's magnetic field variation every 15 s in an automatic mode (Weymouth and Lessard, 1986). The spatial variation of the total field was measured along profiles spaced 1 m apart from each other, stepwise at 1 m intervals. The magnetic sensor was fixed at 0.3 m above the ground surface. A number of subgrids were established in each location in order to facilitate the daily data collection. As an example, the lay out of the subgrids for the location LBDAN is shown in Figure (3).

Time interpolation techniques were incorporated for the correction of the magnetic measurements due to the diurnal variations of the Earth's magnetic field.

In the central part of the region explored, excavations have discovered a number of ditches. In a particular location marked as A in Figure 2, the magnetic susceptibility was measured in the horizontal and vertical directions of an ancient ditch that showed up on an archaeological section. The ditch was 3 m deep and 7 m wide, and sampling was conducted every 1 m. The

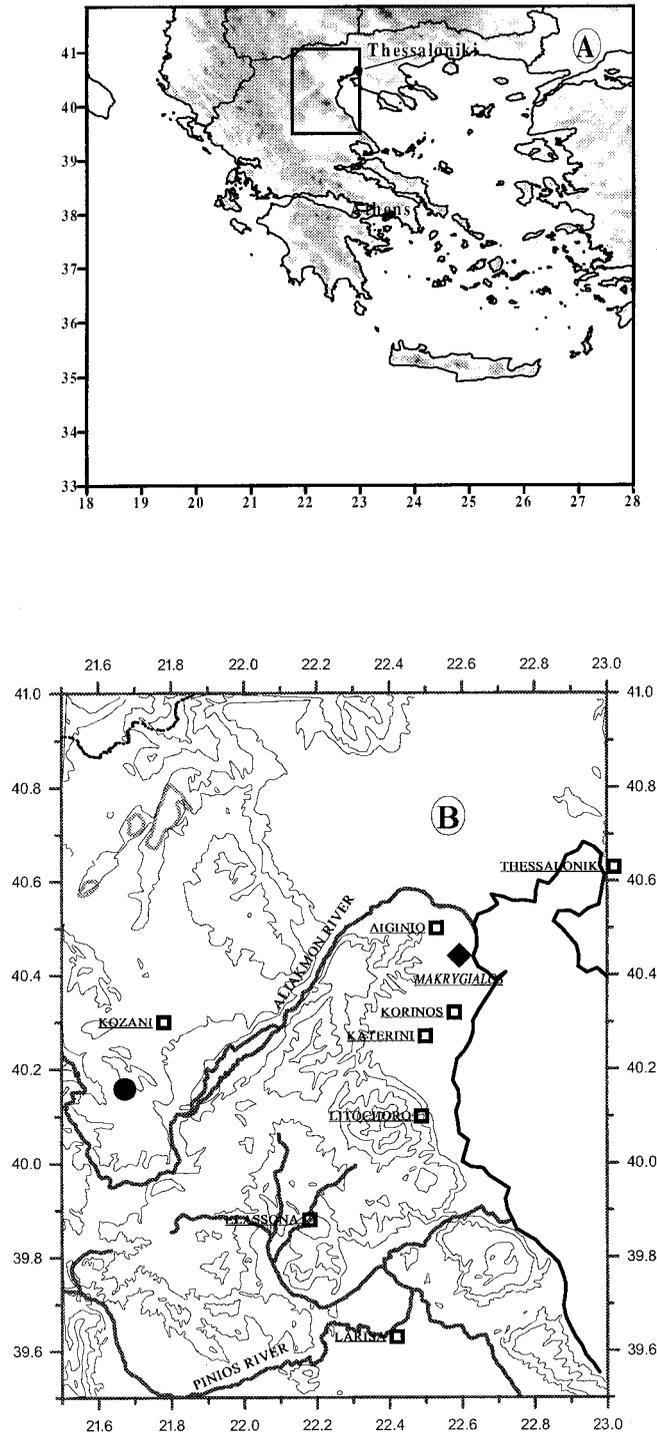


Figure 1. (A) Location of the Makrygialos area in the Balkan Peninsula. The major area around Makrygialos is enclosed by the solid rectangle. (B) The village of Makrygialos (denoted by diamond) is located in North Greece and bears significant archaeological sites, ranging in age from the Prehistoric to the late Byzantine era. The construction projects that are currently in progress in the area have encountered many archaeological sites and threaten them by destruction. The present paper deals with the magnetic prospecting carried out at the site of a large Prehistoric settlement. Map coordinates are in degrees of longitude and latitude.

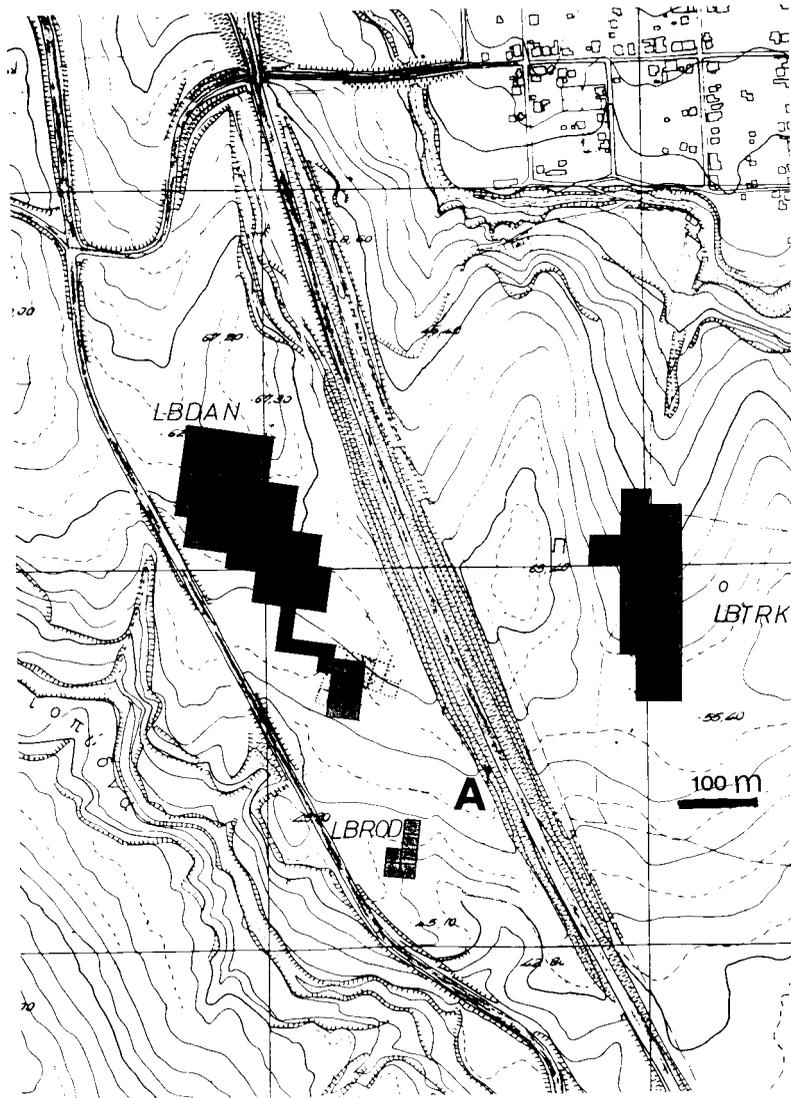


Figure 2. The old national road from Athens to Thessaloniki is the westernmost one shown on this map. The main one shown on the map, along the workings which cut the contours of the central hill, is the new national road. The second re-route, which converts the road into a highway, is adjacent to the west of the old road. The magnetic measurements were taken on grids established in the locations denoted as LBDAN, LBROD and LBTRK. The area LBTRK in particular is very close to the construction works of the railway route.

eastern section of the ditch and the profiles where the susceptibility was measured are shown in Figure 4. The ditch has been dug in a clayish soil and was filled by a similar material, which can be distinguished easily at the surface due to differentiation in colour and the microfractures of the soil matrix. Measurements of the magnetic susceptibility were conducted in the field with a KT3 susceptibility meter. From these measurements, the 'Le Borgne contrast' and the 'normal-

ized Le Borgne contrast' were inferred. This was done because the difference between topsoil (0–30 cm) and subsoil susceptibility can confirm stratigraphic observations of the intensity of habitation of an ancient site. The Le Borgne contrast (LBC), i.e. the vertical variation of the susceptibility ($\chi_{\text{topsoil}} - \chi_i$) varies with the grain-size distribution and the dilution factor. The enhancement of susceptibility versus depth, in correlation to stratigraphy, can identify

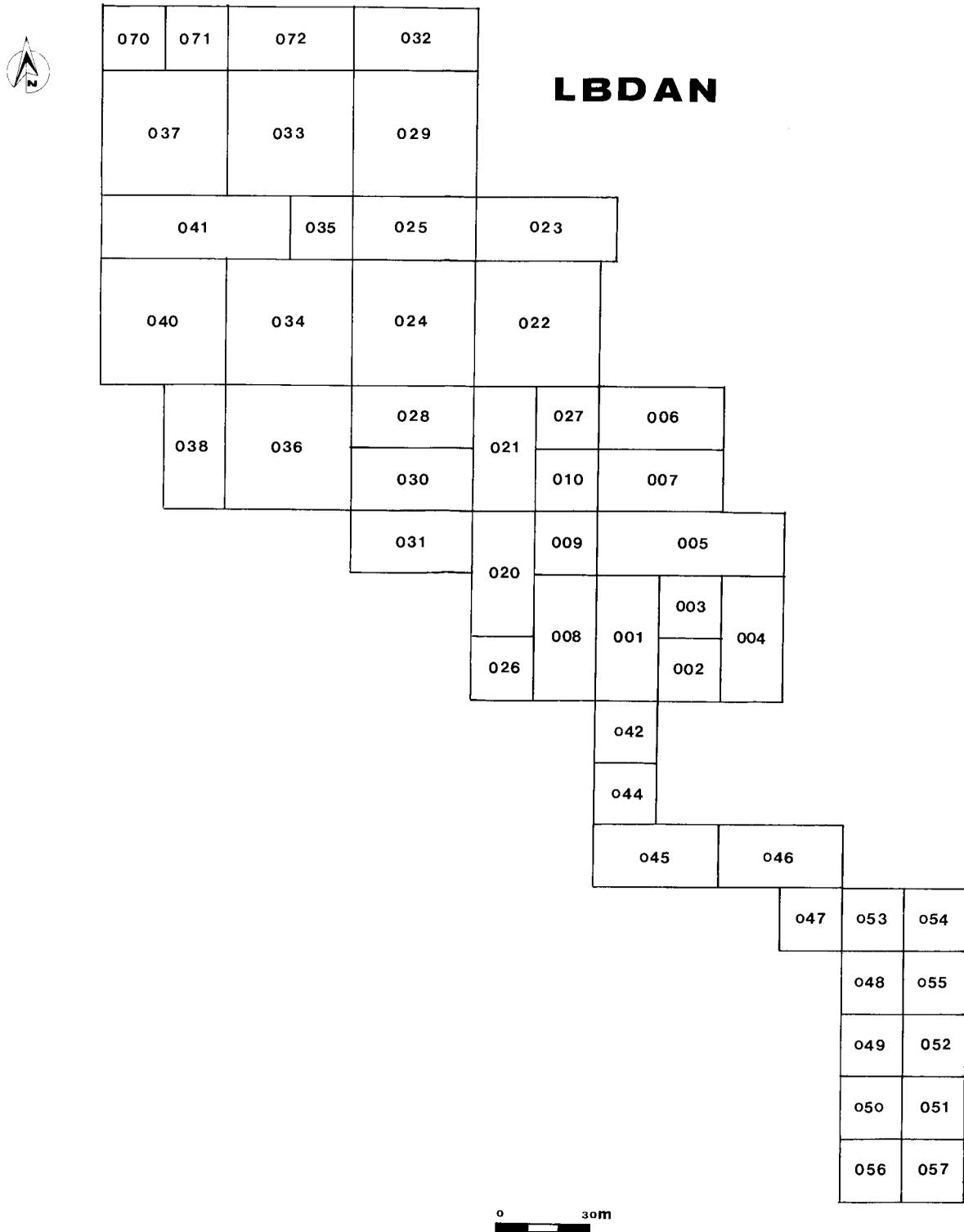


Figure 3. The subgrids that constitute the surveyed area denoted as LBDAN in Figure 2. Subgrid 24 was chosen for the demonstration of the log power spectrum manipulations.

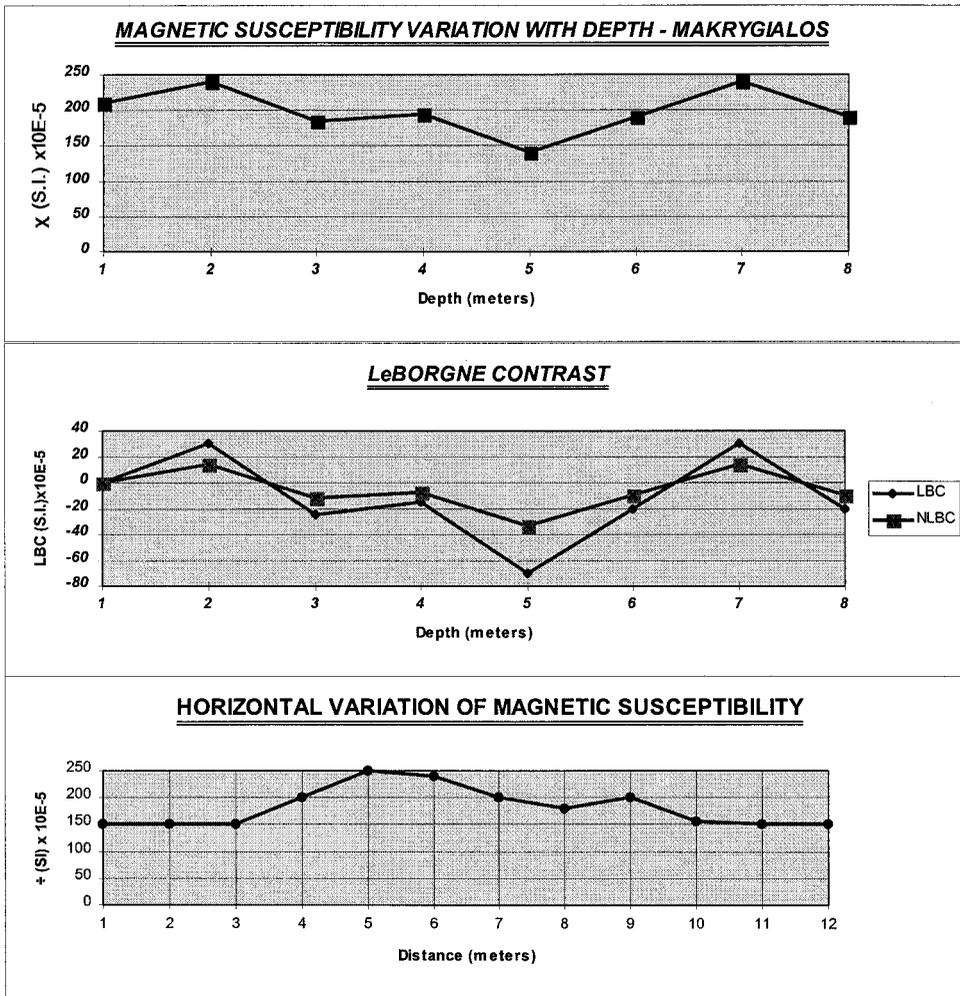
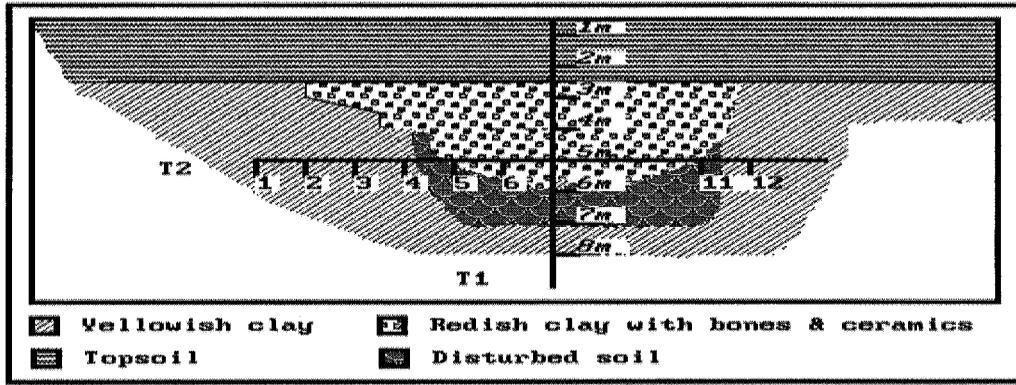


Figure 4. Sketch map of the eastern side of the pit dug in the location denoted as A in the map of Figure 2. The magnetic susceptibility was measured along a vertical and a horizontal traverse. The results along the Le Borgne contrast are depicted in the graphs of the lower part of the figure. It is evident in the lowermost graph that the fill of the ditch has higher susceptibility than the undisturbed subsoil by about 50–100 units. The variation of the susceptibility with depth shows that it does not vary significantly down to a depth of 4 m, i.e., the ditch fill has about the same susceptibility as the topsoil. A horizon of relatively raised susceptibility appears at about 7 m depth, which is consistent with the existence of a magnetic source at that depth indicated by the power spectrum.

the duration and intensity of an occupation level. In the case of small surface variations with abnormal high background susceptibilities, the normalized Le Borgne contrast (NLBC), defined as the ratio of the Le Borgne contrast to the topsoil susceptibility, can be used as an indication of the signal-to-noise ratio in a particular site.

The variation of the Le Borgne contrast or the normalised Le Borgne contrast (Le Borgne, 1955; Sarris, 1992, 1994) with depth (Figure 4) was in perfect agreement with the different layers of the section of the ditch. However, the susceptibility does not seem to vary significantly with depth. Therefore, the ditch fill should have about the same susceptibility as the topsoil. A layer of relatively higher susceptibility magnitude appears at a depth of 7 m. This is consistent with the power spectrum depth estimates, which will be presented in the next section. Useful conclusions also have been reached from the results of the measurements along the horizontal transect of the ditch. The infilling soil shows a change of magnetic susceptibility levels by 50–100 units. The topsoil has also increased levels of susceptibility due to the current cultivation activities and the prolonged occupation of the region (Tite and Mullins, 1971).

Processing

Processing of the data was standardized in order to produce maps that could be matched easily with the topographic and archaeological maps. De-spiking by median filtering was successful in eliminating peaks due to instrumental noise. Neighbouring average and Hanning smoothing, followed by the removal of geological trend, was capable of showing a more representative picture of the subsurface relics. A correction factor was applied to all grids in order to produce a better mosaic of the areas consisting of a large number of grids (Sarris, 1992).

Two-dimensional power spectra were calculated for each subgrid after the fast Fourier transformation of the data using the Singleton algorithm (Singleton, 1967). The corresponding one-dimensional power spectra were calculated by azimuthal averaging. Based on the above results, bandpass filters were constructed and applied in the frequency domain (Spector and

Grant, 1970; Mishra and Naidu, 1974). An example is shown in Figures 5 and 6, where the raw total field data and their logarithmic azimuthally averaged power spectrum are shown, respectively. The sample subgrid contains the anomalies produced by two elongated features, one bent and the other apparently straight. The effect of the bent one creates the peak at about 0.8 rad m^{-1} of the log power spectrum, which corresponds to a wavelength of about 8 m. Also, another peak at about 1.4 rad m^{-1} represents the anomaly of the relatively narrow and apparently straight ditch. The other peaks at the lower wavenumbers ($\lambda \approx 15.7 \text{ m}$) reflect deeper sources. Thus, the appropriate filters can be easily designed in order to enhance the elongated dominant anomalies.

The depth estimates constitute another benefit of the spectral analysis. According to Spector and Grant (1970) the slopes of the linear segments of the log power spectrum multiplied by a scale factor give the depth to the top of the magnetic sources responsible for the particular segments. The spectrum of Figure 6 yields three magnetic sources lying at 0.35, 2.5 and 6.7 m depth. Presumably, the first one reflects the magnetic topsoil, if we take into account that the sensor was placed 0.3 m above the ground level. The source at 2.5 m depth corresponds to the ditches, a fact that was verified at the existing archaeological pits and is in excellent agreement with the depth shown in Figure 4. Also, the deeper source should represent the layer described as disturbed soil in the same figure.

Image processing techniques were applied for a better representation of the geophysical data. Resampling techniques were able to increase the number of pixels for a better representation of the image. A weighted average based on the neighbourhood values was used as the index of brightness for each pixel. Finally, the dynamic range of measurements has been adjusted interactively in order to give emphasis to the weak anomalies of the data (Scollar *et al.*, 1986). Further filtering including edge enhancement and high-pass filtering has been able to improve the image of the geophysical data (Burt, 1983).

Figures 7, 8 and 9 show the final result for the locations LBDAN, LBROD and LBTRK after applying the processing scheme described above.

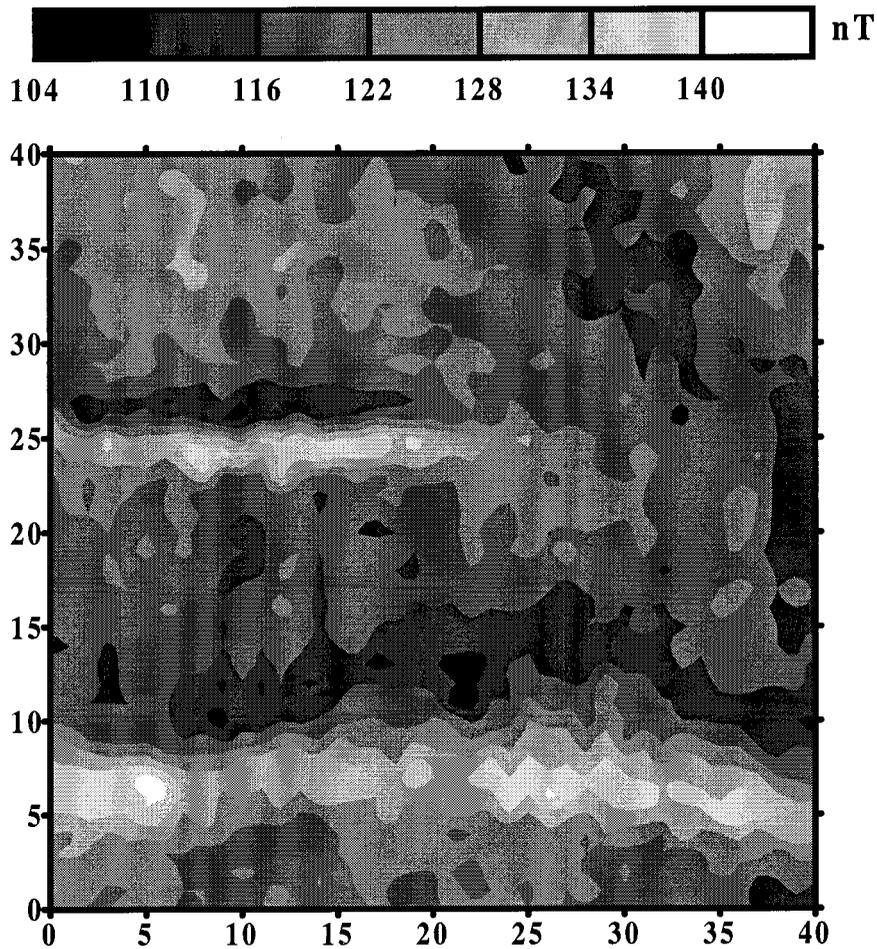


Figure 5. The raw data of subgrid 24. Two elongated anomalies dominate the map, which presumably are caused by two concealed ditches. The data displayed was collected from a 40 m \times 40 m survey square.

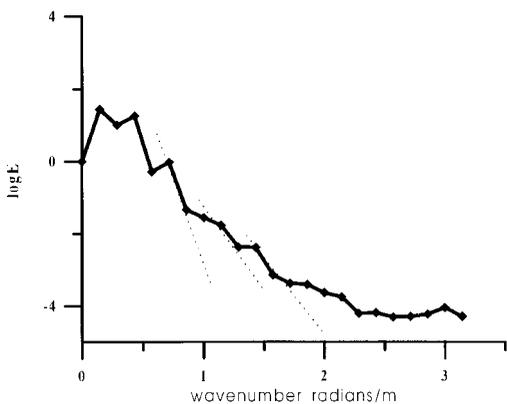


Figure 6. The logarithmic power spectrum of the total magnetic field distribution encountered in the subgrid 24 (Figure 5). Azimuthal averaging has been performed in the wavenumber domain. The dashed lines represent the linear segments fitted to the power spectrum curve to yield depth estimates.

Results

The large area named LBDAN lies between the old national road and the new highway (Figure 2). Although the area is clear of magnetic sources and external noise, measurements were collected during the days of low traffic because it is in the vicinity of the old national road. An area of 38,400 m² was covered and the result after processing is shown in Figure 7. A number of long positive curvilinear anomalies extending for more than 120 m are present in the central and northern part of the map. The southern anomaly (A in Figure 7) was interpreted as representing a ditch (ditches posing as negative anomalies are rather rare, e.g. Munro and Papamarinopoulos, 1978). The ditch seems to belong to the same

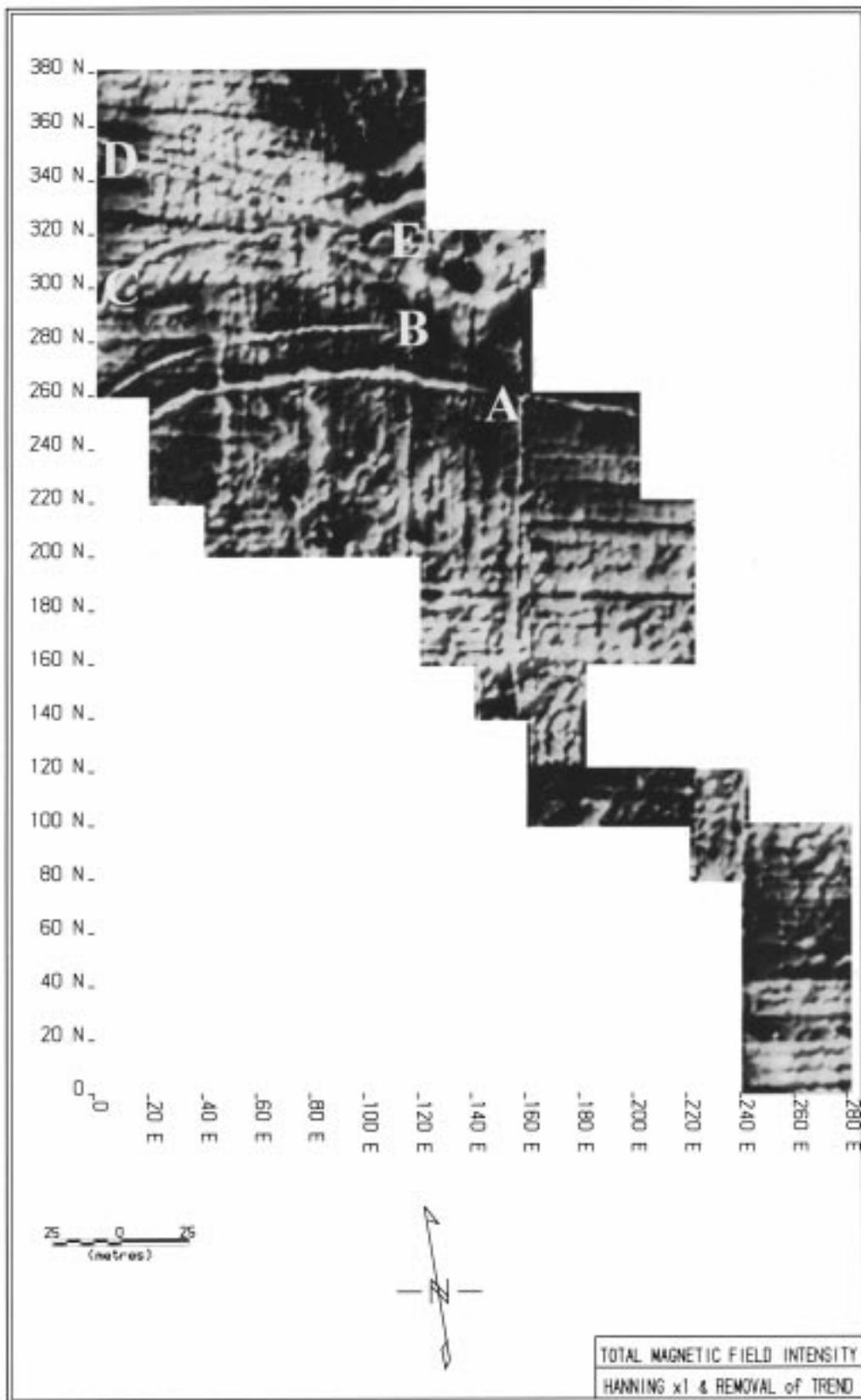


Figure 7. Spatial distribution of the magnetic total field for the location LBDAN after processing of the data and transformation to image form. The linear offsets in the data between subgrids 44, 45 and 46 is due to incorrect edge matching between them.

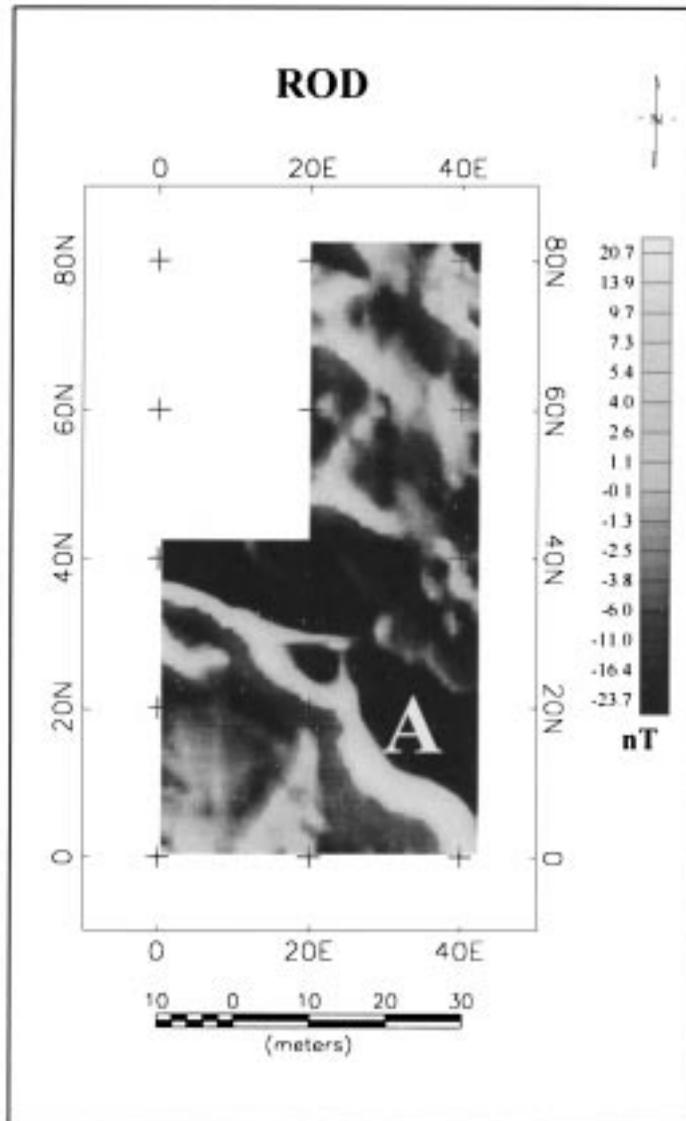


Figure 8. Spatial distribution of the magnetic total field for the location LBROD after processing of the data and transformation to image form.

configuration of ditches that were discovered along the new re-route and during the construction of the railway line, east of the new national road. To the north, another curvilinear anomaly marked as B in Figure 7, parallel to the first, reflects a concealed structure that is more magnetic than the host environment. Further north, a third curvilinear anomaly, of greater curvature than the previous anomalies, is present 40 m away from the latter anomaly and it is annotated with a C. The positive character of the anomalies

(~15–20 nT) is justified due to the filling of the ditch with topsoil, which has relatively higher magnetic susceptibility, as inferred by the measurements presented in Figure 4.

The northern part of the region is dominated by a linear anomaly, probably indicating that a segment of an ancient road or even a ditch of a different time period is concealed there. This anomaly is denoted with the letter D in Figure 7. However, the position of this linear feature leaves space for speculation that is due to a road of the

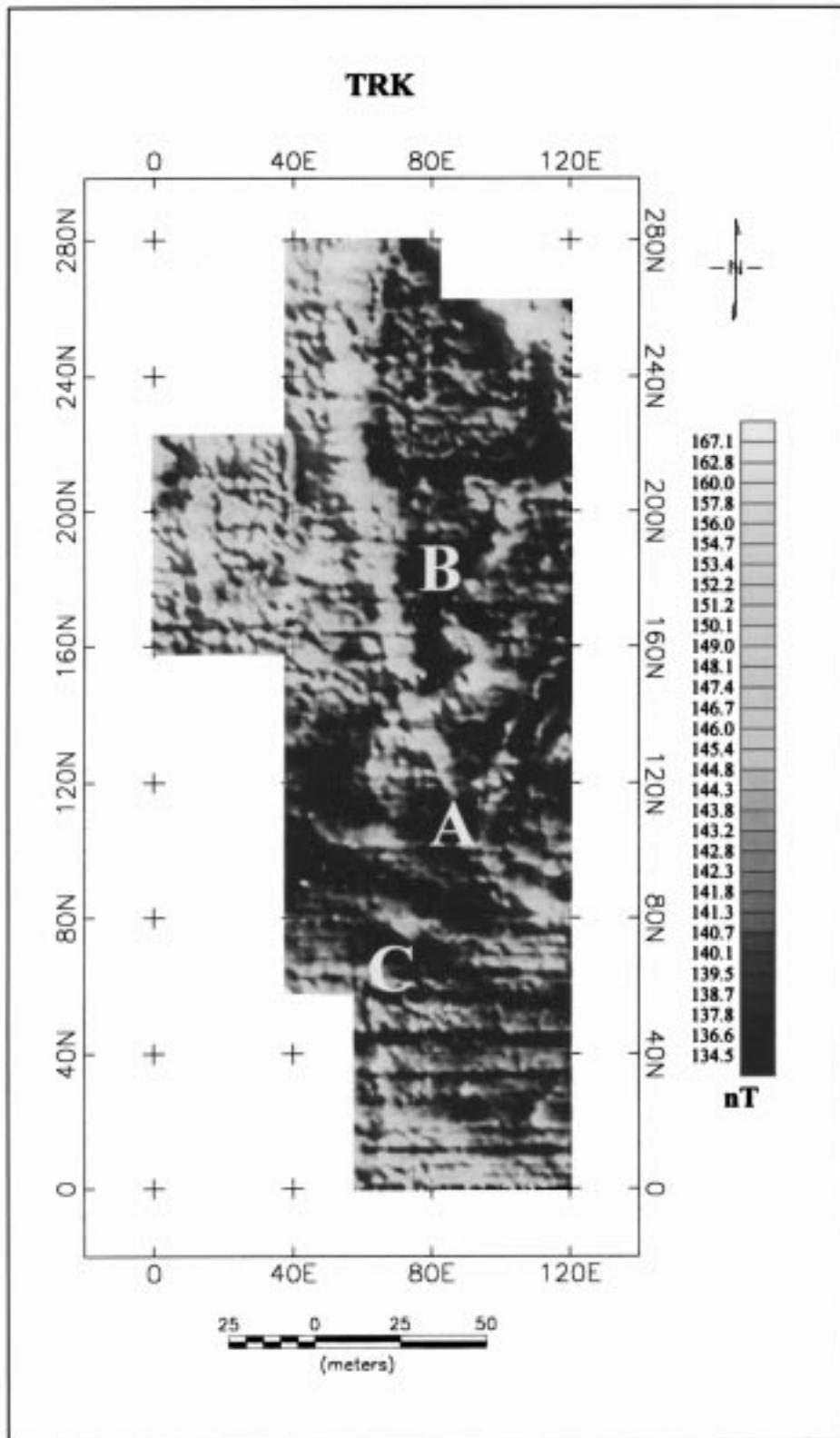


Figure 9. Spatial distribution of the magnetic total field for the location LBTRK after the processing of the data and transformation to image form.

Roman era or perhaps even older. On the south-east side of the above anomaly, a strong, well-shaped positive anomaly appears (E). It seems that the structure creating this anomaly also has a strong remanent magnetization. The anomaly may well be a kiln. The central and southeastern parts of the area LBDAN are dominated by a number of small-amplitude anomalies, possibly pits or small circular structures.

At the southern part of the location LBDAN, the small area named LBROD was scanned in an effort to locate the southern limits of the site (Figure 8). A linear anomaly appears in the southern part of the area, consisting of two branches that have been transposed in a parallel manner. The anomaly is marked by an A in Figure 8. It is of positive nature, and its strength is approximately 50 nT. It is probably related to a ditch, possibly used as one of the southern defences of the settlement.

Finally, magnetic prospecting applied in the area extending east of the national road, in the vicinity of the construction works for the railway line (LBTRK). An area of 22,300 m², has been investigated and a number of anomalies have been recognized in the map of the magnetic data (Figure 9). A prominent curvilinear anomaly extends to the north following a N-NW path and it is marked by an A in Figure 9. A similar helical anomaly is superimposed on the first (B in Figure 9), indicating different habitation levels. A number of circular, small wavelength anomalies can be attributed to pits or other related structures. The letter C in the figure locates one of them.

Two-dimensional inversion filtering (Tsokas and Papazachos, 1992) was also applied to a part of the magnetic data. The process is based on the construction of the least-squares filter created by a rectangular model (McGrath and Hood, 1973). The convolution of the filter with the magnetic data has been successful in reconstructing the outline of the corresponding structures, a method that has proved valuable on other sites.

Figure 10 shows the result of inverse filtering applied to the data of the subgrid 24 of the location LBDAN. The data were first subjected to de-spiking and light smoothing by a three-points averaging operator (Figure 10A). The two parallel ditches discussed earlier produce the anomalies

marked as d1 and d2. Then, low-pass filtering was applied using the software designed by Hildenbrant (1983). The cut-off threshold was put at 11 m and the roll-off ramp was extended up to 9 m. The filtered data are shown in Figure 10B, where the elongated anomaly of the relatively narrower ditch (d1) has been removed.

The inverse filter was then computed by inverting the effect produced by a vertical sided rectangle with a depth of 2 m and a cross-section of 2 × 2 m², and its upper surface is buried at 2 m depth. The existence of induced magnetization only was assumed. Convolution of the inversion filter with the low-pass filtered data yielded the image of Figure 10C. This image can be viewed as mapping the spatial distribution of magnetization of the subsurface (Tsokas and Papazachos, 1992) at a zone between 2 and 4 m depth. Thus, the exact course of the ditch labelled as d2 can be delineated and its width can be assessed to range between 5 and 7 m.

Bandpass filtering was then performed, again on the de-spiked and smoothed data, putting the high- and low-pass thresholds at 4 and 14 m respectively (roll-off ramps at 3 and 15 m). This was done in order to clear the effect of the narrower ditch from the long wavelength variations and the high-frequency noise simultaneously. A new inverse filter was then designed based on the effect of a rectangular vertical-sided prism of depth extent 1 m and cross-section of 1 × 1 m², buried at 2 m depth. The convolution of this filter with the bandpass filtered data resulted in image of Figure 10D. In this picture, the anomaly of the small ditch (d1) has been reinstated, giving the exact lateral extent of the concealed feature. Its width is concluded as being about 3 m.

The dimensions and features predicted here were verified by subsequent excavation. However, in order to investigate further the efficiency of the inversion scheme applied, we divided the outcome for the ditch d2 by the normal undisturbed field of the area. That is, the magnetization distribution of Figure 10C was divided by the value of 46,100 nT, which represents the value for the normal field encountered by the base stations set in the area for the needs of the project. The result represents the susceptibility mapping of the subsurface and is depicted in

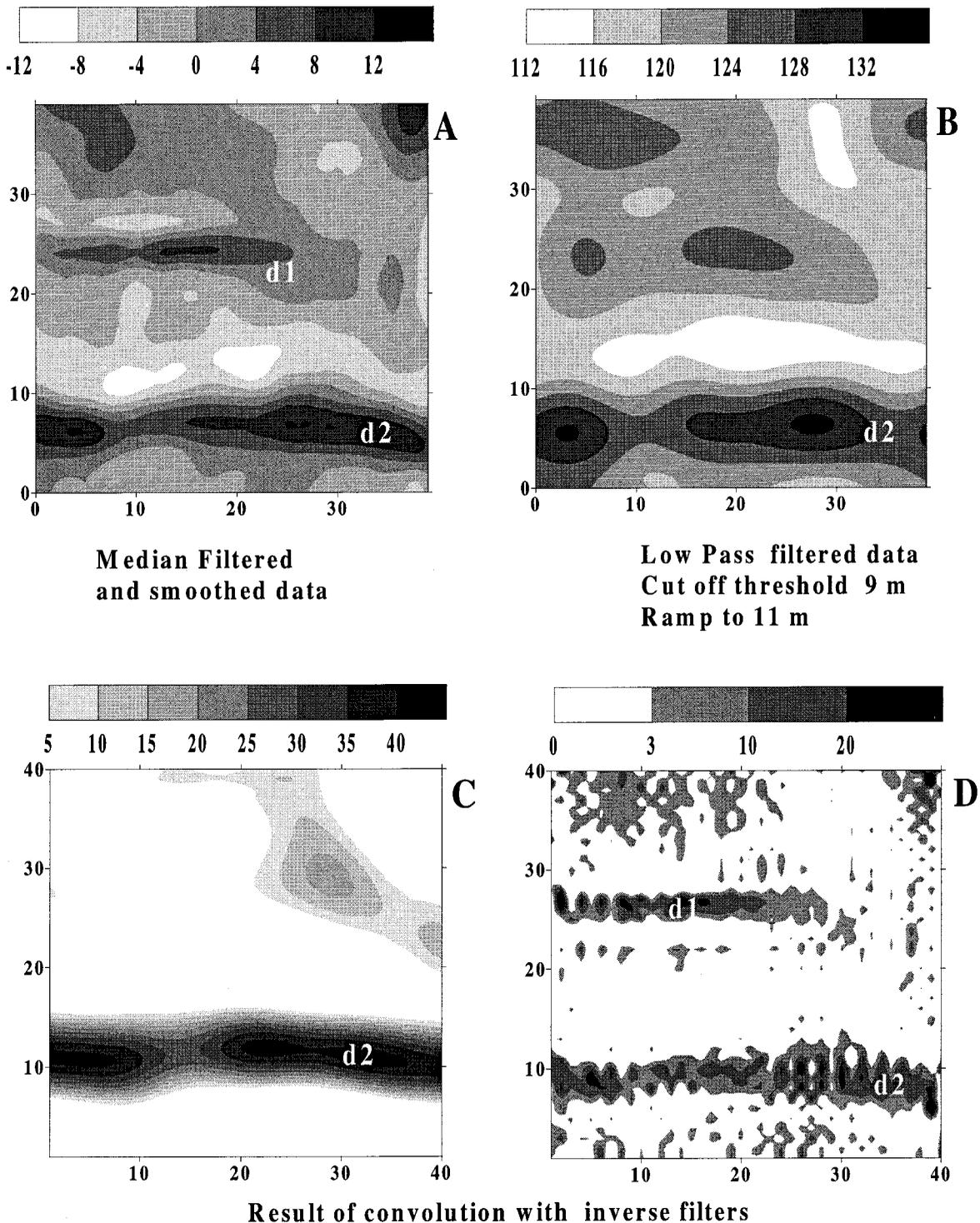


Figure 10. (A) De-spiked and smoothed filtered data of subgrid 24 of the area LBDAN. (B) Low-pass filtered version of the data of A. (C) The result of inverse filtering of data of the subgrid 24 prepared by de-spiking, smoothing and low-pass filtering. The picture depicts the subsurface distribution of magnetization concerning the large-scale structures. (D) The result of inverse filtering of the data of subgrid 24 prepared by de-spiking, smoothing and bandpass filtering, where relatively smaller wavelengths than those of B have been preserved. The picture depicts the subsurface distribution of magnetization. However, the wider ditch is not as clear as in C because of the particular bandpass preparation procedure.

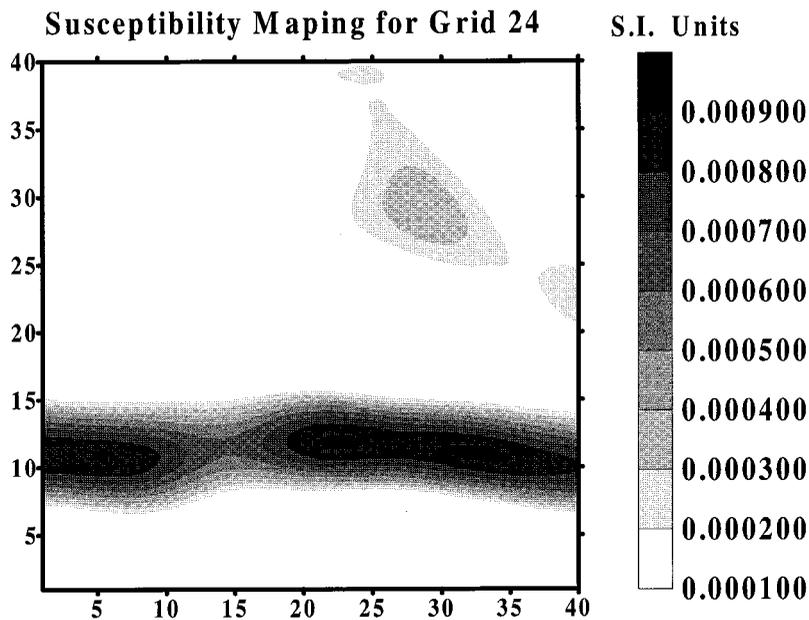


Figure 11. Magnetic susceptibility mapping inferred by dividing the outcome of inverse filtering shown in Figure 10C by the normal field value. The maximum value is about 100×10^{-5} which is in agreement with the measured susceptibility variation shown in Figure 4.

Figure 11. The maximum value shown in Figure 11 is about 100×10^{-5} , which has to be checked against the lateral variation of the magnetic susceptibility measured at the archaeological section of Figure 4. The actual measurements also show maximum lateral variation of susceptibility of the same order.

Epilogue

The magnetic search of Makrygialos, covering more than 60,000 m², located a number of ancient subsurface archaeological remnants. The main interest of the site was concentrated in the northern section of the site (LBDAN), where a system of three ditches has been located.

Two habitation phases were recorded by the excavation results: one dated before the Dimini phase of the Late Neolithic Period, whereas the second is contemporary to the Dimini phase (end of the Late Neolithic Period) (Pappa, 1995, 1996; Pappa and Bessios, 1997). During the first phase of occupation, the settlement was surrounded by a system of ditches, which formed a large circle. Groups of houses were discovered inside the circular defensive system, while open space

extended between the structures. The excavation of the site concluded that the size of the settlement decreased during the second phase, whereas the density of the constructions increased. Most of the houses excavated have been circular in shape, as indicated by the pits dug into the ground. The superstructure of the houses was made of perishable materials, wooden posts and wattle-and-daub, traces of which are clearly distinguished outside the pits. Remains of small ovens and hearths for cooking and firing of pottery were found outside the houses.

Conclusions

The use of the various geophysical techniques illustrates their importance in the management of archaeological sites threatened by large-scale construction projects. The geophysical involvement in large- or even small-scale development projects is necessary for the protection and conservation of the cultural heritage of the Balkans, which is situated in a most historically sensitive area on a world-wide scale.

Inverse filtering extracts valuable information from the magnetic anomalies by rectifying them

and highlighting their lateral extend. It also provides estimates of the magnetization of the concealed structures.

References

- Bessios, M. (1987). Excavations in N. Pieria (1987). *The Archaeological Work in Macedonia and Thrace 1*: 109–213. (In Greek.)
- Bessios, M. (1988). Excavations in Pydna (1988). *The Archaeological Work in Macedonia and Thrace 2*: 181–193. (In Greek.)
- Bessios, M. (1989). Excavations in the northern cemetery of Pydna. *The Archaeological Work in Macedonia and Thrace 3*: 155–160. (In Greek.)
- Bessios, M. (1990). Excavations in the northern cemetery of Pydna. *The Archaeological work in Macedonia and Thrace 4*: 241–243. (In Greek.)
- Bessios, M. (1991). Excavations in N. Pieria (1991). *The Archaeological Work in Macedonia and Thrace 5*: 171–178. (In Greek.)
- Bessios, M. (1992). Excavations in N. Pieria (1992). *The Archaeological Work in Macedonia and Thrace 6*: 245–248. (In Greek.)
- Bessios, M. (1995a). Ancient Pydna. In *Pydna*: Bessios, M. and Pappa, M. (editors) (Pieriki Anaptiksi publications, Katerini): 5–9. (In Greek.)
- Bessios, M. (1995b). Excavations in N. Pieria, Pydna. In Mpesios, M. and Pappa, M. (editors) (Pieriki Anaptiksi Publications): 10–14. (In Greek.)
- Bessios, M. and Pappa, M. (1993). The Neolithic settlement of Makrygialos in Pierria. *The Archaeological Work in Macedonia and Thrace 7*: in press. (In Greek.)
- Bessios, M. and Pappa, M. (1994). The Neolithic settlement of Makrygialos. *The Archaeological Work in Macedonia and Thrace 8*: in press. (In Greek.)
- Bessios, M. and Pappa, M. (1995). The Neolithic settlement of Makrygialos in Pierria. *The Archaeological Work in Macedonia and Thrace 9*: in press. (In Greek.)
- Bessios, M. and Pappa, M. (1997). The Neolithic settlement of Makrygialos in Pierria. *Arceologia Analekta ex Athinon 23*: in press. (In Greek.)
- Burt, P. J. (1983). Fast algorithms for estimating local image properties. *Computer Graphics and Image Processing 21*: 368–382.
- Hildenbrand, T. G. (1983). FFTFIL: A filtering program based on two dimensional Fourier Analysis. *United States Geological Survey Open File Report 83-237*, pp. 30.
- Le Borgne, E. (1955) Susceptibilite magnetique anormale du sol superficiel. *Annales de Geophysique 11*: 399–419.
- McGrath, P. H. and Hood, P. J. (1973). An automatic least-squares multimodel method for magnetic interpretation. *Geophysics 38*(2): 349–358.
- Mishra, D. C. and Naidu, P. S. (1974). Two dimensional power spectral analysis of aeromagnetic fields. *Geophysical Prospecting 22*: 345–353.
- Munro, M. A. R. and Papamarinopoulos, S. (1978). The investigation of an unusual magnetic anomaly by combined magnetometer and soil susceptibility surveys. *Archaeophysika 10*: 675–680.
- Pappa, M. (1995). The prehistoric settlement in Makrygialos, Pydna. In *Pydna*: Bessios, M. and Pappa, M. (editors) (Pieriki Anaptiksi Publications, Katerini): 15–17.
- Pappa, M. (1996). The Neolithic settlement of Makrygialos in Pierria. Initial results of the study. *The Archaeological Work in Macedonia and Thrace 10*: in press. (In Greek.)
- Pappa, M. and Bessios, M. (1997). The Makrygialos Project. Rescue excavations at the Neolithic site of Makrygialos, Pieria, Greece. *The Neolithic Society in Greece*. In Halstead, P. (editor) (Sheffield Centre for Aegean Archaeology, Sheffield University): in press.
- Sarris, A. (1992). Shallow depth geophysical investigations through the application of magnetic and resistance techniques. Lincoln: University of Nebraska-Lincoln PhD thesis.
- Sarris, A. (1994). Magnetic susceptibility surveying in ancient Mantinea, Greece. *59th Annual Meeting of the Society for American Archaeology*, Anaheim, CA, 18–24 April.
- Sarris, A. and Jones, R. (1998). Geophysical prospection of archaeological sites in the Mediteranean region. *Journal of Mediteranean Archaeology* in press.
- Scollar, I., Weidner, B. and Segeth, K. (1986). Display of archaeological magnetic data. *Geophysics 51*(3): 623–633.
- Singleton, R. C. (1967). A method for computing the fast Fourier transform with auxiliary memory and limited high speed storage. *IEEE Transactions on Audio and Electroacoustics AU-15*: 91–97.
- Spector, A. and Grant, F. S. (1970). Statistical models for interpreting aeromagnetic data. *Geophysics 35*: 293–302.
- Tite, M. S. and Mullins, C. (1971). Enhancement of the magnetic susceptibility of soils on archaeological sites. *Archaeometry 14*: 229–236.
- Tsokas, G. N. (1993). Research Project 8053. Unpublished report on the Geophysical Project of Makrygialos, (Thessaloniki, Macedonia, Greece: Geophysical Laboratory, Aristotelian University of Thessaloniki).
- Tsokas, G. N. and Papazachos, C. B. (1992). Two-dimensional inversion filters in magnetic prospecting: application to the exploration for buried antiquities. *Geophysics 57*: 1004–1013.
- Weymouth, J. W. and Lessard, Y. A. (1986). Simulation studies of diurnal corrections for magnetic prospecting. *Prospezioni Archaeologiche 10*: 37–47.