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Quality management for electrical and penetration soundings (VES & EGPS)

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The possibilities of utilizing Quality Control (QC) and Quality Assessment (QA) in the inversion of the Engineering Geophysical Penetration Sounding and in the inversion of Vertical Electrical Sounding methods are dealt with. The possible geological targets and their models, and the parameters to be determined are described. The general elements and operations of the quality controlled geophysical technology are shown. Lithology classification, quantitative evaluation, and mixed qualitative-quantitative evaluation are utilized. Field examples are used to demonstrate the evaluation results.

Keywords: geoelectrics, penetration soundings, quality management, VES, EGPS

1. Introduction

The Vertical Electrical Sounding (VES) and the Engineering Geophysical Penetration Sounding (EGPS) methods are widely used in Hungary for investigating loose sediments. Determination of the quality (reliability and/or accuracy) of their data acquisition capability and their data inversion is not only an important part of geophysical methodology, but it has recently become a strict requirement for standardizing geophysical activities too. These general technical standards relate to both the accreditation of the field data acquisition (ISO/IEC 17025: 1999) and the quality control of the inversion of the measured sounding data (ISO 5725-1: 1994/Cor. 1:1998).

The key aspects of our work are quality control (QC) and quality assessment (QA), which together will hereafter be referred to as quality management (QM). It is a very simple engineering and scientific axiom that a measured quantity without error estimation amounts to nothing. Thus

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every geophysical prospecting technology should be accompanied by reliability and/or accuracy analysis. This is a general requirement for standardization. Special planning, data acquisition and inversion techniques are needed to solve the qualification problems of the engineering geophysical exploration by VES and EGPS. The paper presents the results of methodological research work for assessing some important quality managing (QM) problems concerning the mentioned geophysical sounding methods.

At present there are no standardized quality management rules for geophysical activities, but trends can be found especially in hydrocarbon well logging. The Schlumberger, the Baker Atlas, and the Halliburton companies have worked out QC log acquisition and QC log evaluation procedures on the basis of quality controlling technology [see BATEMAN 1985] and on the basis of mathematical statistical inversion theory [see SERRA 1986]. They have been applying them since the 1980's. In their log evaluation algorithms and in software packages the quality of the output results is measured quantitatively by the Reduced Incoherence function [Schlumberger: MAYER, SIBBIT 1980; Halliburton: ALBERTY, HASHMY 1984], or by the Weighted Sum of Squared Error (WSSE) function [Baker Atlas: RODRIGUEZ et al. 1989] and by other quality indicators.

In order to determine the quality of the geophysical output results, one needs to know the data acquisition errors and the errors when modelling the inversion. For most evaluation algorithms the characteristics of the input errors are formulated as the sum of variances of two components, viz. the dispersion of the observational errors and the dispersion of the modelling errors. Qualification of the whole geophysical procedure — which includes measurement planning, execution of measurement, and data inversion — can be done by applying sophisticated modelling and mathematical statistical estimations.

2. Characterization of the examined objects

2.1. Geological targets and characteristics of the target model to be determined

VES and the EGPS are shallow penetrating methods. They are effective for the examination of young sedimentary structures, mainly loose sediments. The objects targeted by our suggested measurement and inversion technology are objects which are equally important in environment protection, water management, and engineering:

- — riverine water resources and flood areas;
- — sub-soil of waste deposits;
- — sub-soil around mud dumps;
- — other clayey, sandy and gravelly sedimentary structures;
- — river banks and dams and their geological basement;
- — earth dams around refuse dumps and their neighbourhood;
- — dikes similar to the previous ones, e.g. barrages and their neighbourhood.

The target bodies show mainly stratified structure. The task of geophysical soundings is to give a reliable qualitative classification of the soil layers and quantitative estimation of the layer parameters with a prescribed accuracy. Let us denote the unknown characteristics of the model object by the symbol x.

a) For qualitative classification ν is the particular variable of x so that there are N unknown discrete classes with the codes $\nu = 1, 2, \ldots, N$. For instance when the task is to determine the type of a given soil, the classes and codes can be for $N = 4$: clay ($\nu = 1$), sandy clay ($\nu = 2$), clayey sand ($\nu = 3$) and sand ($\nu = 4$).

b) For quantitative estimation x is replaced by the parameter vector $p(p_1, p_2, \ldots, p_I)$. A typical problem is the VES inversion, when the components of p are the resistivities ρ_m and the thicknesses d_m of a one-dimensional layer model:

$$p = p(\rho_1, d_1, \rho_2, d_2, \ldots, \rho_m, d_m, \ldots, \rho_{M-1}, d_{M-1}, \rho_M) \quad (1)$$

In the quantitative inversion of EGPS data the following models are applied, their parameter vectors are:

$$p = p\left(V_{sd}, V_{cl}, \phi\right) \quad (2)$$

and

$$p = p\left(V_{sd}, V_{cl}, \phi, S_w\right) \quad (3)$$

where

V_{sd} is the amount of sand,
V_{cl} is the amount of clay,
ϕ is the porosity and
S_w is the water saturation.

c) For simultaneous qualitative-quantitative estimation, when the unknowns are both the $\nu = 1, 2, \ldots, N$ possible classes, and for a given ν the continuous p_ν variables too, the particular realization of the symbol x is the parameter vector $p_\nu(p_{\nu 1}, p_{\nu 2}, \ldots, p_{\nu I})$. For example, the unknowns of VES can be the number M of the layers and the resistivities and thicknesses of the layers:

$\nu = 1$, if $M = 2$ and $p_1 = p_1(\rho_{11}, d_{11}, \rho_{12})$,
$\nu = 2$, if $M = 3$ and $p_2 = p_2(\rho_{21}, d_{21}, \rho_{22}, d_{22}, \rho_{23})$,
$\nu = 3$, if $M = 4$ and $p_3 = p_3(\rho_{31}, d_{31}, \rho_{32}, d_{32}, \rho_{33}, d_{33}, \rho_{34})$.

Another example is when EGPS measurements are inverted: the codes ν relate to the class of composition of the soil and the components of p_ν vector are determined by the volumetric ratios of the elementary compounds:

$\nu = 1$, if there are sand, clay, water and air, $p_1 = p_1(V_{sd}, V_{cl}, \phi, S_w)$,

$\nu = 2$, if there are sand, clay, water, hydrocarbon and air, $p_2 = p_2(V_{sd}, V_{cl}, \phi, S_w, S_{CH})$, where S_{CH} is the hydrocarbon saturation.

For our quality controlled interpretation problems the models a), b) and c) are applied.

2.2. Measured data and the corresponding theoretical responses

During the measuring activity one gets the measured data which will be denoted by y_k, for $k = 1, 2, \ldots, K$, where K is the total number of measurements.

The other types of quantities are the computed or theoretical tool responses denoted by $f_k(x)$, which are the counterparts of the observed data. Other notations of measured and theoretical quantities are the superscripts (M) and (T) respectively.

The group of experimentally observed quantities for VES contains the results of geoelectric sounding measurements, with the usual arrangements or with any arbitrary electrode configurations. The data vector for the measured $\rho_a^{(M)}(K_i^{(M)})$ apparent resistivity values is:

$$y = y\left(\rho_a^{(M)}(K_1^{(M)}), \rho_a^{(M)}(K_2^{(M)}), \ldots, \rho_a^{(M)}(K_I^{(M)})\right) , \tag{4}$$

where $K_i^{(M)}$ is the experimental coefficient of the ith arrangement.

The second group of quantities contains the computed model responses. The theoretical $\rho_a^{(T)}(p,K_i^{T)})$ apparent resistivity values for parameter vector *p* given by Eq. (1) is:

$$f(p)=f\left(\rho_a^{(T)}(p,K_1^{(T)}),\ \rho_a^{(T)}(p,K_2^{(T)}),\ldots,\rho_a^{(T)}(p,K_l^{(T)})\right) \qquad (5)$$

where $K_i^{(T)}$ is the theoretical coefficient of the *i*th arrangement. All geoelectric sounding theoretical values are deduced from the well-known integral of Stefanesco and can be computed by digital filtering [see SALÁT, DRAHOS 1974 and DRAHOS, SALÁT 1975].

For EPGS the first group of quantities contains the field results of penetration soundings. Cone resistance ($RCPT^{(M)}$) and electrical resistivity ($RES^{(M)}$) are measured during penetration. Natural gamma ray ($GR^{(M)}$), density ($RHOB^{(M)}$), and neutron porosity ($NPHI^{(M)}$) are measured in the penetration steel tube after it has reached its maximum depth. The symbolic data vector for EGPS is:

$$y=y\left(RCPT^{(M)},\ GR^{(M)},\ RHOB^{(M)},\ NPHI^{(M)},\ RES^{(M)}\right)\ . \qquad (6)$$

The second group of quantities contains the corresponding tool response functions. The theoretical values of $f_k(p)$ logs at *p* parameter vector given by Eq. (2) or Eq. (3) form the vector:

$$f(p)=f\left(RCPT^{(T)}(p),GR^{(T)}(p),RHOB^{(T)}(p),NPHI^{(T)}(p),RES^{(T)}(p)\right) \qquad (7)$$

These two types of quantities relate to a depth point or they are the representative values for a preselected layer.

For quantitative inversion the theoretical tool response functions are [see SERRA 1986]:

$$GR^{(T)}(V_{cl})=GR_{sd}+V_{cl}(GR_{cl}-GR_{sd})\ , \qquad (8)$$

$$RHOB^{(T)}(V_{sd},V_{cl},\phi,S_w)=\phi\, S_w\rho_w+V_{cl}\rho_{cl}+(1-\phi-V_{cl})\rho_{sd}\ , \qquad (9)$$

$$NPHI^{(T)}(V_{cl},\phi,S_w)=\phi\, S_w+V_{cl}\phi_{Ncl} \qquad (10)$$

and

$$R_t^{(T)}(V_{cl},\phi,S_w)=\frac{1}{(\phi+V_{cl})^m}\left(\frac{\phi+V_{cl}}{\phi\,S_w+V_{cl}}\right)^2\frac{1}{\dfrac{V_{cl}}{\phi\,S_w+V_{cl}}\dfrac{1}{R_{cl}}+\dfrac{\phi\,S_w}{\phi\,S_w+V_{cl}}\dfrac{1}{R_w}} \qquad (11)$$

is the theoretical resistivity of the soil.

In the above equations the so-called zone parameters are as follows:

GR_{sd}: gamma ray activity of sand,
GR_{cl}: gamma ray activity of clay,
ρ_w: density of pore water,
ρ_{cl}: density of clay,
ρ_{sd}: density of sand,
ϕ_{Ncl}: neutron porosity of clay,
R_w: resistivity of pore water,
R_{cl}: resistivity of clay,
m: cementation exponent.

3. Basic principles of quality controlled geophysical technologies

3.1. Elements and operations of geophysical activity

Following the inversion theory of GOLZMAN [1971, 1982], ZVEREV [1974, 1979], and TARANTOLA [1987] the essential elements of any geophysical exploration are:

— q => the sources of the field data, i.e. the environment and the transmitter and the noises;
— y_k => the data set registered by the kth measuring configuration;
— x =>the unknown that is searched for or some appropriate environmental target model;
— $\hat{x}$ => the approximate solution for the unknown x or the final result or conclusion;
— $d(x,\hat{x})$ => the difference between the exact unknown x and the approximate solution $\hat{x}$.

The basic operations or transformations between the above-mentioned elements are:

— **A** => the field measurement or the data acquisition process;
— **B** => the data processing or the inversion;

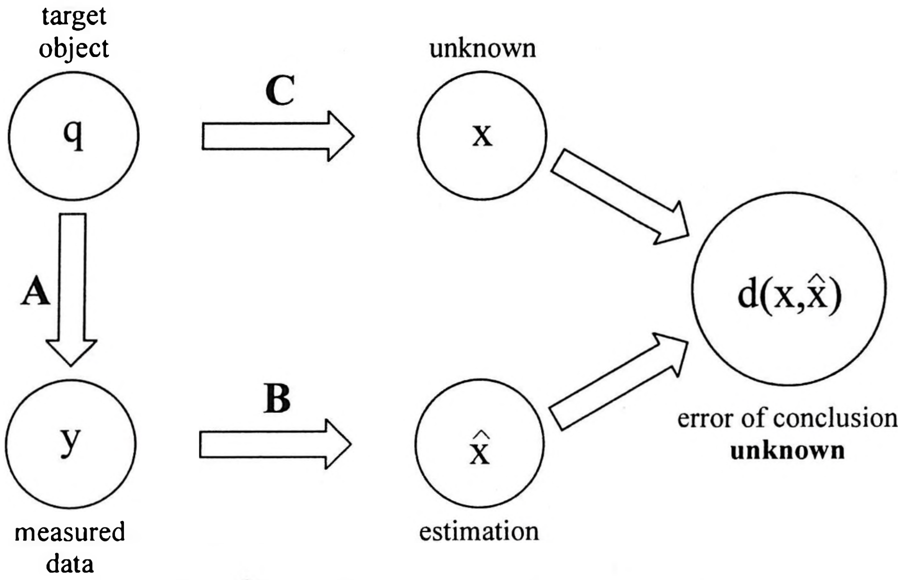
- **C** => the purpose or the modelling of the environmental target or regularization. The **C** operation selects or defines the most wanted unknowns x of the sought target object q.

In that $x = Cq$ and $y = \mathbf{A}q$ and $\hat{x} = \mathbf{B}y = \mathbf{B}(\mathbf{A}q)$, the theoretical formula for the actual individual error of the final result is:

$$d(x,\hat{x}) = d\{[\mathbf{C}q,\mathbf{B}(\mathbf{A}q)]\} \tag{12}$$

An important requirement to be satisfied by the whole geophysical procedure is that it should provide minimal average errors of the conclusions. This formula has an important role in measurement planning and in the inversion.

Figure 1 outlines the above geophysical exploration processes.



$$d(x,\hat{x})=d(\mathbf{C}q,\mathbf{B}y)=d(\mathbf{C}q,\mathbf{B}(\mathbf{A}q))$$

Fig. 1. Outline of geophysical exploration processes (modified scheme of ZVEREV [1974])
1. ábra. A geofizikai vizsgálatok folyamatábrája
(ZVEREV [1974] sémájának módosított változata)

3.2. Mathematical bases of quality management

The mathematical background of quality management of geophysical exploration can be found in GOLZMAN [1971, 1981, 1982], MENKE [1984, 1989] and TARANTOLA [1987]. The essence of these investigations is the determination of the extremum of a statistical objective function. Such a function may be the

- — $prd(x \mid y)$ posterior probability function, or the
- — $prd(y \mid x)$ likelihood function, and the very often applied
- — *WSSE* (Weighted sum of squared error) function, which has the form of:

$$WSSE(p) = \sum_k \frac{[y_k - f_k(p)]^2}{\sigma_k^2} = \min \Rightarrow \hat{p} \quad . \qquad (13)$$

In this formula the variance σ_k^2 is the sum of the variances $(\sigma_k^{obs})^2$ and $(\sigma_k^{mdl})^2$ which variances respectively represent the error of the observation and the error of modelling, if they are uncorrelated:

$$\sigma_k^2 = \left(\sigma_k^{obs}\right)^2 + \left(\sigma_k^{mdl}\right)^2 \quad . \qquad (14)$$

The covariance matrix $\mathbf{Cov}(\hat{p})$ of the results is the inverse of the so called Fisher-information matrix $\mathbf{Info}(\hat{p})$:

$$\mathbf{Cov}(\hat{p}) = \mathbf{Info}(\hat{p})^{-1} \qquad (15)$$

The (I, j) elements of the information matrix in our case are given by:

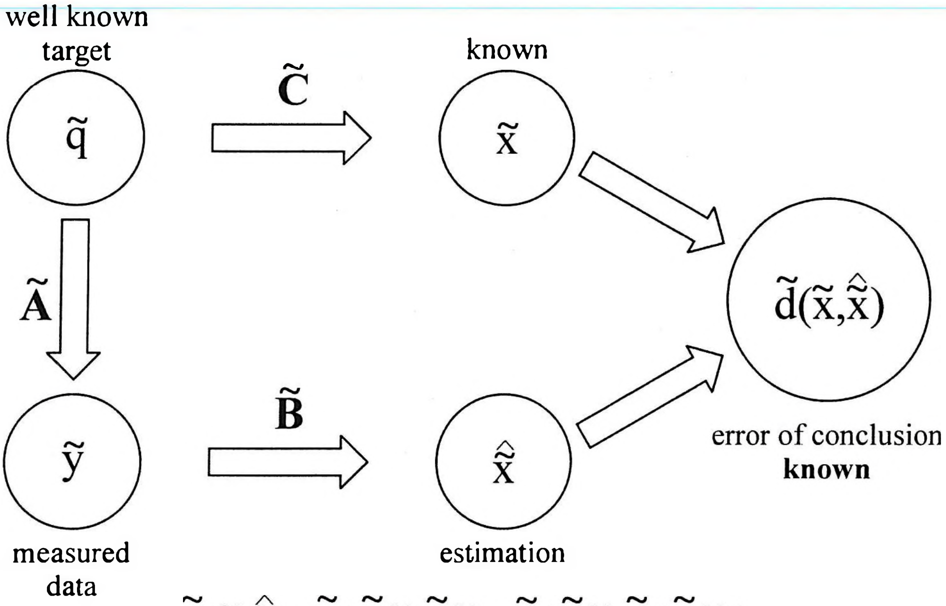
$$Info_{i,j} = \sum_k \left[\left(\frac{\partial f_k(p)}{\partial p_i} \right) \cdot \frac{1}{\sigma_k^2} \cdot \left(\frac{\partial f_k(p)}{\partial p_j} \right) \right]_{p=\hat{p}} \quad . \qquad (16)$$

The $\mathbf{Cov}(\hat{p})$ covariance matrix characterizes the accuracy of the results $\hat{p}$, its (i, j) element is $\sigma_i \sigma_j r_{ij}$. σ_i is the dispersion of the ith estimated parameter: the smaller its value, the greater the accuracy of the estimate. r_{ij} is the correlation coefficient which measures the level of the dependence between the ith and jth estimates.

4. Qualification of the data–modelling connection between VES and EGPS

4.1. Qualification for VES based on results of EGPS

The purpose of qualifying the data–model connection is to determine the magnitude of the dispersions σ_k. The direct method of determination is experimental testing. It means that geophysical measurements are carried out on sites where the underground structure is well known from other investigations. The results of the other surveys should be at least one order more accurate than that of the geophysical method to be applied. *Figure 2* shows the scheme for qualifying the data–model connection of the geophysical exploration processes.



$$\tilde{d}(\tilde{x},\hat{x})=\tilde{d}(\tilde{\mathbf{C}}\tilde{q},\tilde{\mathbf{B}}\tilde{y})=\tilde{d}(\tilde{\mathbf{C}}\tilde{q},\tilde{\mathbf{B}}(\tilde{\mathbf{A}}\tilde{q}))$$

Fig. 2. Outline of the qualification analysis of the data–model connection of geophysical prospecting (modified scheme of ZVEREV [1974])

2. ábra. A geofizikai vizságlatokban szereplő adat–modell viszony minősítés analízisének folyamatábrája (ZVEREV [1974] sémájának módosított változata)

With VES measurements the EGPS results can be used. From the EGPS measurements layer thicknesses and resistivities can directly be read. From these data VES theoretical apparent resistivities are computed and compared with the measured ones, and the statistics of the differences determine σ_k. Another known method for VES inversion on logarithmic scale is to assume that $\sigma_k = \sigma_0$ for $k = 1, 2, \ldots, N$. The common σ_0 can then be computed from the residuals.

4.2. Qualification of EGPS based on results of drillings

With regard to EGPS, the results of laboratory measurements on soil samples may form the basis for qualifying both qualitative and quantitative interpretations.

Table I contains the results of processing some 850 m penetration logs of RCPT, GR and RHOB. The soil samples were classified into the four lithological classes (clay ($\nu = 1$), sandy clay ($\nu = 2$), clayey sand ($\nu = 3$) and sand ($\nu = 4$)) after their visual inspection, and then the empirical means and dispersions of the corresponding log readings were calculated.

ν (LITHO CLASS)	Number of samples	RCPT mean (bar)	RCPT dispersion (bar)	GR mean (cpm)	GR dispersion (cpm)	RHOB mean (g/cm^3)	RHOB dispersion (g/cm^3)
1	2707	27.4	21.4	1660	282	1.93	0.11
2	1358	56.4	26.4	1096	199	1.93	0.08
3	2014	79.2	30.7	828	150	1.96	0.08
4	2491	128.4	41.5	742	162	2.03	0.09

Table I. Empirical means and dispersions of RCPT, GR and RHOB penetration logs for different four lithological classes

I. táblázat. RCPT, GR és RHOB penetrációs mérésekre vontakozó empirikus várható értékek és szórások négy litológiai osztály esetén

Table II contains the first approximations of the dispersions for quantitative EGPS inversion which were determined in a similar manner to the dispersions of Table I.

Measurement	σ_k Dispersion	Unit
Gamma Ray	0.2 – 0.3	GR_{cl}–GR_{sd}
Density	0.05 – 0.1	g/cm^3
Specific resistivity	0.3 – 0.4	On log scale
Neutron porosity	0.05 – 0.1	On decimal scale

Table II. The σ_k dispersion intervals for different EGPS logs related to three component soil model

II. táblázat. A három komponensből álló talajmodellre vonatkozó σ_k diszperziós értéktartományok

The next step is taking into account these σ_k's in the evaluation and to compare the evaluated results with the original ones, i.e. the determination of the actual values of quantity $\tilde{d}(\tilde{x},\hat{\tilde{x}})$. If these values are not small enough, there are various ways to intervene: changing the aim **C**, applying different measurement configuration **A**, or the algorithm **B** of evaluation can also be changed.

5. Examples for interpretation

5.1. Soil classification on the basis of EGPS logging data

The measured data were registered at a young alluvial region and the task was to classify the layers into the varieties in accordance with the model defined in section 2 (model a). The classification was done on the basis of the RCPT and GR logs. *Figure 3* shows the result of the classification.

The quality of the results of the classification was tested on more than 800 m length of penetration. Based on these studies the reliability of the classification was found to be 82 %.

5.2. Quality controlled quantitative evaluation of EGPS logs

A previous investigation [DRAHOS 2004] showed that the penetration electric log $RES^{(M)}$ holds real information about the soil resistivity, therefore in the following it is regarded as the measured value of the true resistivity ($R_t^{(M)}$) of the soil and it is combined with the measuring complex which now consists of the gamma ray ($GR^{(M)}$), the density ($RHOB^{(M)}$), the neutron porosity ($NPHI^{(M)}$), and the resistivity($R_t^{(M)}$).

Quality controlled formation evaluation of the measured penetration logs y_k was applied, which is widely used now in quantitative well log analysis, see MAYER, SIBBIT [1980], ALBERTY. HASHMY [1984], RODRIGUEZ et al. [1989] and CSEREPES et al. [1994a, 1994b]. The principle of quality controlled log evaluation is briefly described in section 3.2.

The measured values y_k of four different logs at a particular depth point or the representative ones for a preselected layer are $GR^{(M)}$, $RHOB^{(M)}$, $NPHI^{(M)}$, $R_t^{(M)}$. Their theoretical counterpart values computed for a soil model characterized by model parameters $p = p(V_{sd}, V_{cl}, \phi)$ (see formula (2)) are the theoretical tool response functions given by formula (8) for

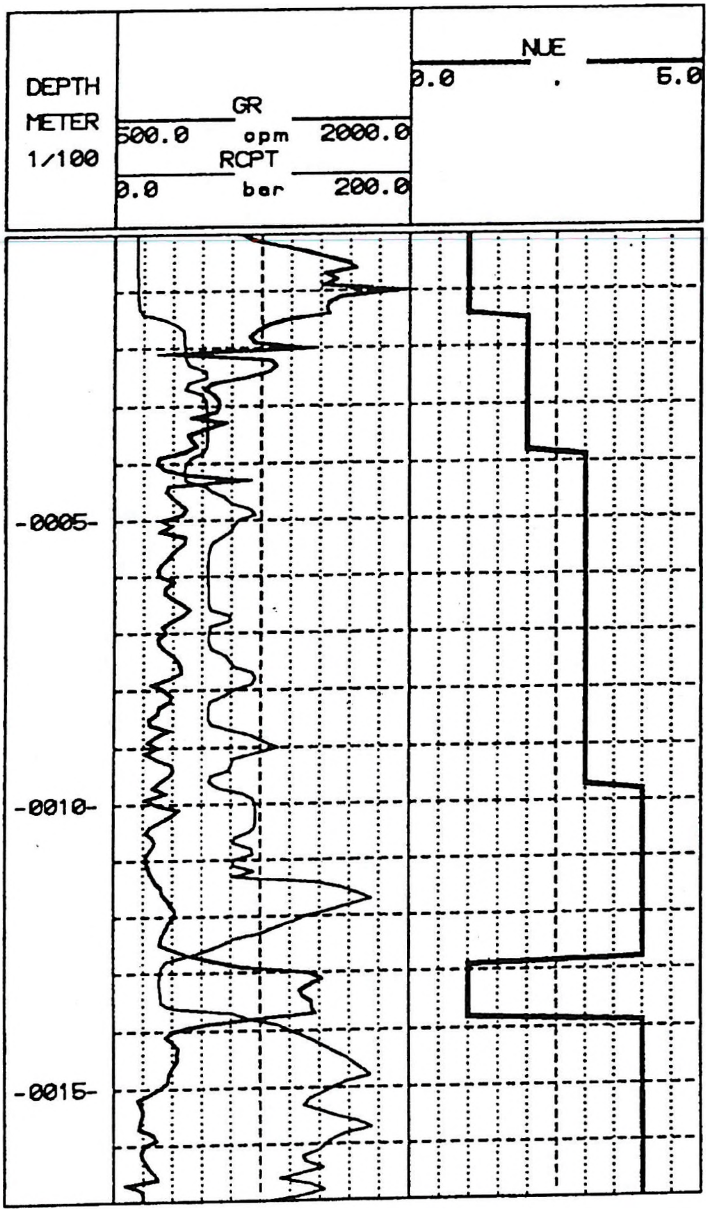


Fig. 3. Results of soil classification (NUE) based on gamma ray (GR) and cone resistance (RCPT) penetration logs (see Table I.)

3. ábra. A talajrétegek NUE minőségi osztályba sorolása természetes gamma (GR) és csúcsellenállás (RCPT) szelvények alapján az I. táblázat szerint

$GR^{(T)}(V_{cl})$, by formula (9) for $RHOB^{(T)}(V_{sd}, V_{cl}, \phi, S_w)$, by formula (10) for $NPHI^{(T)}(V_{cl}, \phi, S_w)$, and formula (11) for $R_t^{(T)}(V_{cl}, \phi, S_w)$.

Assuming normal probability distribution for the differences of the measured values y_k and the theoretical tool responses $f_k(p)$ with diagonal covariance matrix and applying the maximum likelihood estimator, one arrives at the weighted least squares criteria of (16), where σ_k^2 represents the variances relating to differences $\varepsilon_k = [y_k - f_k(p)]$ in the criterion function $WSSE(p)$:

$$WSSE(p) = \tag{17}$$

$$= \frac{[GR^{(M)} - GR^{(T)}(p)]^2}{\sigma_{GR}^2} + \frac{[RHOB^{(M)} - RHOB^{(T)}(p)]^2}{\sigma_{RHOB}^2} +$$

$$+ \frac{[NPHI^{(M)} - NPHI^{(T)}(p)]^2}{\sigma_{NPHI}^2} + \frac{[R_t^{(M)} - R_t^{(T)}(p)]^2}{\sigma_{RES}^2} =$$

$$= \min.$$

The soil model consists of sand and gravel (V_{sd}), of clay (V_{cl}), and of pore space (ϕ) saturated with water ($S_w = 1$). The following identity holds for them:

$$V_{sd} + V_{cl} + \phi = 1 \quad , \tag{18}$$

which means that there are only two unknowns ($p_1 = V_{cl}, p_2 = \phi$), and V_{sd} is calculated from (18). The applied theoretical tool response functions are the well-known formulae (8), (9), (10) and the resistivity equation of DeWitte's shaly sand model (11).

Fulfilling the condition (17) one gets the estimated values of the model parameters. The covariance matrix can also be determined by formulae (15) and (16):

where
$$\mathbf{Cov}(\hat{p}) = \left(\mathbf{A}^{TRP}\,\mathbf{Cov}(\varepsilon)^{-1}\,\mathbf{A}\right)^{1} \tag{19}$$

$$A_{ki} = \left[\frac{\partial f_k(p)}{\partial p_i}\right]_{p=\hat{p}} \tag{20}$$

and $\mathbf{Cov}(\varepsilon)$ is the covariance matrix of the differences $\varepsilon_k = [y_k - f_k(p)]$:

$$\mathbf{Cov}(\varepsilon) = \begin{pmatrix} \sigma_{GR}^2 & 0 & 0 & 0 \\ 0 & \sigma_{RHOB}^2 & 0 & 0 \\ 0 & 0 & \sigma_{NPHI}^2 & 0 \\ 0 & 0 & 0 & \sigma_{RES}^2 \end{pmatrix} \tag{21}$$

With regard to the determination of the dispersions σ_{AR}, σ_{RHOB}, σ_{NPHI}, σ_{RES} see Table II in section 4.2. Quality control is the reduced incoherence (RINC) proposed by MAYER, SIBBIT [1980]. The results of the quality controlled formation evaluation of engineering geophysical penetration sounding logs are shown in *Figs. 4* and *5*.

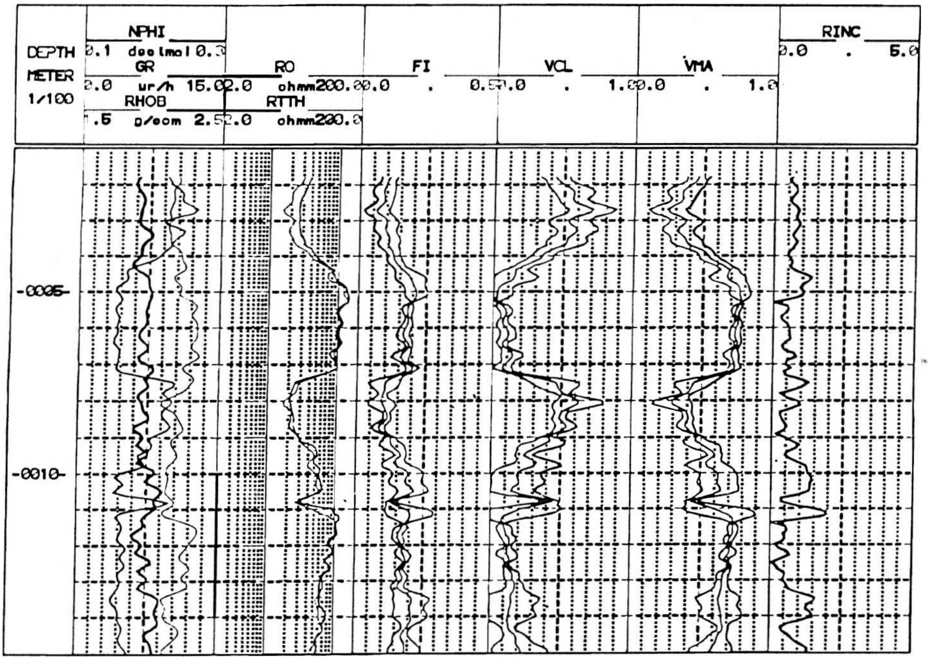


Fig. 4. Quantitative evaluation of gamma ray (GR), neutron (NPHI), density (RHOB) and resistivity (RO) EGPS logs. The volumetric ratio results are the porosity (FI), clay content (VCL) and sand content (VMA) with their plus-minus dispersion logs. The dimensionless RINC measures the overall quality of the evaluation

4. ábra. MGSZ szelvények (természetes gamma (GR), neutron porozitás (NPHI), sűrűség (RHOB) és fajlagos ellenállás (RO) adatsorainak) kvantitatív kiértékelése. Az eredmények a porozitás (FI), az agyagtartalom (VCL) és a homoktartalom (VMA) szelvények, plusz-minusz egyszeres szórásokkal együtt ábrázolva. A dimenziótlan RINC szelvény a formáció kiértékelés általános minősítésére szolgáló szelvény

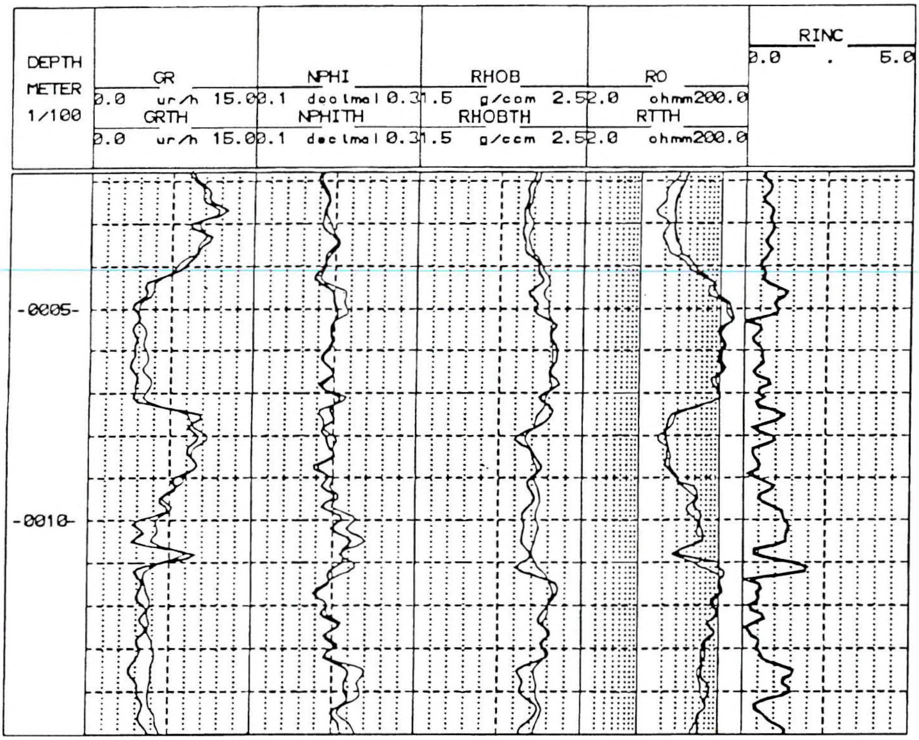


Fig. 5. Comparison of measured gamma ray (GR), neutron (NPHI), density (RHOB) and resistivity (RO) logs with the corresponding theoretical logs GRTH, NPHITH, RHOBTH and RTTH respectively

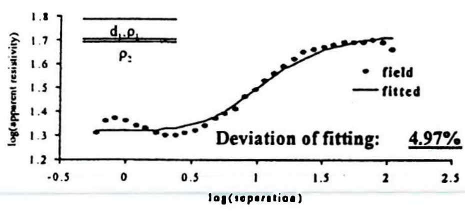
5. ábra. A mért GR, NPHI, RHOB, és RO szelvények összehasonlítása az elméleti GRTH, NPHITH, RHOBTH és RTTH szelvényekkel

5.3. Simultaneous qualitative–quantitative VES evaluation

The model which was applied is described in section 2.1 (model c) where, besides the layer parameters, the number of layers N belongs also to the unknowns. The statistical evaluation method was proposed by the authors SALÁT, DRAHOS [1974].

In *Fig. 6* there are evaluation results for two, three and four layer models for the same measured data. When the number of layers is increasing, the overall fitting between the measured and theoretical curves is decreasing. But on the contrary, the average uncertainty of the estimated parameters is increasing together with the highest correlation coefficients. The best result was achieved for the four layer model when a priori

One horizontal layer over basement



Results of the quality controlled inversion

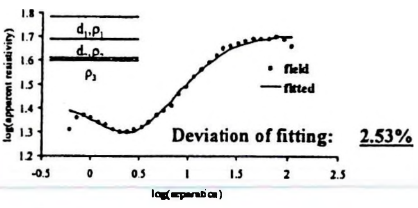
$\hat{\rho}_1 = 20.9 \pm 0.35\ \Omega m$ (1.67%)

$\hat{\rho}_2 = 52 \pm 1.13\ \Omega m$ (2.17%)

$\hat{d}_1 = 3.7 \pm 0.24$ m (6.48%)

Average uncertainty: 3.44%
Highest correlation (between ρ_1 and d_1): 0.622

Two horizontal layers over basement



Results of the quality controlled inversion

$\hat{\rho}_1 = 25.4 \pm 1.34\ \Omega m$ (5.27%)

$\hat{\rho}_2 = 17.5 \pm 0.86\ \Omega m$ (4.91%)

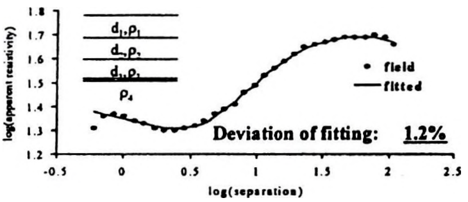
$\hat{\rho}_3 = 51.3 \pm 0.55\ \Omega m$ (1.07%)

$\hat{d}_1 = 0.51 \pm 0.13$ m (25.5%)

$\hat{d}_2 = 2.41 \pm 0.29$ m (12%)

Average uncertainty: 9.75%
Highest correlation (between ρ_3 and d_2): 0.97

Three horizontal layers over basement



Results of the quality controlled inversion

$\hat{\rho}_1 = 24.6 \pm 0.56\ \Omega m$ (2.27%)

$\hat{\rho}_2 = 18.1 \pm 0.43\ \Omega m$ (2.37%)

$\hat{\rho}_3 = 55.8 \pm 1.13\ \Omega m$ (2.02%)

$\hat{\rho}_4 = 41.2 \pm 3.4\ \Omega m$ (8.25%)

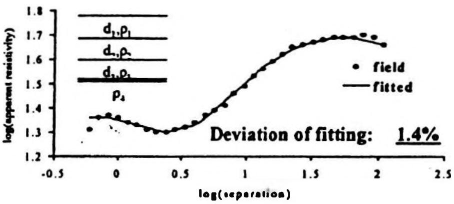
$\hat{d}_1 = 0.54 \pm 0.08$ m (14.8%)

$\hat{d}_2 = 2.81 \pm 0.19$ m (6.76%)

$\hat{d}_3 = 31.6 \pm 10.9$ m (34.5%)

Average uncertainty: 10.14%
Highest correlation (between ρ_3 and d_2): 0.961

Three horizontal layers over basement



Results of the quality controlled inversion,
using the apriori information

$\hat{\rho}_1 = 24 \pm 0.29\ \Omega m$ (1.2%)

$\hat{\rho}_2 = 16.7 \pm 0.14\ \Omega m$ (0.83%)

$\hat{\rho}_3 = 54.4 \pm 0.45\ \Omega m$ (0.82%)

$\hat{\rho}_4 = 37.1 \pm 1.47\ \Omega m$ (3.96%)

$\hat{d}_1 = 0.72 \pm 0.035$ m (4.86%)

$\hat{d}_2 = 2.3$ m (*known*)

$\hat{d}_3 = 46$ m (*known*)

Average uncertainty: 0.97%
Highest correlation (between ρ_1 and d_1): 0.76

Fig. 6. Results of simultaneous qualitative–quantitative evaluation of VES data, *field* means observed data, and *fitted* means theoretical model response

6. ábra. VES adatsorok mennyiségi–minőségi kiértékelésének eredményei, mért (*field*) és számított (*fitted*) értékek information of d_2 and d_3 was built in, which came from EGPS measurements. In this case the average uncertainty was less than 1%, and the greatest value of the correlation coefficients was only 0.76.

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Elektromos és penetrációs szondázások minőségellenőrzése

SALÁT Péter és DRAHOS Dezső

A dolgozat a minőségellenőrzés (QC) és minőségbiztosítás (QA) geofizikai alkalmazhatóságát vizsgálja mérnökgeofizikai szondázás és vertikális elektromos szondázás kutatómódszerek esetében. Ismerteti a minőségellenőrzés geofizikai technológiájának elveit, módszereit. Bemutatja a kutatandó objektumok modelljeit és a meghatározandó modell-paramétereket. Az alkalmazott kiértékelési módszerek: minőségi osztályozás, mennyiségi kiértékelés és összetett minőségi-mennyiségi kiértékelés.

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Dezső Drahos, for a photograph and biography, see this issue, p. 220.