19

Methods for Processing Digital Geophysical Data in Archaeology

V. Hašek*

R. Vencálak†

19.1 Introduction

To process and interpret large amounts of geophysical field data, numerous programs have been developed for personal computers and mini-computers (Hašek *et al.* 1988, Hašek 1989) to carry out:

1. primary data evaluation and specification of graphic outputs (profile curves, maps of isolines, etc.), and
2. quantitative interpretation (separation of regional and residual anomalies of the geomagnetic field, computation of correlation coefficients, etc).

The programs in BASIC and FORTRAN

- enhance the primary processing of data files, and
- make the interpretation more effective and provide the archaeologist with more detailed information.

19.2 The main trends in geophysical data processing

According to Nikitin (1986) there are two principal approaches to the evaluation and interpretation of geophysical data: the deterministic and the statistical.

The deterministic approach is based on the principle of causal nexus between the values of the measured physical field and disturbing bodies (inhomogeneities in the crust, atmospheric and cosmic effects, etc.). The anaytical methods associated with this approach are based on potential theory (magnetometry, gravimetry, D.C. geoelectric methods), on Maxwell equations (EM methods), and on the theory of elasticity (seismic methods). In favourable cases they not only help us find the disturbing bodies, but also help us evaluate their parameters.

The statistical approach to geophysical data has been widely developed in recent years. It is assumed that geophysical measurements at individual points may be considered mutually independant, and that noise due to measurement errors, small inhomogeneities, field variations, etc creates field data which are random in character using statistical methods, it may be possible to separate the useful information from the noise even if the intensities of variations due to 'real' effects and to noise are comparable.

* Geofyzika s.p.,
Ječna 29a,
612 46 Brno,
Czechoslovakia

† The Ordzhonikidze Geological Institute,
Volgina 8,
Moscow 117 485,
U.S.S.R.

19.3 Primary processing of the field data

Primary processing of the magnetic and geoelectric site data involves programs which correct incorrectly input data, compute normal fields, subtract variations, smooth data and prepare data sets for interpretation (Vencálek 1988).

Further programs exist for the graphic representation of field data or derived fields. They can plot profile curves and isolines and represent them in perspective. The construction of maps composed of lines of equal ΔT ('isolines') interpolation using bicubic splines onto a regular grid. One-metre and two-metre grids are mainly used for geophysical measurements in archaeology. To smooth out the curves, the interpolation grid interval is reduced. The map of ΔT anomalies from the site at Němčičky (Znojmo district) in Fig. 19.1 exemplifies the use of the program.

The legibility of the map is increased by colouring the areas between the ΔT isolines. A hatched map of ΔT anomalies is given in Fig. 19.2.

Occasionally, especially on archaeological sites with large ΔT anomalies, it is useful to represent the data in perspective (Hašek *et al.* 1979). A program has been written for plotting the views from abitrary distances, in arbitrary directions and on arbitrary scales.

An analogous program for representing the digital model of an archaeological locality, or an object, has been written for data at discrete points in an irregular triangular grid. The input data are corrected in the first stages of the program. Owing to the applied methods of axonometric representation and of linear interpolation the model can be constructed from either an irregular or a regular grid (Eisler *et al.* 1988). The method can therefore be used not only for modelling the outputs based, for example, on geodetic measurements of the Earth's crust before an investigation and of archaeological objects revealed during excavation (Fig. 19.3), but also evaluating data obtained by different geophysical methods. The digital model in Fig. 19.3 simulates the major parts of a temple as they were excavated on the basis of geophysical measurements.

In the primary evaluation of field data the values can be displayed on a colour screen (Bálek *et al.* 1986). This way of processing was developed in co-operation of Mathematical Institute of Czechoslovak Academy of Sciences, Prague (Segeth) and the Laboratorium für Feldarchäelogie, Rheinisches Amt für Bodenkmalpflege Bonn, Germany.

The input data were first interpolated using bicubic splines (Bernstein 1976, Scollar *et al.* 1986) so that image processing software could be used. A fine non-linear low-pass filter was used to attenuate the effect of gross measurement errors. High-pass filtering was done in the space domain using the Wallis algorithm. The algorithm for crispening (Pratt 1978) was also used for the filtering.

19.4 Qualitative interpretation

19.4.1 Separation of the geometric field

In order to process the magnetic data, a package of programs was developed for the separation of the high-frequency component of the spectrum (i.e. filtering), for transformation (Pašteka 1977), and for the following operations which do not affect the spectrum at all:

- calculating the arithmetic mean of the measured data;
- calculating the higher derivatives (improved differentiation of magnetic anomalies); and

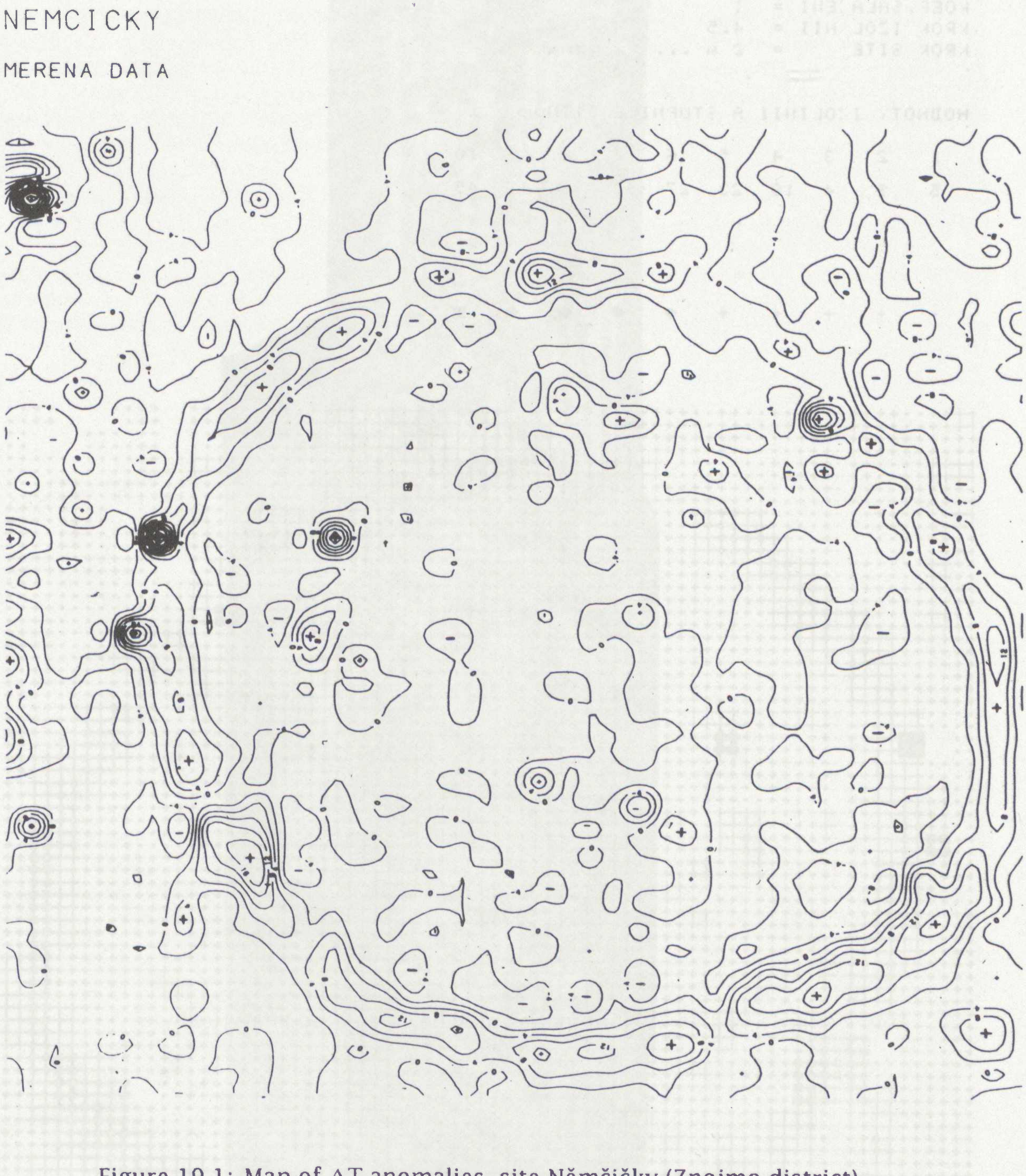

Figure 19.1: Map of ΔT anomalies, site Němčičky (Znojmo district).

```
ZOBRAZENI: VSTUPNI POLE ZE SOUBORU FONM1
*********************************************

KOEF.SHLAZENI =  1
KROK IZOL NII =  4.5
KROK SITE     =  2 m ...  2  znaky

HODNOTY IZOLINII A STUPNICE STINU

  1    2    3    4    5    6    7    8    9   10
  5    9    4   18   23   27   32   36   41   45
```

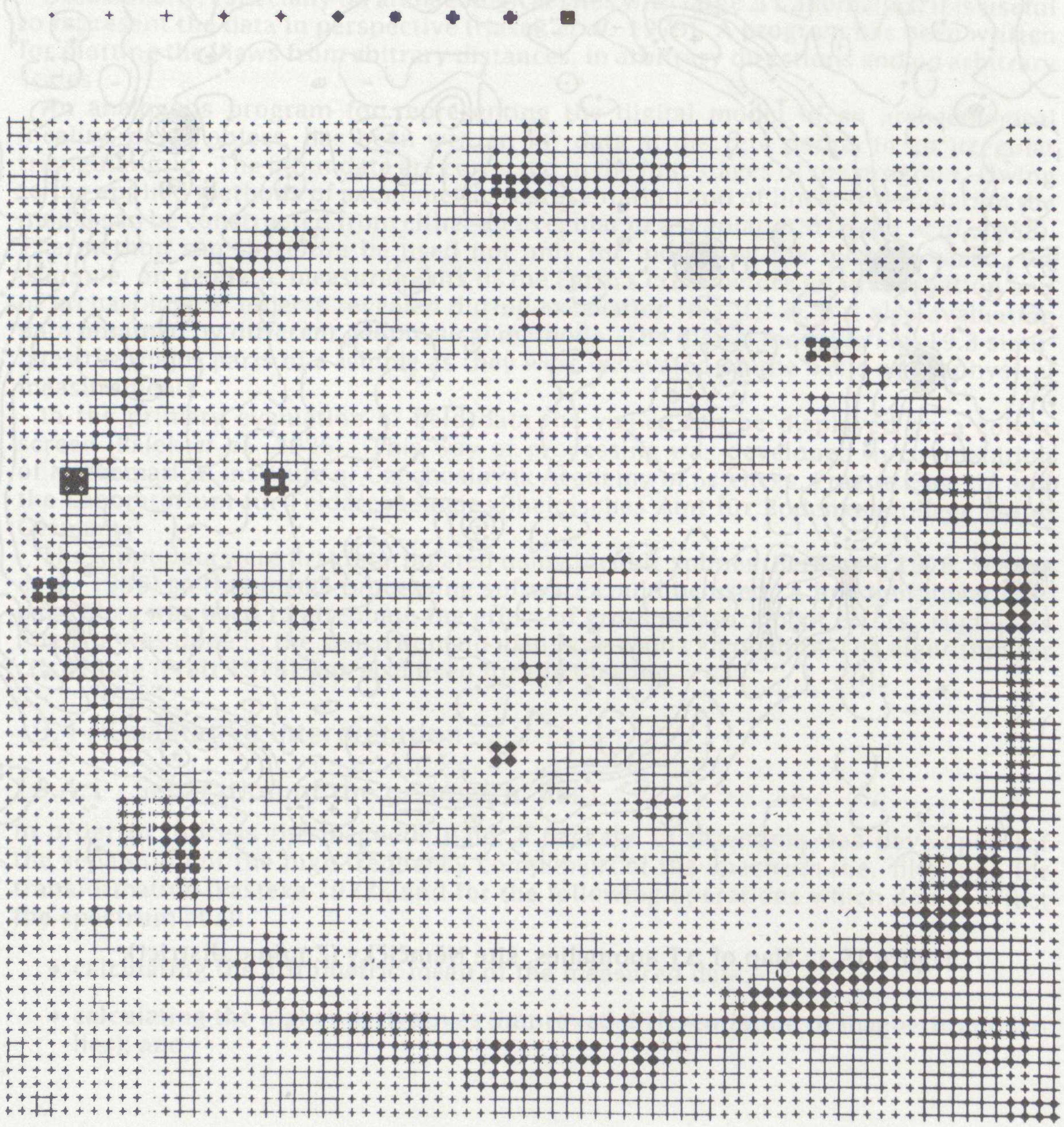

Figure 19.2: Hatched map of ΔT anomalies from Fig. 19.1

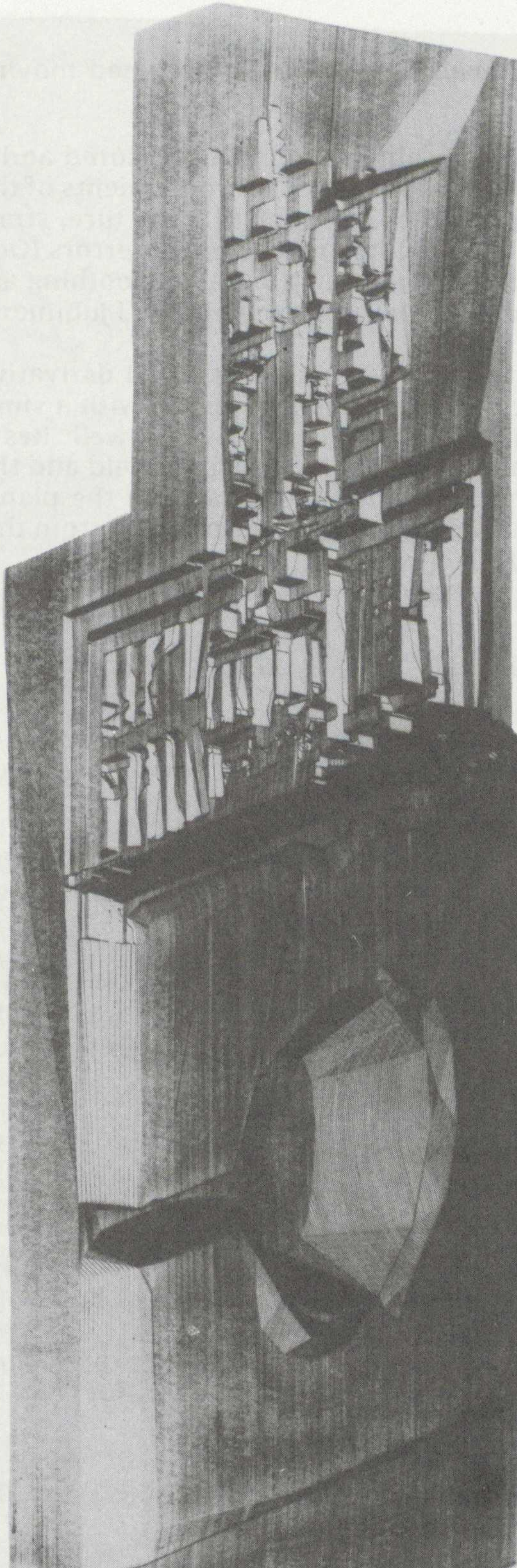

Figure 19.3: Axonometric representation of Raneferef's mortuary temple, Abusir, Egypt—1984 (Eisler *et al.* 1988)

- computing derived anomalies according to weighed moving averages (Griffin 1949).

The aim of the separation is to obtain from the measured and processed data the geophysical effects of the sought objects. Other components of the field are regarded either as a manifestation of the deeper geological structure, stratigraphic and facial change in the rock massif, or as random measurement errors (Odstrčil 1989).

The computation of coefficients of filters for data smoothing and the computation of higher derivatives are based on the approach of G. A. Ljubimov and A. A. Ljubimov (Ljubimov & Ljubimov 1983).

Fig. 19.4 shows the construction of a map of second derivatives from the site of the Raneferef's mortuary temple near Abusir overlaid with a simplified ground plan of the excavated object. The temple elements correlate well. Residual anomalies can be computed as the difference between the measured field and the regional anomaly express the regional field as a weighted mean value in the plane field S, where the weight of the indivdual values depends on their position from the centre of the field in which the computing point P lies.

To compute the regional anomaly, we thus (Mareš *et al.* 1979):

$$\Delta T_{reg}\,(P) = \frac{1}{\mu}\,\frac{\int\int}{s}\Delta T\,(M)\mu\; M\;\; ds$$

where M is an arbitrary point in the field S, $\mu(M)$ is the weighting function at the point M for the field S and $\mu = \int\int \mu(M)\; ds$ is the normalisation coefficient.

For the numerical calculation we set the weighting function $\mu(M) = 1$, i.e. we ascribe the same weight to each value of the field. The field S is then a circle with radius $R = \Delta\sqrt{5}$ (where Δ is the measurement interval). Then the regional field can be expressed as a function of average values on several circles with radius R.

Figs.19.5–19.7 show comparisions of radii R used in calculating arithmetic means of anomalies and residual ΔT anomalies from the site of the defunct medieval village Srnávka near Lelekovice (Brno district). They demonstrate that the effect of the filter applied in the processing depends on the ratio of the area of plane field S and the area of the anomaly induced by the investigated archaeological object.

It is obvious from Fig. 19.6 that if, for example, $R = \Delta\sqrt{5}$ is applied, then in the map of residual ΔT anomalies mainly noise is separated.

All information about the environment (the useful component) is contained in the map of "regional" anomalies. With larger R, e.g. $R = 2\,\Delta\sqrt{5}$ (Fig. 19.7) the constructed maps, despite various accompanying fictitious anomalies of negative sign, clearly show the local effects of objects of interest on the background of "regional" anomalies whose geological sources presumably occur at greater depths. However, the effects of major archaeological structures such as a complex of buildings or layers of loam with objects may be observed.

Some of the programs can be successfully used for processing profile geoelectric measurements, namely for smoothing profile curves, or for calculating higher derivatives.

19.4.2 The method of cross-correlation coefficients and controlled filtering

For quantitative interpretation programs were written based on the method of cross-correlation coefficients, calculation of anomalous values by the method of amplitude filtering, the method of main components, and controlled filtering.

If a local anomaly is clearly oriented in a particular direction, method of cross-correlation coefficients can be applied. It is based on stepwise comparison of the

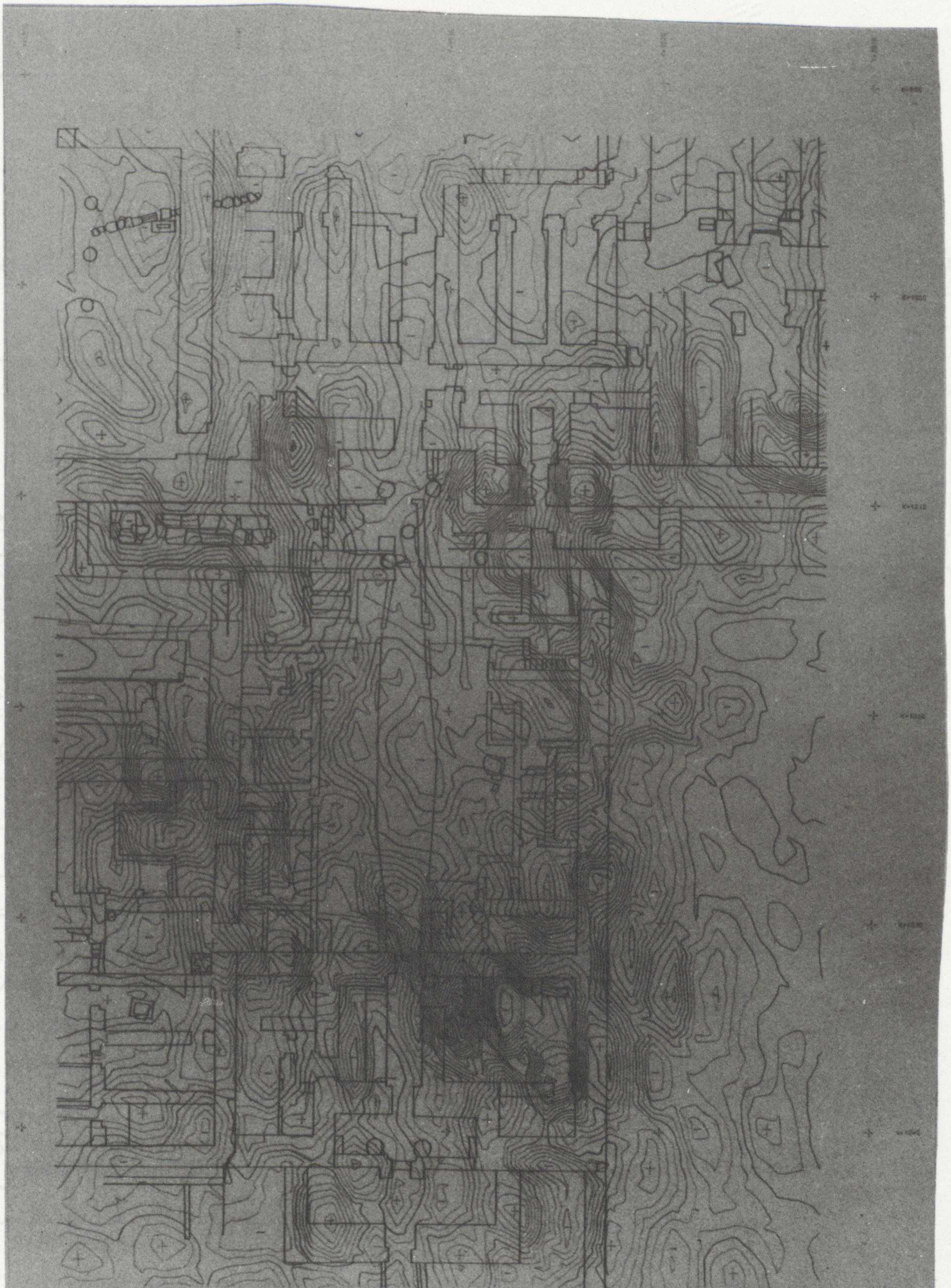

Figure 19.4: Map of second horizontal derivatives from the site of Raneferef's mortuary temple near Abuiser compared with the excavated object groundplan

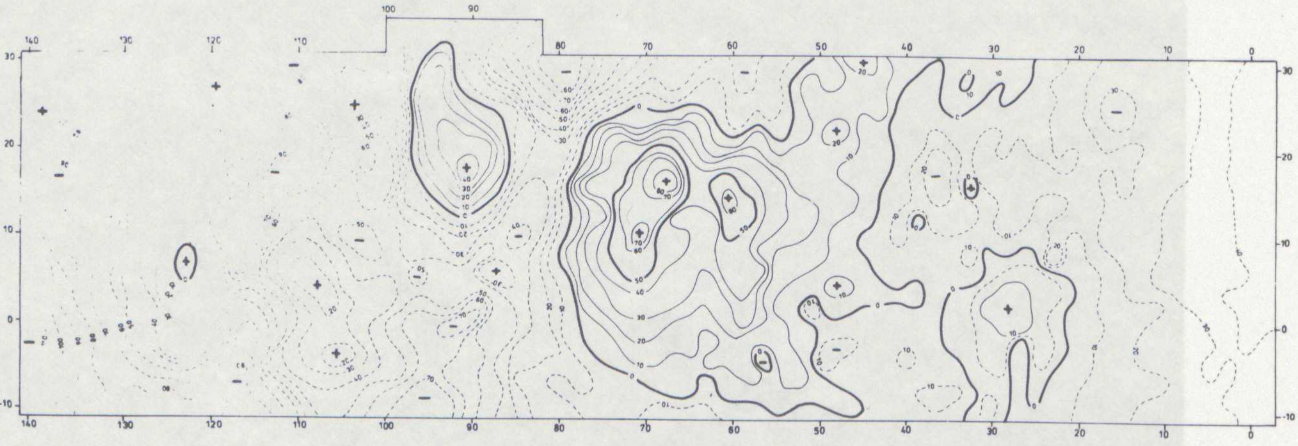

Figure 19.5: Map of ΔT anomalies on the site of defunct medieval village Srnavka near Lelekovice (Brno district)

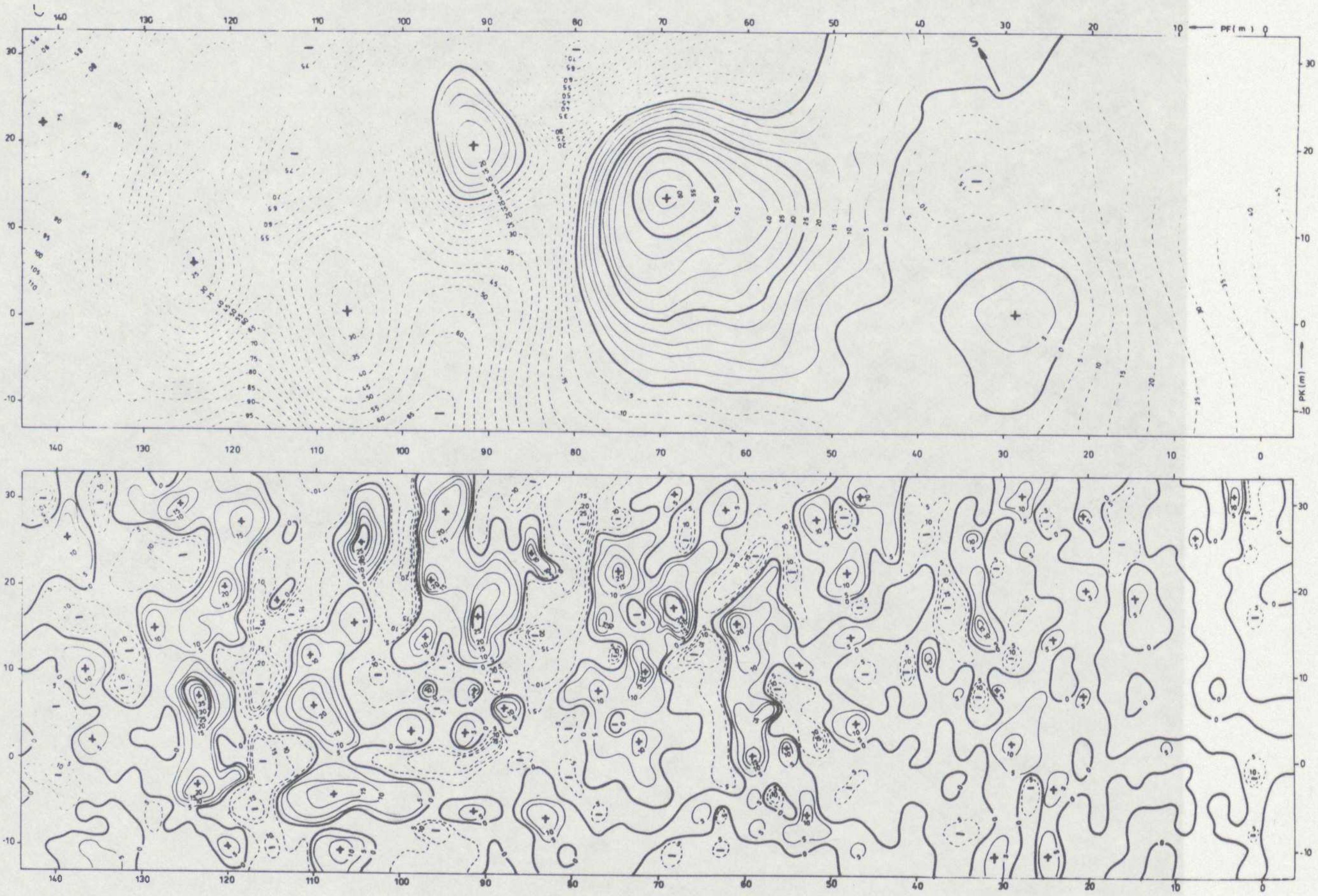

Figure 19.6: Map of centered upper and residual lower ΔT anomalies for $R = \Delta \quad \sqrt{5}$, site Srnavka near Lelekovice

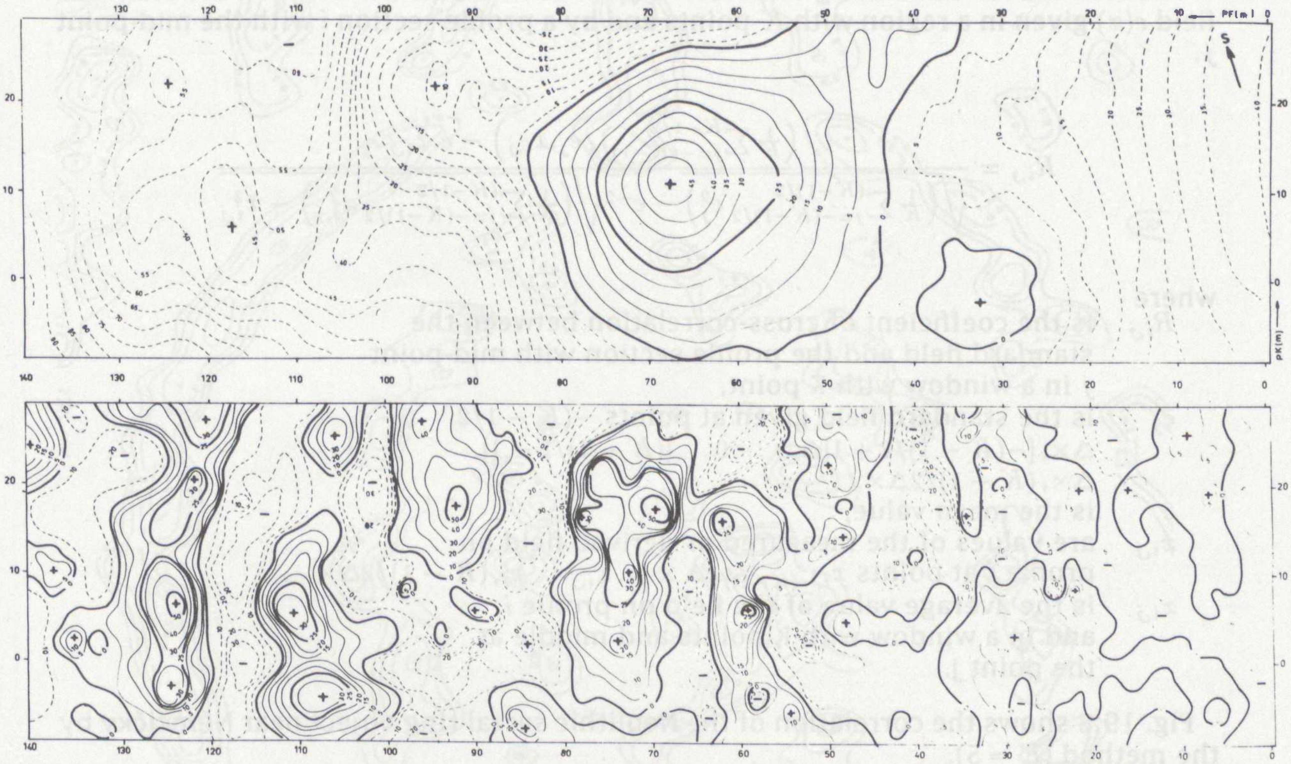

Figure 19.7: Map of centered upper and residual lower ΔT anomalies for $R = 2\Delta \sqrt{5}$, site Srnavka near Lelekovice

effects of inhomogeneity in a particular region with the measured field (Záhora in Hašek *et al.* 1985). The standard can be a theoretical curve over the sought object or field values measured in places where the position of the sought object was confirmed by another method. The method can also be applied to derived fields. The output is a matrix of cross-correlation coefficients whose columns correspond to individual profiles. The maximum values of correlation coefficients whose position on a profile always relates to the middle of the sought sections indicate the continuation of the observed anomaly on adjacent profiles.

The formula for calculating cross-correlation coefficients (R) between the standard field $e(x)$ given in a region with K points and by a profile section i with the mid-point j.

$$R_{i,j} = \frac{\left(\frac{1}{K}\sum_{j=-(K-1)/2}^{K-1/2} e_j . x_{i,j}\right) - \bar{e}.\bar{x}_{i,j}}{\sqrt{\left(\frac{1}{K}\sum_{j=-(K-1)/2}^{(K-1)/2} e_j^2\right) - e^{-2}}\sqrt{\left(\frac{1}{K}\sum_{j=-(K-1)/2}^{K-1/2} x_{i,j}^2\right) - \bar{x}_{i,j}^2}}$$

where

- $R_{i,j}$ is the coefficient of cross-correlation between the standard field and the profile section with mid-point j in a window with K point,
- e_j is the standard field given at points $-(K-1/2.\Delta\times, [-(K-1)/2+1]\Delta\times\ldots 0\ldots[(K-1)/2-1].\Delta\times, (K-1)/2\Delta\times$,
- $\bar{e}$ is the mean value,
- $x_{i,j}$ are values of the measured or derived field on profile i at points $x_{i,-(K-1)/2}\Delta\times\ldots x_{i,j}\ldots x_i, (K-1)/2\Delta\times$,
- $x_{i,j}$ is the average value of the field on profile i and in a window with K points and middle at the point j.

Fig. 19.8 shows the correlation of the Neolithic sacral ring object near Němčičky by the method ($K = 5$).

The algorithm of controlled filtering for a complex of two geophysical methods consists of calculating and comparing the correlation coefficients for anomalies and noises within the chosen region with N profiles and m measurements points on each profile (Sikorskij 1979).

The reliability of separating geophysical anomalies depends on estimation of correlation coefficients of the useful signal. The dimensions of the chosen region are determined by size of anomalies. If the correlation dependence is strong with useful signals and weak with noises, it can be said that the anomalies correlate.

The existence or non-existence of an anomaly is determined by an analysis of the parameter

$$\mu = R_a - R_n.$$

Fig. 19.9 shows an example of the complex evaluation of DEMP and micro-gravity measurements in Zbýšov near Rosice (Brno district), where the methods of calculating correlation coefficients and of controlled filtering were applied in a search of cavities due to mining activity. The positions of mining galleries are evident from the results.

Figure 19.8: Map of isolines if cross-correlation coefficients, site Němčičky (Znojmo district)

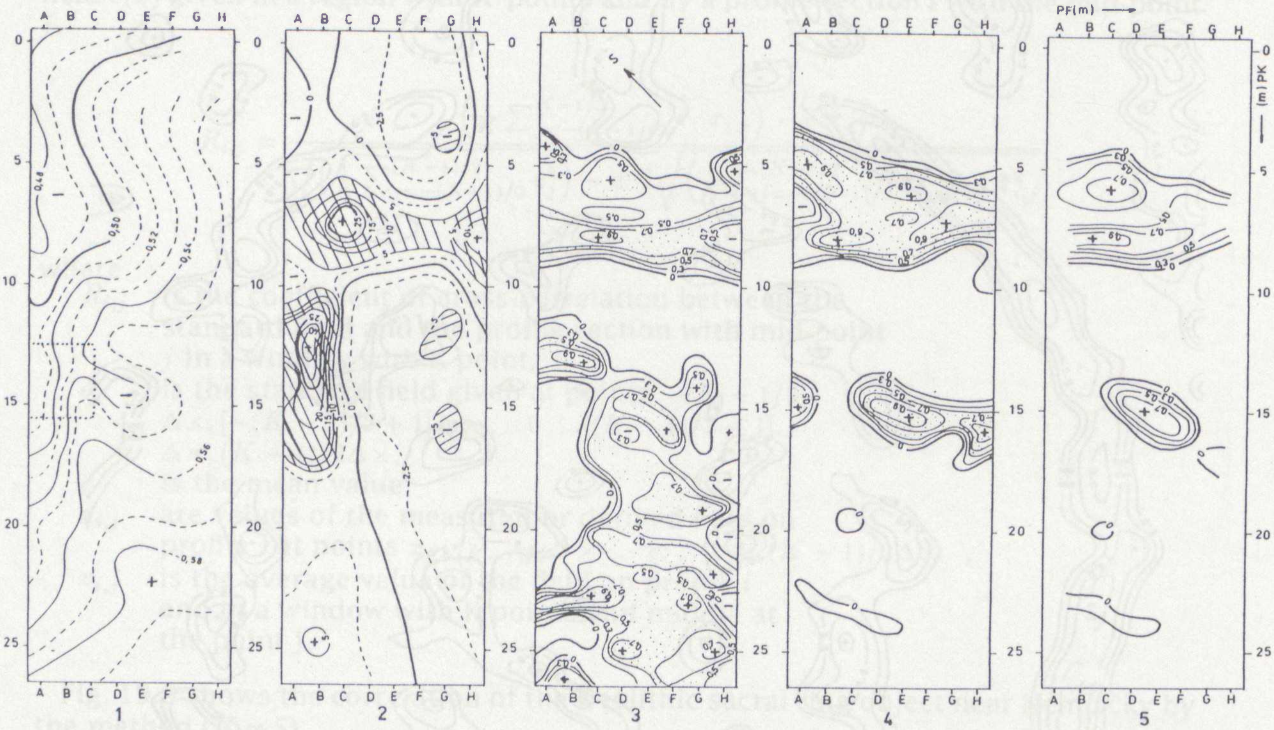

Figure 19.9: Complex processing of geophysical data from the site Zbyšov near Rosice (Brno district)

1. map of relative anomalies Δg_{rel},
2. map of isolines of DEMP anomalous resistivities,
3. map of isolines of cross-correlation coefficients for $\zeta_z^{EM}(K=3)$,
4. map of isolines od cross-correlation coefficients for $\Delta g_{rel}(K=3)$,
5. map of isolines of parameter μ.

19.5 Conclusion

We have attempted to outline some possible techniques for processing geophysical data in archaeological research, using computers available in geophysical and archaeological institutions in Czechoslovakia.

The package of programs developed for evaluation and interpretation of magnetic and geoelectric data represents only one method of solution though it may be more generally applied, for example in engineering geology and hydrogeology.

Bibliography

BÁLEK, M., V. HAŠEK, Z. MĚŘÍNSKÝ, & K. SEGETH 1986. "Metodický přínos kombinace letecké prospekce a geofyzikálnich metod při archeologickém výzkumu na Moravě", *AR*, XXXVIII: 550–574.

BERNSTEIN, R. 1976. "Digital image processing of Earth observation sensor data", *IBM J. Res. Develop.*, 20: 40–57, 300.

EISLER, J., J. PEJŠA, & K. PREUSS 1988. "A Digital Model of Archaeological Excavations as the Starting Point of a Database of Primary Information in Egyptology". In Rahtz 1988.

GRIFFIN, W. R. 1949. "Residual Gravity in Theory and Practice", *Geophysics*, 14: 39.

HAŠEK, V. 1989. *Některé nové možnosti aplikace numerického zpracování geofyzikálních dat v archeologii.* Geof. v arch. a Moder. met. ter. výzk. a dokum, Gottwaldov.

HAŠEK, V., T. B. HORÁK, & F. OBR. 1979. "Uplatnění přírodovědných metod při archeologickém výzkumu hutnického střediska v Sudicích", *Sbor. OVM Blansko*, X: 46–60.

HAŠEK, V. *et al.* 1985. "Výzkum geofyzikálních metod pro přípravu a dobývání uhelných zásob". MS Geofond Praha.

HAŠEK, V. *et al.* 1988. "Geophysical Data Processing Systems in Czechoslovak Archaeology". In Rahtz 1988.

LJUBIMOV, G. A. & A. A. LJUBIMOV 1983. "Vytchislitelnje schemy dlja sglazhivanija, interpoljscii i opredelenija vyshshich proizvodnych geofizitcheskich polej", *Razv. Geof.*, pp. 130–136.

MAREŠ *et al.* 1979. *Úvod do užité geofyziky.* SNTL, Praha.

NIKITIN, A. A. 1986. *Teoretitcheskije osnovy obrabotki geofizitcheskoj informaciji.* Nedra, Moskva.

ODSTRČIL, J. 1989. *Poznámky k separaci gravimetrického a geomagnetického pole.* Geof. v arch. a Moder. met. ter. výzk. a dokum, Gottwaldov.

PAŠTEKA, V. 1977. "Transformacia pola v magnetiometrii", *Baň. listy, mimoř. č. BU SAV*, pp. 80–87.

PRATT, W. K. 1978. *Digital Image Processing.* Wiley, New York.

RAHTZ, S. P. Q., (ed.) 1988. *Computer and Quantitative Methods in Archaeology 1988*, International Series 446, Oxford. British Archaeological Reports.

SCOLLAR, I., B. WEIDNER, & K. SEGETH 1986. "Display of archaeological magnetic data", *Geophysics*, 51: 623–633.

SIKORSKIJ, V. A. 1979. "Kompleksnaja interpretacija geofizitcheskich dannych na osnove koreljacionnoj samostrojki", *AN SSSR Geologija i geofizika*, 10: 120–126.

VENCÁLEK, R. 1988. "Programový systém umožňující vytvoření souboru dat z profilových měření a jejich zpracovaní na počitači GEOMICS a I 102F". ZN č. 3388, MS Geofyzika s. p. Brno.