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Geophysical data processing systems in Czechoslovak archaeology

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14.1 Introduction

A logical result of seeking the most effective methods of modern archaeological prospection and interpretation was including geophysics in the complex of scientific methods and technical disciplines supporting archaeological investigations. As one of the tasks of geophysical prospection is to investigate inhomogeneities originated by the action of various geological factors in a rock environment, it is used in archaeology to reveal micro-inhomogeneities represented by archaeological objects, remnants of human activity during the evolution of human society.

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Applications of geophysical methods in Czechoslovak archaeology date back to the first half of the 1960s. In the second half of the 1960s E. E. Linington conducted geophysical measurements at selected localities in Bohemia. At the turn of the 1970s there followed numerous projects realized at various types of archaeological localities, which resulted in close cooperation between archaeology, geophysics and other natural and technical sciences. The aim of the integrated research activity should be an interpretation of studied phenomena within a broader framework of social, cultural and economic development. Archaeological-geophysical investigations progressed from minor experiments and verification projects to investigations of large settlements, architectonic objects, fortifications, burial grounds, production objects, and places of exploitation of raw materials. Very detailed measurements of graves, tombs, masonry, production and settlement objects were also conducted.

An optimum way of handling these tasks proved to be inter-disciplinary cooperation between archaeological (e.g. Archaeological Institute of the Czechoslovak Academy of Sciences, Philosophical Faculty of the University of J. E. Purkyne, Brno, state and regional museums) and geophysical (Geofyzika Brno, Faculty of Natural Sciences of Charles University, Prague and School of Mines and Metallurgy, Ostrava) institutions. In Moravia aerial prospection combined with ground geophysical follow-up has been conducted prior to archaeological excavations (Bálek & Hašek 1985, pp. 19–26; Bálek *et al.* 1986, pp. 550–564). This complex field activity has yielded numerous new findings and a notable methodical contribution. The extent of archaeological activities and the quantity of data obtained gradually necessitated generation of suitable systems of geophysical data processing.

14.2 Geophysical methods in archaeological prospection and research

The geophysical disciplines employed for years in archaeological prospection in Czechoslovakia can generally be divided into two groups:

1. the most frequently applied methods—magnetometry (standard profiling, gradiometers), D.C. electrical methods (resistivity profiling with various arrangement of electrodes, VES);

2. auxiliary methods—electromagnetic (DEMP-conductometers, VLF, radiolocation, induction detectors), microgravimetry, shallow refraction seismics.

For data processing and evaluation, software was created for personal computers and microcomputers to handle:

1. field data primary processing to the form of profiles and maps of isanomals,

2. qualitative interpretation (separation of regional and local anomalies, higher derivatives, deconvolution, directional filtration, etc.),

3. quantitative interpretation (modelling, estimation of parameters of sources of geophysical anomalies by means of gradual approximation, etc.).

14.3 The main computing techniques applied for individual geophysical methods

14.3.1 Magnetometric methods

The measured values (input data) are automatically stored in memory units (semiconductor recorder). For evaluation programs are used written for the Geomics desk computer manufactured in Geofyzika Brno, namely calculation of Δ T anomalies by subtracting geomagnetic field variations and the normal field statistically determined from the measured values, or processing of data from gradient measurements.

For further data processing there are numerous programs enabling division of the measured field in local and regional anomalies, and anomalies due to noise. Of the formal mathematical methods, weighted sliding means, higher derivatives, wavelength filtration methods, directional filtrations, convolution and other methods using the same principles as gravimetry are used.

Modelling of the magnetic effects of known or assumed magnetically active inhomogeneities corresponding to the archaeological objects being sought (direct problem) and modelling used to estimate the parameters of sources of Δ T anomalies (inverse problem) determines the detection possibilities of geophysical prospection in archaeology. Although new universal methods of determining some characteristic parameters of sources of more complicated anomalies have been sought, the classical methods still play a key role in interpretation.

For quantitative interpretation program modules are applied based either on the direct analysis of measured data, *i.e.* methods using the characteristic points of curves, the method of gradual approximation, etc., or an analysis of derived data, *i.e.* using gradients, analytical field continuation, etc. Most programs for qualitative and quantitative interpretation have been modified for Hewlett Packard, ICL and DEC PDP 11/70 (LFA Bonn) computers.

14.3.2 Geoelectric methods

The measured data is stored either in the semiconductor recorder, or are recorded in field journals which are stored in the computer memory unit and are ready for further processing. So far only data yielded by D.C. methods (*i.e.* resistivity profiling and VES) is recorded automatically. Data yielded by electromagnetic profiling methods (DEMP-conductometers, VLF) except radiolocation (where the output is a time section of the measured profile, obtained during field measurements) is stored through a key-board.

The evaluation programs compiled for the Geomics and ICL computers provide information about apparent resistivities from individual methods, and smoothed or unsmoothed curves ρz anomalous resistivities along the profile and in area, gradients (combined resistivity profiling and VLF), vertical sections of apparent current densities (VLF) and pseudodepth sections (VES). Graphic outputs are curves of quantities and maps of isolines.

For profile D.C. and electromagnetic methods subroutines are used for computing higher derivatives, an application of the method of cross-correlation coefficients for 2-D linear filtering or main components, and controlled filtering. Mathematical modelling is less frequent than in magnetometry and gravimetry. More often physical modelling is used when anomalies of artificial physical fields are interpreted induced by bodies (models) situated in a medium with constant or variable physical properties. This model on a given scale simulates natural conditions.

Programs have been written for mathematical modelling of simple 2-D and 3-D conducting and non-conducting bodies for the resistivity version of the VLF method (Chyba in Bláha *et al.* 1978; Hašek *et al.* 1981). It is based on the plane wave expansion in series of Bessel or Mathieu functions. The model of the body is a circular cylinder serving for assessment of the behaviour of individual field parameters. Theoretical curves calculated for the studied body can also be used for a qualitative estimation of the effects of complex bodies. The calculation of $\rho\frac{VLF}{a}$, above a sphere is in principle identical with the calculation of the field above the cylinder though it is technically more complicated. The plane wave expansion in series of spherical waves means that the anomalous field is expressed in the form of a series of multipoles whose field is again deformed at the boundary earth-air.

Analogous is the program for interpretation of DEMP results and for determination of the detectability of horizontal conducting and non-conducting slabs.

Quantitative interpretation of geoelectric methods is performed with VES data only to determine the thicknesses and resistivities of individual layers of sections. For computer data processing it is necessary to estimate input parameters $(h_1 \dots h_{n-1}, \rho_1 \dots \rho_n)$, which can be done in several ways. A program for the direct problem (Chyba 1981) is based on a combination of the linear least squares method for ill-posed matrices, with the Marquardt algorithm for solving the non-linear least-squares problem. An optimum combination of parameters (ρ_1, h_{i-1}) is sought. The computation of the VES curve ρ starts with the Ghosh relation. The modified program uses the Nyman and Landisman coefficients.

14.3.3 Gravimetric methods

In archaeological prospection the GRASMIP gravimetric program system for microcomputers is used (Odstrčil 1984, pp. 468–472). It consists of 5 subsystems for individual phases of gravity survey, geodetic data processing, gravity data processing, computation of topographic and anthropogeneous corrections, interpretation of 2-D and 3-D anomalies, curves and fields. The first three subsystems deal with adjustment of levelling and gravimetric networks, adjustment of coordinates and elevations from polygonal and levelling traverses, formal testing and error chasing in input data, computation of mean errors, digitization of the topographic relief of anthropogeneous objects, computation of topographic and anthropogeneous corrections, data files handling, selection of gravity points along profiles and in smaller areas for interpretation and data catalogizing.

Two interpretation subsystems serve for data handling, graphic outputs of curves, maps of isanomals, axometric representation, for computing separations of 2-D and 3-D anomalies and anomalous fields by convolution, bicubic splines, polynomial methods, and for statistical data processing. In each interpretation subsystem the individual program modules are used for computation of the direct problems for individual geometric bodies and complex density models by means of polygonal horizontal and vertical prisms, and triangular prisms with inclined bases and with constant and variable densities. The programs also solve the problem for inhomogeneous medium surrounding the sources and defined by density relations to depth. Inverse gravity problems are computed for individual anomalies, and on profiles and in area for one density boundary.

The entire interactive gravimetric program system has uniform format data files by means of which the data is transferred between modules. Processing can be done in optional coordinate systems and in various units.

14.3.4 Seismic methods

In archaeogeophysical prospection refraction seismic data are processed by two programs for

1. interpretation of seismic travel-time curves by the t_o method—determination of the boundary between two layers
2. analysis of travel-time curve in two versions and determination of velocity distribution.

The two algorithms differ by the first processing stage. The data is adjusted by the first program the data by the polynomial of the chosen order by means of the least-squares method or the summation method, while the second program uses linear or parabolic interpolation.

14.4 Conclusion

With the development of our computing techniques, routines and subroutines for individual geophysical methods have been continuously improved. We have aimed in this paper was not to present practical results of our work, but to show the different methods used in archaeogeophysical data-processing in Czechoslovakia.

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