

ON THE DESIGN OF DETECTION SYSTEMS IN THE
SHALLOW GEOPHYSICAL INVESTIGATIONS

G.N. TSOKAS

Geophysical Laboratory, Dept. of Geology, Univ. of Thessaloniki, Thessaloniki 54006, Greece.

ABSTRACT

The design of detection systems in the shallow geophysical investigations is presented and discussed.

An improvement of the crosscorrelation system is attempted which is based on the inherent properties of the autocorrelation function of predefined signals. Hence, the exploitation of the autocorrelation function as a measure of absolute likeness is studied.

A detector based on polarity coincidence array and another based both on crosscorrelation and semblance are presented.

All the presented systems are classified to non parametric ones. Comments are made on parametric systems where econometric magnitudes might be involved.

1. INTRODUCTION

Recognition of specific patterns in the presence of stochastic and coherent noise is probably the most severe and challenging topic in the shallow geophysical investigations. Especially when dealing with high resolution Geophys-

ics (Wynn 1986), i.e. with archaeological site search, the overall efficiency of the employed methods is much dependent on this matter.

The present study is focussed on the design of detection systems in "archaeological geophysics". However, the developed systems are applicable more or less in all cases of shallow geophysical investigations such as engineering problems, cavity and Karst exploration, mineralization e.t.c.

An illustrative case study was chosen from the exploration of the archaeological site of Dion (Pieria, N. Greece). It is a sample of 20x50 m which was explored by magnetic means. Figure (1) shows the total magnetic field distribution within this bit of land.

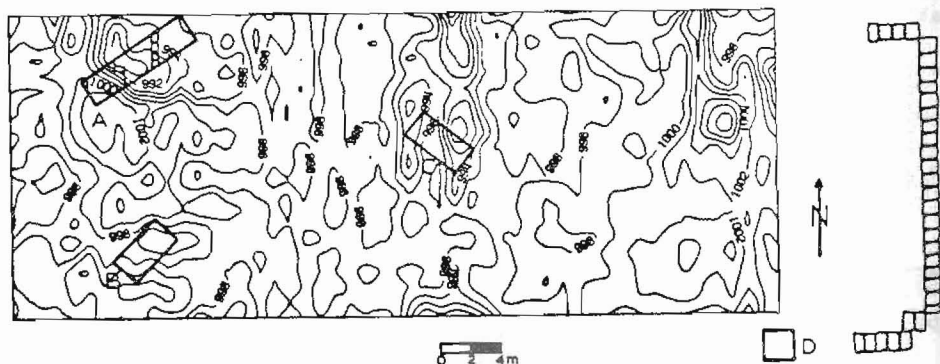


Fig. 1. Magnetic total field values from an area in the archaeological site of Dion (N. Greece). Measurements were reduced with respect to the diurnal variation of the earth's field and a first order regional was removed. The locations of trial pits have been marked. Already revealed antiquities have been also drawn.

2. THEORETICAL FOUNDATIONS

By casting the problem of detection of specific patterns, several efforts have been made in the past concerning mainly radar and acoustic signal detection. In those fields, the need for development of such systems is more pronounced since, for instance, several problems of seismic processing and interpretation can be attacked.

In Geophysical search of archaeological sites, procedures based on the properties of the crosscorrelation function, have been successfully applied (Bernabini et al. 1986, Brizzolari et al. 1986, Alder 1988). Tsokas (1988) and Tsokas and Kiriakidis (1988) pointed out a severe limitation of the detection ability of such procedures. This is the fact that different signals which have the same wavelength content in one direction produce large values of the crosscorrelation function misleading the interpretation.

An attempt to overcome that specific drawback has been presented by Tsokas and Dimitropoulos (1989). The unwanted wavelength content was suppressed by filters which were based upon the archaeological - historical information. Such filters are optimum in the sense that they reflect the characteristics of a specific signal.

The former researchers commented also on the dependance of the amplitude of the crosscorrelation function on the burial depth of the target. They proved that when either the simulation of a structure, which is used to produce a spe-

cific pattern, or the structure itself is buried deeper than expected, the values of the crosscorrelation function are reduced.

This is a considerable instability of the detection system since burial depth may vary 1 or 2 grid units whatever small the searched area might be.

Bernabini et al. (1988) applied a crosscorrelation procedure to enhance the signal to noise ratio in resistivity profiles. They employed as "matched filter" the distance - reverse of the signal. In case of Gaussian noise, such a filter is an absolute optimum (Robinson 1967, Kulhanek 1976). In case of autocorrelated noise the distance - reverse filtering will again result in dumping of the prevalent noise frequencies. However, the noise autocorrelation function must be known and noise should be considered stationary. Furthermore the noise should not be in a level close to the signal one.

A detection system which weights the same weak and strong events was presented by Tsokas (1989). It was based on a sing - semblance statistic and proved to give fairly good results in cases of small signal to noise ratio. In addition the probability of false alarms can be evaluated.

3. IMPROVEMENT OF THE CROSSCORRELATION SYSTEM USING THE AUTOCORRELATION OF THE SIGNAL

It is well known that the crosscorrelation function (CRF) between two functions, one considered as operator and the other as signal, is a measure of similarity between

them.

If one can built up a realistic model of the wanted structure and calculate its effect, this can be used as signal. By correlating such a signal with the measured field a detector can be developed since the CRF possesses high values wherever the signal recognizes itself. In particular a high degree of resemblance to the signal autocorrelation function (ACF) should be performed wherever the specific signal is present.

As already referred to, such a system employed in shallow geophysical investigations is unstable. It is mainly an amplitude based system, therefore it weights more the strong events. Additionally noise might correlate with the signal if the wevelenght content is the same in one direction.

An effort to improve the system consists in using the characteristics of the ACF of the signal. These are: the mean and the maximum values and the distance between the maximum and first zero crossing. Alternatively, the two dimensional pattern of the ACF can be used directly in a qualitative manner.

In order to illustrate the former considerations, a signal has been calculated by the simulation of a NS ranging wall (figure 2a) and shown along the 2 - dimensional ACF (figure 2b). The resulted correlogram of the considered signal and the operator of figure (1) is shown in figure (3).

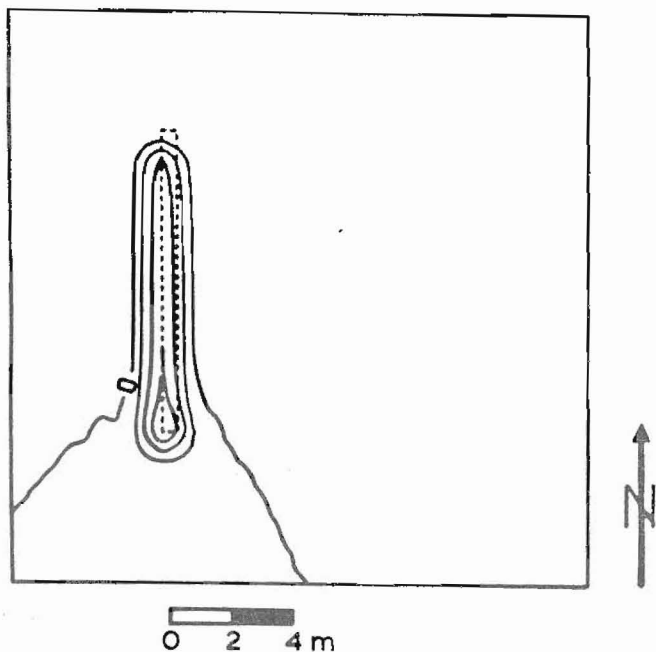
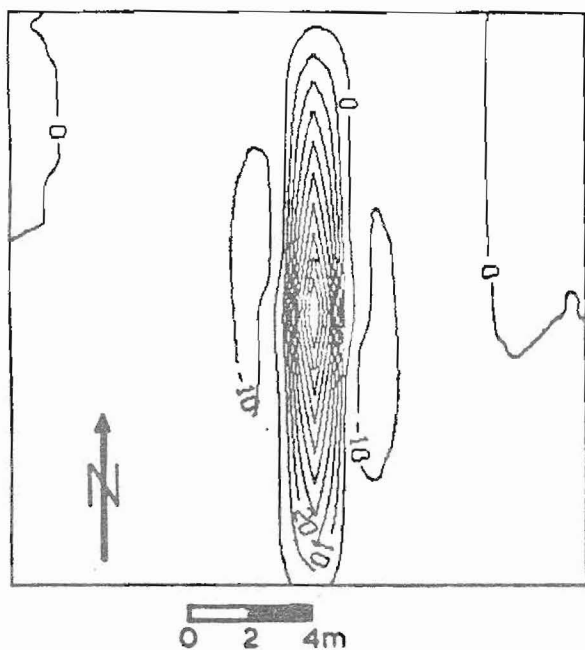


Fig. 2.
 A vertical sided rectangular prism simulates the remains of a foundation wall. It has been plotted along with the calculated effect in (a). The model was constructed with dimensions $0.5 \times 10 \times 1$ m, burial depth of 0.5 m and susceptibility contrast -0.43×10^{-4} CGS units. The formula used was that of Bhattacharyya (1964). The ACF of the produced effect is shown are (b). Contours are in nT in (a) and nT^2 in (b).



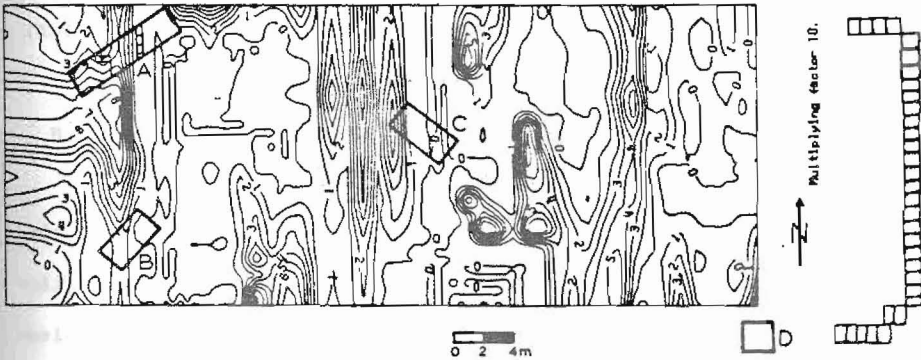


Fig. 3. Correlogram between the signal of figure (2a) and the operator of figure (1). Contours are in mT^2 .

The numerical characteristics of the ACF of the example are listed below:

1. Mean value : 1.15
2. Maximum value : 104
3. Distance between maximum and first zero crossing: 4 grid units

The ACF was realized in a particular window. Using the same window dimensions, the distribution of the numerical characteristics can be calculated. This is illustrated in figures (4a), (4b) and (4c) respectively for the 1,2 and 3 characteristics. We can now consider that a safe detection has been made at the locations where the evaluated characteristics are within some limits around the respective ones of the considered ACF. The interpretation has to be based on the archaeological - historical information as well. Never-

theless, the last factor is always taken into account. The resulted map of the locations where similar to the structure of figure (2a) are buried is shown in figure (5).

The treatment of the problem in the performed manner is equivalent to the consideration of the numerical characteristics as statistics. Since no assumption on the distribution function of signal and noise has been made the system is classified to non parametric detectors. The problem was essentially posed as one of the "decision making theory" in the following context.

H_0 : Signal is not present in the particular window.

H_1 : Signal is present in the particular window.

Or, quantifying the hypotheses:

$$H_0 : f_i < f_{oi} - c \text{ or } f_i > f_{oi} + c \quad (1)$$

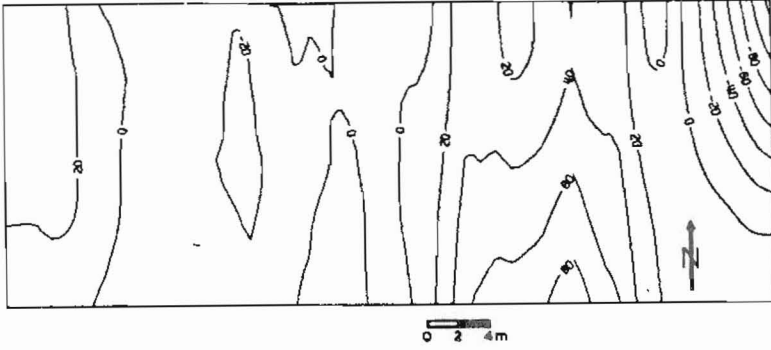
$$H_1 : f_{oi} - c < f_i < f_{oi} + c$$

where, f_i , a particular statistic.

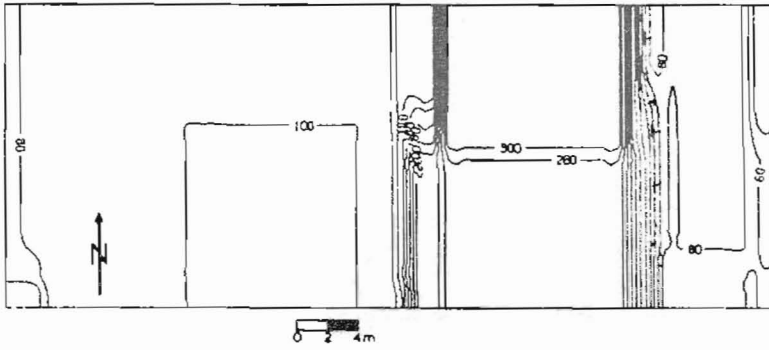
Since no distribution function considerations were made, error probabilities can not be calculated.

The normalized correlograms with respect to the maximum of the ACF can be used for depth estimations (Alder 1988). However, such a treatment is applicable in simple cases.

α



β



γ

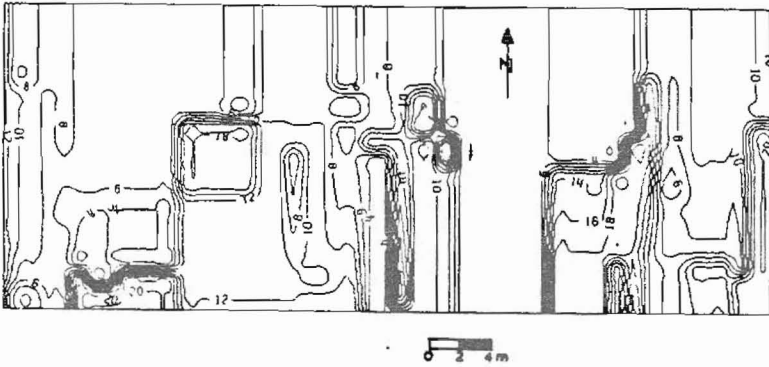


Fig. 4. Spatial distribution of the mean value of the CRP realized in 10×17 grid units window (a). Spatial distribution of the maximum value (b) and of the distance between the maximum and the first zero crossing (c).

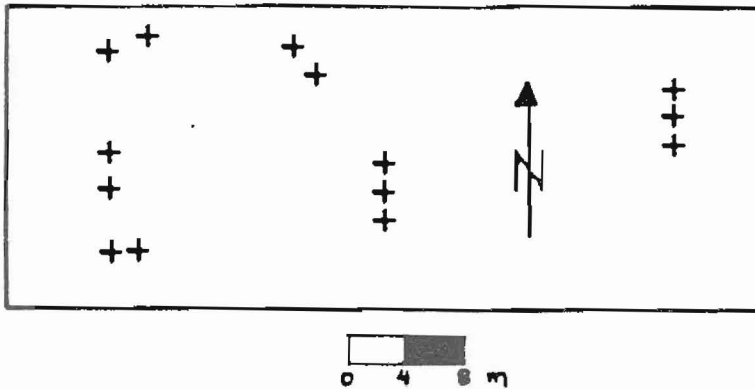


Fig. 5. Final proposal of the locations where features similar to the one of figure (2a) are expected. It was presented after the evaluation of features of figure (3) and (4).

4. DETECTION BASED ON POLARITY COINCIDENCE ARRAY

Kanefsky (1966) proposed a statistic based on the sign function which was proved powerful in seismic exploration. Since its evaluation was based only on the sign bit of the bytes which store the value of a sample of the seismogram, it was reasonably termed sign - bit semblance. This is defined as

$$f = 1/4 \sum_{i=1}^m \left(\sum_{j=1}^n \text{sgn}(F_{ij}) \right)^2 \quad (2)$$

where, m and n are the dimensions of the data window. The sign function is defined as

$$\text{sgn}(F_{ij}) = \begin{cases} \frac{F_{ij}}{|F_{ij}|} & \text{for } F_{ij} \neq 0 \\ 0 & \text{for } F_{ij} = 0 \end{cases} \quad (3)$$

The detector is developed by shifting a window on the data and make a decision on the existence of the signal. This decision is based on the comparison of the calculated each time f with a predetermined threshold f_0 as shown by relation (1).

The threshold can be either determined by the signal or be set in order to have a wanted probability of type I error (Cochran 1973).

Kanefsky (1966) proved that if we accept that noise is equally probable to be positive and negative, the sign bit semblance is normally distributed under H_0 . The mean value is then $mn/4$ and the variance $mn(n-1)/8$.

In our example, such an assumption for the noise distribution function is reasonable. Hence, the application of the proposed detection system yields figure (6).

The false alarm probability is given by

$$Q_0 = \int_{f_0}^{\infty} P(f/H_0) df \quad (4)$$

where, $P(f/H_0)$, is the probability density function of f given that H_0 is true.

The relation (4) results in a negligible probability for our case.

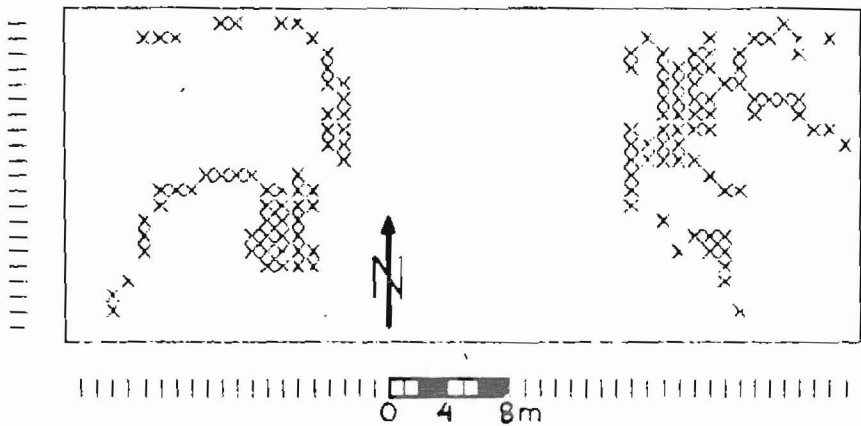


Fig. 6. Locations where the sign - bit semblance system pointed detection.

DISCUSSION

Two differently generated detectors were presented in the preceding pages. Obviously, an infinite number of detectors can be developed with respect to the considered statistic or strategy or the mathematical operation. The efficiency of each system is much related to the considered problem. In particular, it is much dependant on the noise characteristics.

The sign bit semblance draws an advantage over the cross-correlation. Since no amplitude consideration is involved, weak and strong signals are weighted the same.

Models have to be constructed for either the CRF or the semblance system, consequently, the systems are equally easily applied. However, the degree of rapidness that the CR system produces some results depends on how many characteris-

teristics of the ACF are used.

The semblance is more insensitive to the possession of the same wavelength content in one direction between signal and noise than the CR one. This is due to the fact that signs are averaged out in two directions. It is illustrated in the presented example by the negative result at location C of figure (1), where coherent noise is present which is positively correlated in the EW direction with the signal.

Statistical detection theory states that parametric detectors are generally the most powerful (Helstrom 1968). In any particular detection case, one could develop a better parametric system than the presented ones or a specific non parametric. However, these procedures lack of generality and require knowledge or assumptions on both the statistical characteristics of signal and noise.

If this can be achieved and simultaneously the cost matrix is given, the detection system can then be optimized in the econometric sense as well. In other words, to find the optimum possibilities in terms of the involved costs in any decision.

Any of the presented systems can be used separately or in conjunction each with other. The last case is suitable for application to systematic excavations where time limits are more flexible. In case where swift operation is required and noise can be considered Gaussian the sign semblance proposed by Tsokas (1989) is much more convenient to be applied.

Figure (7) shows the results of a detection system

applied on the correlogram of figure (3). The polarity coincidence array of relation (2) was calculated from the ACF of figure (2b). This system gives the locations where detection is almost confident but the practically evaluated "missed detection" probability exceeds 0.8. The practical use of such a system is confined to the cases where a confident detection is required in order drilling or excavation activity to be commenced.

It must be noticed that usually we are dealing with the detection of more than one signal. Hence, noise varies each time a detection run is attempted. In other words, the effect of other signals, than the wanted one each time, is counted as noise.

In large sites, where several different structures are expected, and the data sample is quite large, experience has pointed out that the Gaussian approximation of noise conditions is usually fulfilled. This fact facilitates the design of the suitable detection system.

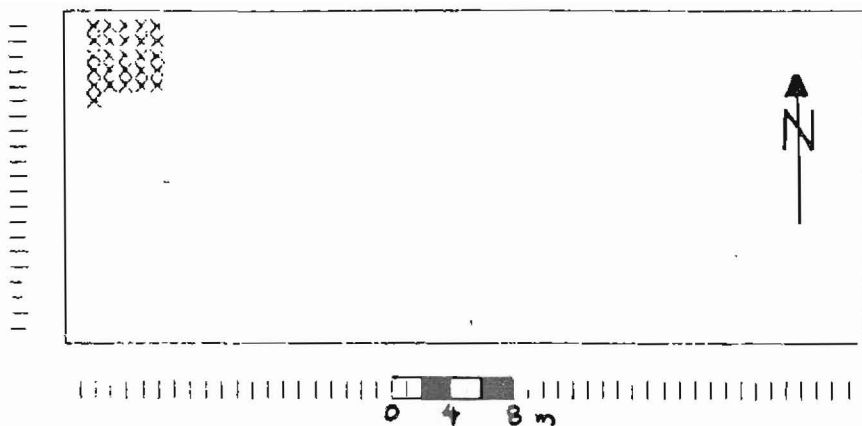


Fig. 7. Results of a detector which was based on sign bit semblance and applied on the correlogram of figure (3).

Finally, the dimensions of the moving window contribute to the efficiency of the detection systems.

This is reasonable since parameters are calculated within this window. Thus, it must be designed in such a manner that the signal vanishes out at the bounds.

CONCLUSIONS

Several detection systems were presented in the preceding pages. However, it is emphasized that the best detector in each exploration case is the one designed upon the specific features of the problem.

The efficiency of the CR system is much enhanced if the numerical characteristics of the ACF are taken into account.

The use of polarity coincidence arrays is recommended wherever we deal with weak events. In addition, they are less sensitive to coherent noise in one direction.

Detectors could be classified with respect to geological,

geomorphological, archaeological and historical aspects. Such an attempt could be supplemented with the estimation of econometric magnitudes which are important in case of rescue excavations. In other words, one could have a rough idea about the expected antiquities in a particular geographical region and the cost of each decision. Therefore, if some other features could be rapidly evaluated the optimum solution can be given to the archaeologists.

REFERENCES

- Alder, M.J. Locating Archaeological features in magnetic data by crosscorrelation. "Archaeometry" 30, 1, 145-154, 1988.
- Bernabini, M., Brizzolari, E., Orlando, L., Piro, S. and Versino, L. Searching for superficial cavities and buried man-made objects using indirect geophysical methods. Paper presented to 25th International Symposium on Archaeometry. Athens, 19-23 May, 1986.
- Bhattacharyya, B.K. Magnetic anomalies due to prism shaped bodies with arbitrary polarization. "Geophysics", 29, 517 - 531, 1964.
- Brizzolari E., Orlando, L., Piro, S. and Samir, A. Frequency analysis and filtering of resistivity profiles for different electrode arrays. Paper presented to 48th annual E.A.E.G. meeting, Ostend, 3-6 June, 1986.

- Bernabini, M., Brizzolari, E., Piro, S. Improvement of signal to noise ratio in resistivity profiles. "Geophysical prospecting", 36, 559-570, 1988.
- Cochran, M.D. Seismic signal detection using sign bits. "Geophysics", 38, 1042 - 1052, 1973.
- Helstrom, C.W. Statistical theory of signal detection. Pergamon press, New York, pp. 467, 1968.
- Kanefsky, M. Detection of weak signals with polarity coincidence arrays. I.E.E.E. Transactions on Information Theory, IT-12, 260-268, 1966.
- Kulhanek, O. Introduction to digital filtering in Geophysics. Elsevier, Amsterdam, p. 168, 1976.
- Robinson, E.A. Statistical communications and detections Griffin ED., London, 1967.
- Tsokas, G.N. Recent prospecting results from ancient Aegae (Verghina, N. Greece). Proceedings of an IAEG international symposiums. The engineering Geology of Ancient works, monuments and Historical sites; Preservation and Protection. Athens, 19-23 Sept., 1131-1134, 1988.
- Tsokas, G.N. A sign - semblance detection system for the shallow geophysical investigations. Paper submitted to "Archaeometry". 1989.

Tsokas, G.N. and Kiriakidis, L. On a forward deconvolution process applied to magnetic data from archaeological sites. Proceedings of an IAEG international symposium. The engineering Geology of Ancient works, monuments and Historical sites; Preservation and Protection. Athens, 19-23 Sept., 1121 - 1124, 1988.

Tsokas, G.N. and Dimitropoulos, K. Can the geophysical maps over buried ancient sites reveal specific structures, if correlated to predetermined signals? Paper presented to the 7th International Seminar on Model Optimization in Exploration Geophysics. Berlin, 8-12 Feb., 1989.

Wynn, G.J. Archaeological prospection: An introduction to the Special issue. "Geophysics", 51,3,533 - 537, 1986.