2 METHODOLOGICAL AND INSTRUMENTAL RESEARCH

2.1 SEISMIC METHODOLOGICAL AND INSTRUMENTAL RESEARCH

2.1.1 High-frequency methodological VIBROSEIS® measurements*

Seismic reflection measurements have found an ever increasing role in ELGI's bauxite exploration program. Because of the adverse terrain- and seismogeologic conditions VIBROSEIS® techniques have come to the foreground. The relatively shallow (200–400 m) exploration tasks face us with several new problems, the most important being how to achieve a proper signal-to-noise ratio and resolution.

There are many possibilities to improve the S/N ratio: with a careful selection of the field parameters one can attenuate the vibrator-generated noise as well as the intensity of ground roll. On the other hand, the cross correlation process could decrease the S/N ratio since the vibrator sweeps that were distorted during propagation by the earth's filtering effect might significantly increase the secondary maxima of the theoretical Klauder wavelet. In order to decrease the secondary correlation maxima specially designed (e.g. nonlinear or combined) sweeps must be used which compensate for the earth's filtering effect. To achieve high resolution the mean frequency of the sweep should also be increased.

To meet these requirements, we need high-frequency vibrators and special control electronics which can generate nonlinear or combined sweeps. ELGI's Failing Y-1100 CB type electrohydraulic vibrators, supplied with Pelton's Advance I Model 5 control electronics meet the above requirements. The vibrators operate in the 8–255 Hz frequency range, the electronic control is programmable, i.e. sweeps of an arbitrary form can be generated.

Methodological measurements were carried out in connection with the bauxite-prospecting seismic reflection survey in the Tükröspuszta–Vasztély region (Hungary). The VE–4/84 profile was first measured by conventional vibrators, with a linear upsweep within the 20–100 Hz limits. A part of the profile was repeatedly measured, using the same field geometry but different sweeps *(Figs. 36 A, B* and *C)*. Section Ve–4.1/84 (Fig. 36/B) was measured by linear sweeps ranging from 44 to 160 Hz, generated by high-frequency vibrators; Section Ve–4.2/84 (Fig. 36/C) was measured by a combined sweep con-

---

* Gombár L., *György L.*, Táborszky Gy.

sisting of linear sweeps between the respective frequency limits of 25–73 Hz, 37–87 Hz and 50–100 Hz. The results are shown as migrated time sections, coloured with respect to amplitude strength.

Upon comparing the sections, it can be stated that the basic exploration task can be solved by any of them, for the surface of the Triassic dolomite basement at 200–400 m depth shows up equally well on all three sections. The signal-to-noise ratio and the horizontal and vertical resolution of the sections, however, show significant differences. On a greater part of section Ve–4/84 (Fig. 36/A) the Triassic basement surface is easily followed, it only becomes uncertain between the 1000–1300 m pickets. The position of the structural elements (faults) is uncertain, but for the relatively large fault at 450 m. The overburden of the Triassic formation cannot be further subdivided, the single event we were able to mark is an out-of-plane reflection coming from a fault proceeding nearly parallel with the profile.

On section Ve–4.1/84 (Fig. 36/B) the structural elements can already be defined with much more certainty, however, the definition of the basement surface and the internal layer boundaries of the overburden are still questionable. Due to the very strong secondary maxima, layer boundaries appear as reflection packets rather than well-defined spikes. This is due to the fact that the filtering effect of the subsurface attenuates high frequencies at a much greater extent and the linear nature of the sweep does not allow one to compensate for this effect. Because of the rapid drop-off of the frequencies due to the earth's filtering effect, even the basement reflections appear as wave trains. In order to increase vertical resolution—especially in thin-layered formations—the secondary correlation maxima should by all means be reduced.

Section Ve–4.2/84 (Fig. 36/C) gives the most reliable information: besides the basement surface, the thin Eocene layer in the overburden can also be traced. On the upper flank of the fault at 450 m the presence of Eocene is uncertain, it is possibly absent. The penetration depth of the sweep is very good since we can even find a horizon within the basement that gives an important clue for a more accurate determination of the younger fault planes (energy decrease within the basement). The vertical resolution has also increased as the combined sweep compensated the subsurface's filtering effect and decreased the secondary correlation maxima.

In conclusion, it can be stated that in our further endeavours toward increased vertical resolution, besides increasing the mean signal frequency, care should be taken that the filtering effect be compensated.

2.1.2 Seismic program package of the COROLLPRESS digital colour plotter*

For a few years now, our Annual Reports have regularly been carrying coloured displays of seismic sections. We should now like to summarize the technical specifications of the plotter and its software; these have reached their present state over several years of development.

First, a few words on the plotter. It is of rotating drum type; pictorial information is applied to a normal paper or transparent foil by electromechanical writing heads supplied with sapphire rollers. The resulting picture dries immediately, does not require any after-treatment and can be preserved for an unlimited time. At present (due to the size of the drum), the maximum picture size is 600×400 mm. It takes some 20 minutes to plot a full-size picture. The four writing heads (yellow, red, blue and black) apply special inks to each picture point, according to the control command defining the desired colour tone. A great number of possible colours and shades are available. By means of these colour mixtures the specific information content of a pixel is greatly increased. The correct operation of the device is easily checked and adjusted by a built-in TEST generator.

Fields of application: Since each pixel is individually controlled and defined, arbitrary visual information can be plotted. The equipment has proved especially useful in the construction of geophysical result maps, isoline maps, histograms, in displaying figures consisting of coloured areas — in all fields of industry, agriculture and research where a multitude of parameters must simultaneously be displayed. Further fields of application arise in image processing, e.g. in displaying satellite imagery. Successful agricultural and medical applications have also been reported.

In accordance with a recently signed contract between ELGI and CGE**, the development of a general geophysical colour plotting program package has been launched, where ELGI's main task will be to visualize seismic measurements and results. Experts of CGE, Moscow, will chiefly be concerned in general-purpose programs to translate the codes of different vector plotters into the raster format of the COROLLPRESS, as well as in problems of the joint visualization of well-log and seismic data.

The programs, already realized in ELGI, serve for the coloured display of seismic sections with respect to amplitude or frequency. The program for coloured amplitude displays eliminates the gross amplitude differences by an AGC-like regulation, and carries out smoothing using the simple 3-point normalized digital filter (0.25; 0.5; 0.25;):

$$\overline{A}_i=(A_{i-1}+2A_i+A_{i+1})/4.$$

---

* *G. Sólyom I.*, Schantzl R.

** Central Geophysical Expedition, Moscow

The aim of amplitude control is to reduce signal amplitudes to about the same level. To achieve this goal, the trace is multiplied by a so-called "regulating function" which, apart from a constant factor, is the reciprocal of the amplitude vs time curve of the given trace. The program plots the smoothed, amplitude-regulated trace, while colouring is made according to the original amplitude values. For scaling purposes, the program either selects the maximum of the trace or some externally defined maximum is accepted. This maximum is then used to normalize the values of the trace within -1 and $+1$. Finally, according to some prescribed "dictionary" of colour codes, the values are written onto magnetic tape in the COROLLPRESS raster format *(Fig. 37)*.

The program for coloured frequency displays determines the instantaneous frequency of the wave from the distance between successive zero-crossings *(Fig. 38)*. (The exact place of a zero-crossing is determined by linear interpolation).

In both programs one can display either peaks or troughs, or both. Distance between traces can arbitrarily be specified in accordance with the desired scale. Wave contours (the "wiggle trace") are plotted in black, the area under the contour is coloured according to the user-specified colour scale. The colour spectrum is also plotted, with necessary annotations and numerical values, on the left-hand-side of the section. We can also plot arbitrary legends, symbols or numbers before the section. Alphanumeric symbols can be plotted in 3 different sizes (1.6, 3, and 4 mm).

In connection with our new 3-dimensional program package it has also become necessary to display time slices in colour *(Fig. 39)*. The seismic data belonging to the same time instants are gathered from the parallel profiles and the set of data obtained is visualized as follows: for each item of data there will correspond a small square of a colour defined by the value of the given data. The correct scale is achieved by two independent scale factors (x and y) which define reduction, (or magnification if x or y is less than 1) in the respective direction. Magnification/reduction is realized by means of a 3-point Lagrange interpolating polynomial.

An important requirement in 3-D surveys is to have a coloured "bin map", i.e. a map where the colour of a given square shows the number of depth points within the given range (Δx, Δy). Also in this program, scales are arbitrarily selected, and the colour-code is user specified *(Fig. 40)*.

The COROLLPRESS provides an obvious way to generate 4 new colours simply by mixing the 3 basic ones (yellow, red, blue) in a 1:1 ratio. This, however, does not suffice for most practical purposes so that a new algorithm had to be developed to generate a greater variety of tones. This task was solved in the Central Geophysical Expedition. They generated 9 different shades of each basic colour by means of densifying and rarifying the dots within a given area. By superimposing these shades $9^3 = 729$ new tones can be obtained

(Fig. 41). The expansion of the colour spectrum offers new vistas for the COROLLPRESS plotter.

Another important part of the graphical software developed in the CGE concerns ways of communication between vector plotter/raster plotter codes. One of these programs can scale, magnify or reduce along the *x* or *y* axis, rotate or shift the results of the vector plots (originally prepared for the BENSON plotter). Another program translates the already properly scaled vector plot into raster codes so that it can directly be displayed on a COROLLPRESS. A further program, also from CGE, can efficiently be utilized for mapping purposes: it can colour by different tones any area bounded by a closed curve of arbitrary shape. The transformations mentioned above can also be carried out.

The DISC 1 program serves for a colour-coded representation of the seismic parameters. By means of this program we can prepare 2-dimensional plots in 32 colours of the different instantaneous parameters (amplitude, velocity, frequency, coherence, etc.), provided that they are stored as standard SDS–3 seismic traces. The colour-coded range of the local variation of the parameters is either automatically computed or externally specified. The automatic procedure is based on the following algorithm: the program statistically analyses the two-dimensional distribution of the given parameter and determines the colour scale; that is, it defines a correspondence between the 32 tones and the local ranges of variation of the parameter. Next, each value of the parameter is translated into the corresponding colour code. It is also possible to compute the average value of the parameter in a sliding time window along a given reflecting horizon, and to plot it as a separate graph below the seismic section *(Fig. 42)*.

There are several further developments under way, in ELGI–CGE cooperation, with the aim of extending the possibilities of the COROLLPRESS colour plotter.

2.1.3 The "Volna 96" marine data acquisition system*

The development of the "Volna" (Russian term for "wave") marine seismic complex is based on the SD–20 microcomputer-controlled seismic field system. The "Volna" complex includes the SDA–III data acquisition system which is a special off-shore version of the SDA–II, developed by ELGI for land use.

During off-shore surveys the length of the data acquisition cycle is several times greater than that of land surveys: the system should therefore be able to be utilized for continuous measurements lasting several hours or even days.

---

* Mészáros Cs.

This, first of all, affects the way the measured data are recorded. Recording is made by a magnetic tape unit. To ensure easy changing of the tapes without interrupting the measurement cycle, two tape drives are used; switching from one to the other is automatic.

For long-term, continuous recording it is absolutely necessary that the system as a whole be stable and eventual errors be easily recognized and eliminated. System stability is ensured by high-quality building blocks and careful mechanical design. Before measurement the system can be thoroughly checked in a relatively short time by means of test programs. Another task of the test programs is to delimit the possible cause and place of the eventual malfunctions. The test program package contains the memory test of the MO–51 microcomputer, the magnetic tape drive test, the test of adjustability of the parameters of the SDA–III data acquisition unit, and a test of the cable. The working conditions of the SDA–III are well characterized by the results of the following tests: dc offset test; S/N ratio analysis; identity check; cross-talk measurement; checking of the accuracy of the gain steps; checking of the corner frequencies of the filters; determination of system noise; dc offset- and linearity analyses of the A/D converter.

The records are visually checked by means of an analog multiplex display. Single-trace display can also be made by the on-line plotter.

Off-shore surveys naturally have their own specific auxiliary devices. The pressure-sensitive hydrophones are placed in long (several km) flexible plastic cables filled with oil. As the immersion of the sensors below sea-level must be taken into account in processing, these depth values should also be recorded together with the seismic data. The depth-measuring device (made in USSR) provides a digital output signal which is recorded on an auxiliary channel. The depth data are provided in time-multiplex form.

Data processing also requires that the direct signal generated by the energy source be digitized and recorded. To save magnetic tape, recording is usually started only after an appropriate delay depending on sea-depth. The source signal, which would otherwise decay during the delay time, has to be digitally stored until the recording of the seismic data begins. For this purpose we use a 4K-word memory. The source signal is recorded in an auxiliary channel. The start of the individual measurements and the timing of the shots depend on the velocity and position of the ship. The exact time of shot command is accurately determined by the ship's navigation system. The operation of the complex is shown in *Fig. 43.* The SDA–III data acquisition unit is remotely controlled by an MO–51 microcomputer. The measured data appear through the TS (Time Sharing) -bus, the formatter of the tape transport is also connected to the TS-bus. Tape transport and the state of the tape drive is continuously supervised by the MO–51. The digital AGC is also connected to the TS-bus: at its output there appears a gain-controlled time-multiplex image of the digital floating point data which can continuously be checked on an oscilloscope. A further unit connected to the TS-bus is the (Soviet) plotter-interface controlled by an ELEKTRONIKA-60 microcomputer, the separating and storing stages (ELGI development) are built in the SDA. If the data acquisition unit is interfaced to the real-time pre-processing system, the shots and the SDA–III are controlled by software.

A further development of the SDA–II data acquisition unit of the SDA–20 land system has resulted in an increase of the original (maximum 48) number of channels to 96 while the minimum 1 m sampling rate was cut to 0.5 ms — without changing the parameters of the well proved digital gain controller and A/D converter of the SDA–II. The following number of channels and sampling rates are used:

24 channels	0.5, 1, 2, 4 ms
48 channels	1, 2, 4 ms
96 channels	2, 4 ms.

The increased speed is due to the multiplex operation of two parallel measuring systems. The operation principles of the SDA–III will be clear on the basis of *Fig. 44:* outputs of the hydrophones or of internal generators are led through the electronic roll-along switch to the input of the preamplifier. The first stage of the preamplifier is a symmetrical, direct (galvanic) input — variable amplification, asymmetric output amplifier. Amplification can be $E=18, 24, 30, 36$ dB. Gain setting is possible in groups of 24 or 48 channels. Next comes a high-pass filter of 24 dB/octave slope, and with cut-off frequencies of 5, 10 or 15 Hz. This is followed by a notch filter rejecting the 50 Hz ac, which can be switched on or off, and by a low-pass (antialias) filter ensuring the appropriate upper limiting frequency in accordance with the sampling rate. Its slope is 72 dB/octave, its cutoff is automatically set to one of the values $f_a=62.5, 125, 250, 500$ Hz depending on sampling rate. The filters and many other functions are controlled by a "parameter setting" unit.

The signal to be measured reaches the input of the digital gain controls through a low-level multiplexer. The digital gain can be $0 \leq E \leq 84$ dB, it changes in $\Delta E=12$ dB steps in accordance with the amplitude of the measured signal. Resolution of the A/D converter is $13+1$ bit, its output signal reaches the TS-bus through an interface unit. The data of the successive channels follow each other with a timing in conformity with the SEG B tape format. The signal formatter (unit 6 of Fig. 43) synchronizes the data recording and matches the digital and analog auxiliary channels. The data finally enter the input of the tape transport. These units generate the final tape format or, in case of playback from the tape, it reproduces the TS-bus format.

2.1.4 Further development of the floating-point array processor*

In 1984 we further developed the floating-point array processor. It was found during field tests that the safety of operation of the processing system can greatly be increased if the disc used as background memory is substituted by a semiconductor memory. Keeping this in mind we developed an "electronic disc", its present capacity is extendable from 1 to 16 Mbytes. We plan a further increase in the capacity of the background memory up to 32 Mbytes. The application of the "electronic disc" also resulted, besides greater working safety, in a decrease in data transfer times. For procedures involving correlation, the required store capacity has been halved since summations can simultaneously be carried out with the loading of data.

The interface of the array processor has also been redesigned, its new version can split the 16 bit words into bytes. The special processor has been supplemented by fast image-processing procedures required by the introduction of underwater photo- and TV techniques used in sea-floor prospecting. The arithmetics of division has also been improved: it can now carry out divisions by fixed-point and floating point numbers as well. The realization of fixed-point division also renders possible the division of non-normalized floating-point numbers.

The presently available Fast Fourier Transform can be used to transform 0.5 K, 1 K or 2 K complex data arrays from the time domain to frequency domain, or back.

The operation requires

7 ms for	0.5 K data
16 ms for	1 K data
32 ms for	2 K data.

The extension of the FFT to 4 and 8 K arrays is currently under way. In order to make full use of the FFT in correlation procedures we have realized the element-wise multiplication of two complex arrays. The schematic diagram of the array processor performing the above-described tasks is shown in *Fig. 45*.

2.1.5 Seismic measurements in Dorog Coal Mines for water prevention purposes**

Dorog Coal Mines, producing one of the best brown coals in Hungary, are seriously endangered by water inrush. Water can mainly be expected from the basement of Eocene sediments, consisting of strongly karstic Triassic limestone

---

* Elsner M., *Komjáthy J.*, Lazarovits Gy., Méry T., Páhi L., Rajnai R.

** *Bodoky T.*, Cziller E., Braun L.

and dolomite, which almost directly underlies the coal-bearing formation. The danger of water inrush is greatly increased by the presence of large—in some cases greater than 100 m—faults, dissecting the basin floor into blocks. In cases when the mining operation proceeds in the downthrown parts of these faults, e.g. in Colliery XXI of Dorog Coal Mines, it is not sufficient to know the position of karstic rocks below the mining level, one also has to know the great boundary faults along which these rocks are elevated high up above the mining area.

To date, the mining industry has only been able to rely on borehole information—from drillings either from the surface or from inside the mines. The first procedure is very expensive whereas the second is, even in itself, a dangerous activity, especially in cases where such high water pressures occur as in the deep levels of Dorog Mines. A further disadvantage of such drillings is that for each of them a water preventing pillar should be marked out which increases the amount of coal left behind and causes difficulties when planning the winning. Consequently, only a limited number of boreholes can be drilled to determine the position of the karstic rocks, i.e. usually, one can only guess the position of the limestone surface in lack of adequate information. These circumstances explain our motivation in experimenting with other, mainly non-borehole, geophysical techniques.

When we analysed the research task and the mines where the measurements were to be carried out, we decided to use the seismic method. In in-mine seismics the elastic waves usually propagate from source to geophone in four different ways: as direct waves, reflected waves, refracted waves or channel waves. The various seismic techniques applied in mines make use of all four types of waves. For in-mine limestone prospecting however, with the aim of water prevention, the analogues of the familiar reflection and refraction methods seemed to be most appropriate.

In Colliery XXI of Dorog Coal Mines we have been carrying out in-mine seismic reflection and refraction measurements since 1982, partly as methodological experiments, partly for geological prospecting purposes. Both in the reflection and the refraction methods special problems have been encountered due to the mine conditions. In the reflection method the main deviation from surface measurements had been the occurrence of reflection arrivals not only from vertical or near-vertical directions but practically from any direction of the whole space. What we recorded was an exceedingly complex, hardly interpretable interference pattern of waves coming from different angles. To circumvent this problem, at least partly, we tried to apply the principle of directed wave fronts for the source, and a three-component recording and "quasi-polarization" processing for the receiver.

For refraction measurements the shortness of open drifts caused the main problem. This difficulty was magnified by the relatively high-velocity Eocene fresh-water limestone overlying the Triassic bedrock which significantly elongated the minimal distances from where the basement would have become detectable. Since this problem cannot be solved by measurement methodology, the refraction technique had to be limited to longer drift sections or to detect very near-lying basement blocks.

Limestone prospecting in Dorog Coal Mines will be illustrated by two measurements: by a reflection and a refraction survey. *Fig. 46* shows reflection results obtained in the No. 38 development drift of Colliery XXI. The location of the fault, which bounded from the north the deep-level mining operations, had been known from two boreholes (D–297, D–199). Mining engineers applied the usual principle of "greater safety" and constructed a relatively flat fault plane based on these two drillings. During winning, the pillar was determined with respect to the fault plane constructed in this way.

The seismic reflection survey performed in development drift No. 38 showed that in the measurement level the limestone wall, i.e. the fault plane, was some 25 m farther than constructed. Thus, on the basis of borehole D–297 and of the seismic results, the boundary fault plane was constructed anew. This resulted in a more accurate definition of the water prevention pillar and in the release for winning of a substantial amount of coal.

Fig. 47 presents a refraction project, in the base road of level –120 m of Colliery XXI. This measurement was decided on when the mining authorities were deliberating about extracting the so-called "C" seam from below the road. The basement below the road was known to the Mining Engineering Office only from laterally projected data of relatively distant boreholes, so that it seemed necessary to check these data by geophysical means. The results of the refraction measurements have shown a striking agreement with former geological maps, with regard to tectonics, i.e. in the location and character of faults, although the depth of the limestone surface, found by refraction, was only about half of the previously assumed 35–50 m. Consequently, the mining plant gave up the idea of extracting the "C" seam as this was within the boundaries of the water prevention zone.

These experiments carried out in Dorog Mines open up a new field of application for in-mine seismics and offer a new tool for miners in their struggle against water inrush. Obviously, these results cannot be considered more than the first exploratory steps along the way towards a powerful new technique.

2.2 GEOELECTRIC AND GRAVITY METHODOLOGICAL AND INSTRUMENTAL RESEARCH

2.2.1 A study of the domain of investigation of frequency sounding*

Practical problems of frequency soundings with artificial sources, both in the field and during interpretation, have called our attention to the following questions. What is the "domain of investigation" of the measurements for different frequencies and how does this domain depend on the applied frequency? A previous study [PRÁCSER et al. 1983] based on numerical calculation of the standard horizontally layered geoelectrical model provided the dependence of the measured field characteristics on the conductivity distribution as a function of depth; this gave us a possibility to investigate the depth-resolution of a given method. This model, however, cannot be applied to derive the dependence of the measured values on lateral conductivity changes.

A full answer to this problem should of course be postponed until the general 3-dimensional direct problem has been solved. Until that time, however, we feel that even partial results might deserve attention. The study to be presented deals with the case of a small-sized interbedding, whose resistivity differs only slightly from that of the surrounding rocks. It is assumed that this interbedding lies in a homogeneous whole space. We study the relative values of the anomaly fields due to the inclusion for different geometrical positions of the latter, along a plane passing through the dipole source and containing its momentum. It is also assumed that these values do not significantly differ from the relative values due to a similar anomalous body placed in a half-space. Thus, in the computations and when stating our conclusions the plane of the magnetic dipole transmitter loop is also referred to as the "surface plane".

Let us consider a normal or primary model consisting of a homogeneous embedding medium of conductivity σ_K for magnetic dipole induction. To this model, there belong the field strength values $E^{(n)}$, $H^{(n)}$ at an arbitrary point of the space. Suppose that the total, or secondary, model consists of a body T of conductivity σ_T embedded in the above-described homogeneous medium, under the same excitation. Denoting the characteristic function of T by χ_T that is $\chi(x)=1$ if the point x is an element of the body T, and 0 otherwise the spatial conductivity distribution of the secondary model becomes

$$\sigma=(1-\chi_T)\cdot\sigma_K+\chi_T\sigma_T \tag{1}$$

---

* Szigeti G.

(see *Fig. 48*). Let the field strengths E, H belong to the model described by conductivity function σ.

In an attempt to solve this general problem, DMITRIEV and FARZAN (1980) derived an integral equation for the field strengths E, H. The integral equation contains the $E^{(n)}$ values as already known quantities. For three-dimensional interbeddings of arbitrary shape the solution of this integral equation is a very difficult task. In what follows, we shall show a very much simplified version of the derivation, for a special type of causative body, which yields a simply computable end result.

For a fixed frequency, the Maxwell equations for the total model assume the form

$$\begin{aligned}\operatorname{rot} E &= i\omega\mu H\\ \operatorname{rot} H &= \sigma E + j,\end{aligned} \tag{2}$$

where j is the current flowing in the loop of the inducing dipole, σ is given by Eq. (1). For the normal model this system of equations becomes:

$$\begin{aligned}\operatorname{rot} E^{(n)} &= i\omega\mu H^{(n)}\\ \operatorname{rot} H^{(n)} &= \sigma_K E^{(n)} + j.\end{aligned} \tag{3}$$

By subtracting system (3) from (2) we find that the anomalous field ($E^{(a)} = E - E^{(n)}$ and $H^{(a)} = H - H^{(n)}$) satisfies:

$$\begin{aligned}\operatorname{rot} E^{(a)} &= i\omega\mu H^{(a)}\\ \operatorname{rot} H^{(a)} &= (1-\chi_T)\sigma_K E^{(a)} + \chi_T\{\sigma_T E - \sigma_K E^{(n)}\}.\end{aligned} \tag{4}$$

If we could consider the second term on the r.h.s. of the second equation of system (4) as a source-term, this would imply that the $E^{(a)}$ and $H^{(a)}$ components of the field were due to independent sources in the homogeneous field of conductivity σ_K.

Let x_0 denote an arbitrary point of $T (x_0 \in T)$. Consider $E(x_0)$ as a function of σ_T and T. Suppose that T is so small that $E(x_0)$ depends only on volume ΔV and on the specific conductivity of body T:

$$E(x_0, \sigma_T, T) = E_{x_0}(\sigma_T, \Delta V).$$

Further, assume that E_{x_0} can be defined as a function of two real variables σ_T and ΔV in a small vicinity of the point $\sigma_T = \sigma_K$ and $V = 0$, and that this function is at least twice continuously differentiable in this neighbourhood of point $(\sigma_K, 0)$. We have

$$\begin{aligned}E_{x_0}(\sigma_K, \Delta V) &= E_{x_0}^{(n)}\\ E_{x_0}(\sigma_T, 0) &= E_{x_0}^{(n)}\end{aligned} \tag{5}$$

implying that the first derivatives are missing in the two-variable Taylor series development of E_{x_0}:

$$E_{x_0} = E_{x_0}^{(n)} + \left.\frac{\partial^2 E_{x_0}}{\partial\sigma\partial V}\right|_{\substack{\sigma=\sigma_K\\ V=0}} \Delta V(\sigma_T - \sigma_K) + \dots$$

where the omitted terms tend to zero at least in the third order. Thus, in Eqs. (4) we can write $E_{x_0}=E_{x_0}^{(n)}$ for an arbitrary $x_0 \in T$ if

$$\Delta V(\sigma_T-\sigma_K)\ll 1 \tag{6}$$

That is, by Eqs. (4), the anomalous field components, $E^{(a)}$, $H^{(a)}$ are due to the current density

$$j=(\sigma_T-\sigma_K)E^{(n)}$$

arising in the points of body T. Finally, if $E^{(n)}$ is assumed as constant whithin T, and T is taken as a prism of cross section A perpendicularly to $E^{(n)}$ and of height dl, the total current flux through T is

$$I=Aj=A(\sigma_T-\sigma_K)E^{(n)},$$

which corresponds, along the length dl, to and electric dipole

$$M_e=dlI=dlA(\sigma_T-\sigma_K)E^{(n)}=\Delta V(\sigma_T-\sigma_K)E^{(n)}.$$

Summing up the results of the derivation: if the interbedding satisfies condition (6), then the anomalous field can be taken as if it were due to a dipole, at the same place as the interbedding and having the moment

$$M_e=\Delta V(\sigma_T-\sigma_K)E^{(n)}. \tag{7}$$

Consequently, the anomalous electromagnetic field can be computed in two steps. First, we take a dipole placed at the spatial transmitter point X_A in a homogeneous total field of intensity M_m and compute the induced electric field $E^{(n)}$ at point x_0 of the causative body. Next, we put an electric dipole into a total field of intensity M_e (obtained from $E^{(n)}$ by Eq. 7) and compute the EM field induced at the receiver point.

Let us now apply Eq. (7) to derive the distribution of the magnetic field component $|H_z^{(a)}|$ of a magnetic dipole source, placed on a plane considered as the surface. The small-sized causative body of small conductivity contrast is moved along a plane S perpendicularly to the surface. The $E^{(n)}$ component of a dipole placed in a total field can be expressed in spherical coordinates as

$$E^{(n)}=E_\varphi^{(n)}=\frac{M_m}{4\pi}\, i\omega\mu \cos\alpha \,\frac{1}{r_1^2}\,(1+\gamma r_1)e^{-\gamma r_1}, \tag{8}$$

where $\gamma=\sqrt{i\omega\mu\sigma_K}$, M_m is the dipole moment of the transmitter. Since E_φ is perpendicular to plane S, the φ' component of the magnetic field of the electric dipole, provided by Eq. (7) in the same direction as E_φ becomes, at a surface point,

$$H_{\varphi'}=\frac{M_e}{4\pi}\,\frac{1}{r_2^2}\,(1+\gamma r_2)\mathrm{e}^{-\gamma r_2}. \tag{9}$$

The meaning of the geometrical parameters is given in Fig. 48.

Introducing the real induction number $B = L\sqrt{\omega\mu\sigma_K/2}$, taking into account that $H_z = H_{\varphi'} \cos\beta$ and that we are only interested in the magnitude of $H_z^{(a)}$, we obtain from Eqs. (7)–(9) that

$$|H_z^{(a)}| = C\frac{1}{(r_1/L)^2}\frac{1}{(r_2/L)^2}\cos\alpha\cos\beta\cdot$$

$$\cdot\sqrt{\left(1+B\frac{r_1}{L}\right)^2+\left(B\frac{r_1}{L}\right)^2}\sqrt{\left(1+B\frac{r_2}{L}\right)^2+\left(B\frac{r_2}{L}\right)^2}\,e^{-B\frac{r_1}{L}}e^{-B\frac{r_2}{L}} \qquad (10)$$

with

$$C = \frac{M_m(\sigma_T - \sigma_K)\omega\mu\Delta V}{16\pi^2}.$$

Figure 49 shows the $|H_z^{(a)}|$ values of the anomaly field due to a causative body moving along plane S, where S is perpendicular to the surface and contains the transmitter and the receiver. Values measured at the receiver points along the surface are displayed at that point where the centre of the causative body is found. Strictly speaking, we plotted the relative values of the anomalous field, normalized by the anomaly value due to a similar causative body placed midway along the transmitter-receiver section. Thus, the distributions shown in Fig. 49. do not depend on the parameters figuring in coefficient C of Eq. (10). A scrutiny of Fig. 49 allows the following conclusions, for the case when the induction number is $B = 0.33$:

a) Identical anomaly fields belong to causative bodies which are symmetrical with respect to the plane perpendicularly bisecting the transmitter-receiver line.

b) Near the surface, very large effects are obtained if the causative body approaches the transmitter (receiver). At surface point $r_1 = L/10$, for example, the effect is 7.66 times larger than at $r_1 = L/2$.

c) Causative bodies situated along a vertical line beneath the transmitter do not cause any anomalies.

d) From among the causative bodies which are in a horizontal plane at a depth of 1/3 the transmitter–receiver distance, or deeper, the greatest anomaly belongs to the body under the point bisecting the transmitter–receiver line.

If we suppose that the geophysical task is to detect a given causative body, then the domains bounded by the different isolines of Fig. 49 indicate the shape and size of that part of the space which can be studied by means of the given frequency. If we define the limit of detectability as a fraction $1/e = 0.37$ of the effect due to a body in the surface symmetry point, we can state—for the induction number $B = 0.33$—that this range consists of an ellipse-like domain beneath the transmitter-receiver range, its depth being some 0.4 times L, as well as of two smaller regions of about 0.3 *L* width, extending beyond transmitter and receiver, respectively.

In *Fig. 50* we study only this domain, i.e. that bounded by the 0.37 isoline, and its dependence on induction number. The explored region becomes gradually deeper and broader as the induction number decreases. In case of lower frequencies we always have to expect during interpretation that there is a non-negligible lateral effect coming from the outside of the transmitter-receiver range.

In further experiments under way we plan to study the spatial movement of the causative body. From these studies we hope to gain new insight into the different resolving properties of frequency soundings carried out dip-wise or strike-wise over geological structures.

2.2.2 Physical modelling of the inductive electromagnetic frequency sounding*

Inductive electromagnetic frequency sounding has successfully been applied in Hungary for several years for prospecting solid mineral resources, primarily bauxite and coal. For horizontally layered models the different electromagnetic field characteristics can fairly accurately be determined by mathematical modelling. For more general 2- and 3-dimensional structures the description of the total electromagnetic field becomes very difficult and—unless special approximations are made—the field strengths can be computed only by time-consuming numerical procedures. Thus, the resolving power of the method, or the distortions due to near-surface inhomogeneities, are more effectively studied by physical modelling. To begin with, we experimented with two- and three-layer models partly to check the equipment itself.

The measurements were carried out in the Electromagnetic Modelling Laboratory in Sopron, jointly established by the Research Institute for Geodesy and Geophysics of the Hungarian Academy of Sciences, the Geophysical Exploration Company of the Hungarian Oil and Gas Trust, and the Eötvös Loránd Geophysical Insitute. Earlier studies from this laboratory concerned the modelling of electromagnetic frequency sounding and profiling with conductive source, magnetotelluric measurements and dc mapping (cf. Annual Report for 1980).

In electromagnetic frequency sounding the ratio of the vertical and horizontal magnetic field strengths is measured and, during processing, apparent resistivity–depth sounding curves are computed. To model such measurements, a new measuring complex was developed in 1983–84. The complex accurately executes a large number of frequency soundings in a relatively wide frequency

---

* *Csathó B.*, Gémes M., Kardeván P., Prácser E., Szarka L. (MTA GGRI)

band (20 kHz–6 MHz), eliminates the need for transmitting high-frequency signals (10 kHz mean frequency) and automatically records the signals *(Fig. 51)*. The power amplifier feeding the transmitter loop is controlled by a high stability syntheser-generator. The signal of the receiver coil is amplified by the wide-band preamplifier near the coil, then it is transposed to 10 kHz mean frequency by the modulator. The modulator signal is generated by the same syntheser-generator controlling the transmitter. Any further transmitting, amplifying and filtering of the signal is performed on 10 kHz mean frequency. A Commodore–64 personal computer is used for data recording; the sampling times are controlled by photoelectric sensors.

In order to check the accuracy of modelling, a horizontally layered two-layer model with resistive basement was simulated in the model tank, using NaCl solution. The field strength ratios were also determined for the corresponding models. As shown by *Fig. 52* the deviations between computed and measured values do not exceed 1% for any frequency.

As is well known, breaks of the transformed ϱ_a (apparent resistivity) versus *H* (apparent depth) sounding curves indicate geoelectric layer boundaries. As an example, consider the MFS curve of *Fig. 53/A*, measured over a brorehole in a Transdanubian study site. It can be seen, that for horizontally layered models, like the present example, no definite break appears on the transformed curve *(Fig. 53/B)*. If, however, we make the layer boundary, i.e. the basement, slightly dipping (2° in the present case), the break appears much more conspicuously (Fig. 53/C). The phenomenon can be observed both with strike- or dip-oriented spreads. Since, in reality, layer boundaries are rarely perfectly horizontal, this might contribute to their chance of being detected.

Figure 54/A shows an electromagnetic modelling result over a conductive interbedding. The layer boundaries are indicated, with an error of 4–6%, by the points of intersection of the tangents of the curve sections. The same phenomena can be observed on the field curves obtained over the Hannukainen (Finland) ore occurrence *(Fig. 54/B)*.

2.2.3 Magnetotelluric instrument development*

By the summer of 1984 we had finished the development of the DEF–7, a new member of the DEF magnetotelluric measuring equipment family. Apart from magnetotelluric measurements, this digital equipment can be used to record electromagnetic field transient measurements, deep frequency soundings as well as induced polarization measurements. A block diagram of the DEF–7 is shown in *Fig. 55*.

---

* Varga G.

By comparison with the DEF–1 measuring device (Annual Report for 1976 p. 134), the DEF–7 has the following advantages:

- it is controlled by an INTEL-8080 microprocessor instead of the TTL circuits used in the DEF-1. The microprocessor means greater reliability and a flexible, programmable measurement control;
- the E_z component of the natural electromagnetic field can be measured in addition to the conventional, 5-channel magnetotelluric measurements. Knowledge of the E_z component promises new possibilities in MT interpretation. By means of E_z one can determine and—during processing—take into account horizontal wave propagation, as well as the inhomogeneity of the source field;
- simultanoeusly with the measurements the measured data can be led, through a parallel output, to a microcomputer which can carry out real-time quality control and preprocessing;
- the connection to an external channel creates a possibility for synchronous measurements.

After field check-ups and calibration, MT measurements were performed with the equipment in the fall of 1984 over 20 points.

2.2.4 Geophysics in the service of archeology*

Within the framework of cooperation between the Central Office of Geology and the Excavation Committee of the Academy of Sciences, our Institute has, for a number of years carried out geophysical reconnaissance surveys to detect archeological finds to promote archeological excavation work.

In the past 2 years we solved various tasks at 10 sites, using different methods. The archeological artifacts can be grouped into three broad categories as regards the geophysical techniques which can be used for their prospecting:

1. High-resistivity (limestone) walls in a (shaly) soil of lower specific resistivity can be detected by radar- and resistivity profiling;
2. Burned objects (fire-places, kilns, debris of brick and roof) can be prospected by magnetic measurements due to their thermoremanent magnetization;
3. Ancient mine pits filled with rubble usually appear as resistivity lows in a higher resistivity surrounding, i.e. their location and size can be determined by geoelectric profiling.

In dowtown Ságvár the digging up of a Roman fortress had been hindered by many obstacles: the built-up area, the incomplete nature of the original walls because of their exploitation during constructions in modern times, and

---

* Pattantyús–Á. M.

the high groundwater level. Even the excavations recommenced in the 1970's could not clarify the position of the eastern wall of the fortress near the marshy area. In view of all the difficulties geophysics was commissioned to determine exactly the location of one of the deepest parts of the fortress, the barbican at the SE corner. Our first measurements were made by the GPR (*G*round *P*robing *R*adar) geological radar system of Geophysical Survey System Inc., USA, whose recommended field of application is archeological geophysics.

Radar provides high-resolution continuous profiling. The basic idea of the method is that an electromagnetic impulse is generated on the surface, the signals reflected from the boundaries between geoelectrically different formations are recorded by a wide-band receiving screen. A characteristic record is shown in *Fig. 56.* On the radar record the wall-remains consisting of materials of higher dielectric constant create many reflected waves while the surrounding soil absorbs a large fraction of the waves. The reflected waves appear in dense, dark zones by means of which the wall-remains can be isolated. The depth was determined by an approximate method: at a known depth near the exploration site, we buried a well-reflecting (metal) object whose clearly recognizable signal provided a reference depth on the records. At the top of the record the places of the characteristic features referring to wall-remains are indicated, together with a resistivity measurement carried out subsequently along the same profile. The resistivity highs appear at the very places where the walls had been assumed on the basis of radar. The mapping of the barbican in the corner of the fortress took only half a day by means of radar profiling.

At the Visegrád–Várkert site magnetic measurements were carried out in a project connected with the archeological excavation of the "Váralja" settlement dating from the XIth century, belonging to the bailiff's castle. For each of the subterranean dwellings kiln-remains were associated causing, according to our measurements, some -50 $+90$ nT magnetic field strength variations. The magnetic map of a smaller area is presented in *Fig. 57/A* where the two greater anomalies are caused by kilns belonging to houses, as proved by excavation. The objects are well defined even though there are two factors disturbing the magnetic field in the survey area:

1. near the southern corner of the area there is a steel container which exerts a considerable effect;
2. the whole site is in an area of recent volcanic rocks which have a high degree of magnetization.

The measurements were carried out at two heights above the ground, and vertical gradients were computed *(Fig. 57/B)* to reduce the disturbing effects. The measured data were also processed by a high-pass filter. The filtered map *(Fig. 57/C)* almost exclusively consists of the anomalies due to the kilns sought for.

The exploration of a Roman homestead at Balácapuszta, over an area of

16 hectares, involved the use of geoelectric resistivity measurements. Archeological excavation of the site began at the beginning of the century; the approximate location and size of 12 buildings have been determined to date; in the 70's two buildings were excavated. In order to locate further buildings geoelectric resistivity measurements were carried out. A characteristic resistivity section is shown in *Fig. 58*. Curve *a* presents the measured values after smoothing. The resistivity map of the site was constructed on the basis of several such profiles. On these maps the resistivity highs refer to near-surface debris zones, that is, they show the extent of the building. Curve *b* of the figure was constructed by convolving the measured values by a filter derived from a theoretical model. The task of filtering had been to extract the effect of the walls from among the effects due to debris. By correlating the wall-indications of the filtered profiles we have succeeded in constructing a possible ground plan of the building complex.

In Farkasrét, on the outskirts of Budapest, various finds (flintstone splinters, tools made of deer antlers) have come to light, scattered over a fairly large area — referring to the presence of a nearby flint mine *(Fig. 59)*. On the basis of the geoelectric profiles measured parallel with the sidewall of the plateau (see Fig. 59), the low-resistivity debris zones within the high-resistivity dolomite were singled out for excavation. One of these low-resistivity zones which, according to the depth sections, reached down to deeper levels, did indeed correspond to the place of the flint mine, as was proved by subsequent excavation. Judging from a preliminary dating by the archeologists, the flint mine is 50,000 years old (Middle Palaeolithic), which is a unique find in Europe, deserving considerable attention. *Figure 60* shows a perspective picture representing the assumed position of the mine pit, constructed on the basis of the measurements.

In addition to the previously mentioned cases, there have been a number of other prospects where geophysics was successfully applied to archeological problems. In Aszód, in the area of the Small Balaton, and at the Alsóhetény-puszta site, we continued the measurements started in former years (Annual Report for 1982 pp. 216–217). In Visegrád, in the interior court of the bailiff's castle built upon a Roman fortress on the Sibrik Hill, we located two buildings by resistivity profiling, their excavation is planned for 1985. In Esztergom, we could also use resistivity profiling to delimit a buried part of a medieval Benedictine cloister, protruding under a sports ground.

In achieving these results we obtained significant help from Dr. József Korek, deputy director of the Hungarian National Museum, and from the cooperating archeologists leading the excavations: Dr. Endre Tóth, Julia Kovalovszky, Zsuzsa Lovag (Hungarian National Museum), Dr. Vera Csánk (Budapest Historical Museum), Szilvia Palágyi (Bakony Museum, Veszprém) and Mátyás Szőke (King Matthias Museum, Visegrád).

2.2.5 Interpretation of gravity measurements in mountainous terrains*

The gravity surveys of mountainous terrains require a special method of interpretation. When constructing Bouguer anomaly maps various corrections are applied to the measured values; in the mountains, however, it is not sufficient to execute these familiar corrections. Since no method has been described to date in the technical literature for these problems, we have undertaken, since 1980, the task of developing a new technique.

In gravity surveys of mountainous terrain, the following are the main sources of error:

- Bouguer anomalies refer to the surface of an irregularly changing topography rather than to a plane: this leads to a distortion of the value and shape of the anomalies;
- since the Bouguer correction is computed by an assumed constant average density, local correlations arise between the altitudes and the Bouguer anomaly values. These local correlations make interpretation even more diffcult.

These sources of errors point to the problems to be solved:

- The gravity anomalies corresponding to varying a.s.l. altitudes should be recomputed to some common datum plane. This can be achieved by analytical upward continuation.
- By making use of the local correlation between the measured gravity data and the altitude values one has to determine, from point to point, the average density of the near-surface rocks, and to use this density function to correct, from point to point, the Bouguer anomaly values.

In 1984 we wrote a program to compute the near-surface average density, and a program for analytical upward continuation. Both have successfully been applied in a smaller experimental site of the Mátra Mts., though as far as the computation of the correlation is concerned, a number of problems remain to be solved.

The new interpretation method will be utilized in the processing of the gravimeter measurements carried out in the W. Mátra Mts. between 1980 and 1984.

---

* *Pintér A.*, Stomfai R.

2.2.6 Determination of the topographic effect by means of a computer*

Previously, for computing the topographic effect, we read out the average altitudes from a map for each point of measurement. The average altitudes referred to annular sectors. The corrections belonging to the given altitude values were found from published tables. This procedure was exceedingly tedious and time-consuming, and a very probable source of error. In view of this, we decided to realize this computation on a computer.

The recently developed method of computing topographic corrections is based on a data system consisting of the average altitude values for regions of 100 m×100 m, read out from contour maps of 1:100,000 scale. As against earlier procedures the region subjected to topographic correction is a square, rather than an annular sector. The earlier procedure took the topographic effect within the area of a circle of 44 km diameter into account, the new method takes into account a square of 51 km side.

The computation of the topographic effect consists of two parts:

- computation of the far-field effect;
- computation of the near-field effect, including the so-called immediate effect.

In the computation of the *far-field effect*, the region subjected to this procedure is divided into square rings (zones, see *Fig. 61*), where the interior side-length of the greater zone equals the outer side-length of the successive, smaller zone. The individual zones are divided into squares of different areas—depending on their distance from the point of measurement—and these squares serve as bases of the prisms. The average heights of these square prisms are also computed as mean values of the average heights of square prisms of 100 m×100 m cross section.

The zones are defined as follows:

	outer side length (km)	inner side length (km)	base area of the prism (km^2)
zone *a*	51	15	3×3
zone *b*	15	5	1×1
zone *c*	5	3	0.5×0.5
zone *d*	3	1.8	0.3×0.3
zone *e*	1.8	0.2	0.1×0.1

The square of 200 m×200 m within the innermost zone (of 1.8 km side-length) means the immediate vicinity of the point of measurement; that is, it belongs

---

* *Schőnviszky L.*, Stomfai R.

to the computation of the *far-field effect* and should not be taken into account in the present case. For those points of measurement which are in the interior area of zone *e* (the area of 1 km×1 km denoted by dashed line in Fig. 61), the distribution into zones is taken as fixed.

To speed up computations, the effect of square prisms exerted on the point of measurement is computed by means of an approximation. Within a neighbourhood of 300 radius around the point of measurement the effect of the square prism is approximated as if it were due to 9 mass points situated at the vertices and at the centre of gravity, respectively, of the prism (this method is due to Prof. F. Steiner of Technical University, Miskolc, Hungary). The more distant prisms are substituted by so-called gravitational sticks ("mass threads"). The procedure is programmed for a RYAD-35 computer. The program computes the far-field effects for the points of a grid of 100 m×100 m spacing, fitted to the lattice on the stereographic maps, for 5 different altitudes. The resulting tables appear as printouts. The tables are used by the field crew in such a way that the topographic far-field effect of a measurement point inside a 100 m×100 m area is determined, between the given altitude ranges, by interpolation, as a function of the distance of the given point from the corner points.

Besides this tabular solution, we also prepared a special program for the RYAD-35 which directly carries out the computations for each point of measurement. The topographic correction for the gravity survey, measured between 1980 and 84 in the Mátra Mts., has also been performed by this latter program.

For the computation of the *near-field effect* the square of 200 m×200 m surrounding the point of measurement is divided into 25 squares of 40 m×40 m size *(Fig. 62)*. The topography of the innermost square of 40 m×40 m yields the *immediate effect*, the average heights of the other 24 squares of 40 m×40 m define the near-field effect. For the computation of the near-field effect the average heights are read out from a contour map of 1:10,000, for each point of measurement. The computation of the near field effect is not based on the square-prism approximation, as this would be very time-consuming, but a third-order approximation is applied, realized on a programmable HP-41C pocket calculator. The calculation of the immediate effect takes care of the central square (solid line in *Fig. 63*). This square contains the point of measurement in its centre. For the computation of the immediate effect, besides the average height of the central square we also need the average heights of the four adjoining squares (Fig. 63). The central square is divided into four truncated smaller squares where a small square of 2 m×2 m is missing from around the point of measurement, as it is assumed that within an area of 4 m×4 m we have a planar terrain. The computation is again based on a rapid third-order approximation.

2.3 WELL LOGGING INSTRUMENTAL AND METHODOLOGICAL RESEARCH

2.3.1 Determining neutron-physical parameters*

Based on results of methodological and instrumental research during the past year, methods of determining new parameters (e.g. slowing-down length, absorption cross section) adding to a more accurate determination of known physical parameters (e.g. density, neutron porosity) enabled us a more reliable interpretation of rock formations.

The flow-diagram for determining density and neutron physical parameters to be calculated from gamma–gamma and neutron–neutron logs is presented in *Fig. 64.* Parameters corresponding to the main components of the theoretical rock model are calculated with the aid of basic data tables. The components of a studied formation should be taken for known in order to be able to set up its theoretical model. Rocks encountered in practice have sophisticated compositions where as in our calculations we are obliged to consider the rock as being composed of 2, 3 or 4 components at most — with a known composition. The relative volume of main components or their composition in weight per cent within the formation is regarded as known. Thus, a general relationship permitting one to determine the said parameters can be written as follows:

$$X_t = V_1X_1 + V_2X_2 + \ldots + V_kX_k$$

where

X_t is a parameter characterizing the studied theoretical model (e.g. density, absorption cross section);

$X_1, X_2, \ldots X_k$ are the parameters calculated theoretically for the main formation components;

$V_1, V_2, \ldots V_k$ are the relative volumes of the main formation components;

k is the number of main formation components.

The density (electron density) and neutron physical parameters are included in basic data tables. For example, the microscopic neutron cross section values of various element types required for calculating the neutron physical parameters are contained in the data store of the SABINE diffusion program elaborat-

---

* *Andrássy L.*, Baráth I., Kovács N.

ed within the scope of EURATOM and published in 1974. The neutron physical parameters (group constants) are produced from the above data by two segments of the mentioned program viz. by the routines SABAD and CSOPAK.

As an example the values of neutron porosity, slowing-down length L_f, diffusion length L_d and migration length L_m for theoretical models of limestone and sandstone are presented in *Table II.*

With the knowledge of the calculated parameters the theoretical flux distribution or the spectral distribution of backscattered gamma-radiation can be calculated for the studied theoretical models (theoretical calculations of four group diffusion, Monte-Carlo calculations) with the corresponding sonde parameters being taken into account.

The Metrological System for Well Logging built in ELGI provides the opportunity to perform the calibration of gamma–gamma and neutron–neutron sondes of any type under idealized borehole conditions (constant temperature, constant pressure, constant water saturation, etc.). From the result of calibration measurements it is possible to deduce mathematical formulae maintaining the relationship between typical parameters of the formation, measured counts and borehole parameters.

To determine density and neutron physical parameters more precisely one has to know the rock matrix. The Th content to be determined from spectral natural gamma logs and the slowing down length L_f to be determined from neutron–neutron logs can be used to plot an L_f-Th cross plot diagram, which in turn permits one to determine the rock matrix. *Fig. 65* presents an L_f-Th cross plot constructed on the basis of theoretical model calculations.

The determination of density and neutron physical parameters from gamma–gamma and neutron logs is illustrated on a practical example. Logs of various types run in borehole "N" are shown in *Fig. 66*. These logs also include the continuous log of slowing down length L . Relying on these materials the density, neutron porosity and neutron physical parameters (slowing down length L_f, diffusion length L_d, absorption cross section Σ_{at}) were calculated for coal, clayey coal, limestone and clayey limestone. The results of this calculation are given in Table II. The values of density ϱ_b, neutron porosity Φ_N and slowing down length L_f shown in the table were determined from continuous logs with the aid of the KFU–4–12 universal surface module. The density and neutron porosity values have been corrected for hole diameter and mud cake effect.

Formations indicated in the table were considered as composed of three main components and, using the three-dimensional cross plot L_d–ϱ_b presented in *Fig. 67*, we determined the relative volume of main components in the given formations [the calculated values are in columns *c* (matrix), *n* (total water content) and *h* (contamination) of *Table III*].

2.3.2 Magnetic susceptibility measurements in coal exploration*

In our Annual Report for 1982 it was mentioned that magnetic susceptibility ($\varkappa$) measurements in boreholes have been conducted by ELGI since 1979. At that time we reviewed the state of the art in all Hungarian survey areas and summarized the values measured in various rock types in the form of a qualitative frequency chart 1982 Annual Report (p. 147). A further task was to elaborate the interpretation technique for typical values of individual rocks. Consideration was given as to whether the magnetite content should be calculated or whether, instead, some kind of relationship should be established between measured results and ancient environment (geochemical environment being implied). Over the past year the bulk of our well logging activities were performed in the lignite area on the southern slope of the Mátra mountain, thus $\varkappa$ logs were run in 14 holes. In the Visonta area the non-productive part of the coal complex was essentially a part of a delta formation which was deposited under water. The whole complex represents a parallel series of coal beds. The log from the Vécs–35 borehole is shown here as a typical example. The series includes—in addition to lignites—clays, silts and sands *(Fig. 68)*. The average susceptibility value of sands is $\varkappa=1.5\times10^{-4}$ in SI. The clays show somewhat higher values of $\varkappa=2\times10^{-4}$ in SI. The highest values are usually related to clays. There is a conspicuously good correlation between the magnetic susceptibility and gamma-ray logs. The minima are related to lignites (the lowest value being $\varkappa=5\times10^{-5}$ in SI). Organic clay deposits overlying and underlying the coal beds or appearing within them as thin laminae manifest themselves with the highest values. It can be assumed that these organic clays containing lignite are analogous with the oil shales in Nógrád county, where similar experience was gained with magnetic susceptibility and gamma-ray logs. In the mentioned borehole the "O" bed and the "I" bed seem to be continuous, the boundary between them can be marked off with the aid of the $\varkappa$ log (an interbedded clay lamina exists at the 87–88.5 interval).

Another diagram is presented from the István Colliery at Komló *(Fig. 69)*. Here the maxima of magnetic susceptibility are connected to barren–turned sections of the coal bed. Samples were also taken from these sites (not from drilling), the magnetizable part of which is composed of a pyritic, but mainly marcasitic intergrown band, and of slaty coal at its top and bottom. These horizons can be assumed to be syngenetic, of marshy origin and not to be due to subsequent changes. Starting from this condition such horizons can be used for the identification of beds. Sidewall samples were also investigated by the KT–5 manual magnetic susceptibility gauge and it was observed that the $\varkappa$ value of black shaly coal is higher than that of the marcasitic part. In the

---

* Zilahi-Sebess L. Jr.

Radiological Department of ELGI, analysis of samples has shown that the iron content of shaly coal and marcasite is nearly the same. Thus deviations in magnetization are due to the iron being present at one place in the form of FeS_2; it turned into hematite or magnetite by losing its sulphur content.

The measurements permit one to infer that the value of magnetic susceptibility is caused by the content of magnetizable minerals, but there is no unambiguous relationship between rock types and magnetic susceptibility like the magnetizability of sand which, being about $\varkappa = 10^{-3}$ in SI, is clearly higher than that of clays. Such relationships exist in certain areas only. As an example, let us mention here the relationship between grain size and $\varkappa$ value observed on the alluvial cone of the Maros river, which is actually due to mineral composition. It can similarly be established that in the lignite area on the southern slope of the Mátra mountain the $\varkappa$ log can, like the natural gamma log, be regarded as a clay indicator. There seems to exist, however, a more general relationship between the lithofacies and magnetizability since it holds everywhere for Pannonian formations that sands are characterized by low magnetizability at $\varkappa = 5 \times 10^{-5}$–$10^{-4}$ in SI, while clays have a magnetizability of $\varkappa = 2-4 \times 10^{-4}$ in SI. An obvious explanation of this phenomenon is that these formations indicate an identical paleo-enviroment, this is why they appear with such similar values.

It was also generally observed that the organic clays, coal bed traces, and the interbedded coal streaks always represent maxima as compared with the embedding rocks. With regard to this observation individual coal beds can also be identified on the basis of the interbedded spoil laminae in them. The magnetizability of common clays is generally low ($\varkappa = 2 \times 10^{-4}$ in SI), thus even for clays the $\varkappa$ value can preferably be related to the paleofacies. Strictly speaking the paleofacies implies the state ratio of iron oxidation from the viewpoint of susceptibility measurement. This means that the magnetizability of deposits formed in stagnant water is carried by secondary formed minerals the genesis of which was affected by redox conditions. Contrary to this, for deposits of running water a primary role is played by the erosion area and the energy of water flow. This was experienced on logs measured over the alluvial cone of the Maros river. Hence, in evaluating the series of river deposits when the place of origin has to be determined the $\varkappa$ log is a valuable aid.

In a sedimentary complex the $\varkappa$ log is used similarly to the natural gamma log, since both can be used for geological correlation, stratigraphic investigations in boreholes, or as clay indicators. These parameters are not directly related to porosity, permeability or density.

Similarly to gamma-ray logs the $\varkappa$ logs are of primary importance in geological correlation and in the recognition of geological facies. Similarly to spectral gamma logging, over a sedimentary area it is the qualitative geological information to be deduced from the ratio of individual radiating materials that actually counts in the measurement of magnetic susceptibility though it is not the actual quantity of magnetite that we are interested in. In quantitative interpreatation it has, like gamma-ray logs, an indirect role since there are many corrections depending on area, i.e. in reality on facies, for the determination of which it furnishes useful data. Here, for example, the strong dependence of the formulae for effective porosity on clay type or the determination of ash content in coals from density, are considered, the latter also being strongly dependent on area, in fact on facies.

2.3.3 Interpretation program systems*

Processing of coal-exploration logs

The coal program system developed for a HP computer at an earlier stage was introduced into daily routine in 1984. It was utilized as a new type of service in the Visonta exploration area.

The replacement of manual interpretation work by computerized interpretation permitted us to calculate and visualize physical parameters point by point along the borehole axis. This was achieved by dividing the procedure into the following phases to be performed on a HP 9825 B type computer:

- digitizing the logs (for analogue logs only);
- entering logs from punched type or field cassette into the data store;
- processing;
- display.

In accordance with the requirements of geological survey and industry, the following kinds of documentation are compiled:

1. Explanatory text containing information about the well and measurement parameters.
2. Computer drawn plots of the measured sections.
3. Computer drawn plots of the results of automatic processing (including lithology, porosity, density, ash content, caloric value, moisture, clay content curves).
4. Tables of crossed coal beds—including thin spoil laminae within the bed—with the indication of characteristic physical parameters.

The above documentation is photographed on microfilm for the purpose of preservation in archives.

---

* *Mészáros F.*, Bihari A., Lach Zs., Kovács N., Bagi R., Szalai M., Karas Gy.

Minicentre

In the course of the year the construction of a well logging minicentre based on a COMMODORE–64 computer was started. The task of the new minicentre will be to perform interactive processing of well logging materials from shallow wells on the one hand, and to establish new measuring techniques, as well as to test them, on the other. At present the minicentre is composed of the following hardware units:

- COMMODORE–64 computer;
- SEIKOSHA graphic printer;
- COMMODORE cassette tape recorder;
- JVC TV monitor;
- input unit (made by ELGI) based on a Memodyne casette tape recorder.

In 1984 the well logging data store system named "WELL" was created. As to its structure, the WELL is a program package for storing measured log data on magnetic disc and furnishing data for individual geophysical programs. The programs of the data store maintain data flow in either direction (borehole parameters, measured diagrams, processed results) between the computer memory and the background store on magnetic discs. After the data storage system had been completed the work on elaborating geophysical processing programs was commenced.

Program system for processing data of small diameter dipmeter measurements

The processing program system for our own developed 3-arm sonde has been elaborated. The correlation technique was chosen as a starting point for determining the true dip angle and dip direction of beds. The procedure for calculating the true dip of strata can be divided into four phases:

1. Entering the data of the dipmeter sonde (three microresistivity curves, the coordinates of the magnetic field: h_x, h_y, h_z, the coordinates of the inclination of the sonde: i_x, i_y, borehole diameter) recorded on magnetic tape into the computer.
2. Identifying indications from identical layers on the entered resistivity curves and determining the relative depth shift of corresponding indications.
3. Determination of dip values on the basis of calculated depth shifts, borehole diameter and orientation data. In the coordinate system of the sonde the normal vector perpendicular to the apparent bedding plane of strata is determined, then this normal vector is transformed into the fixed coordinate system of the Earth. From the transformed normal vector values the true dip angle and the orientation of the layers are determined.

4. Visualization of the calculated results in tables and various plots.

The program package has been put into operation on a R-35 computer by processing experimental field measurement data.

2.3.4 Evaluation of hydrocarbon reservoirs by the COMWELL–B.R./ELGI interpretation system*

In cooperation with the Oil Exploration Company, Szolnok, the COMWELL–B.R./ELGI interpretation system for the evaluation of well logging data obtained in hydrocarbon containing beds of heterogeneous facies is being elaborated. In 1984 the work was oriented towards complicated complexes composed of clayey and silty anisotropic sandstones and shales.

The essence of the problem is that the mineral composition of clays and silts embedded in sandstones as well as their distribution shows sophisticated varieties in Neogene sandstones; the problem is exacerbated by the low ion content of pore waters, which significantly increases the effects of clay minerals and silt fraction on the well logging parameters. It is often observed, too, that the electric resistivity of hydrocarbon-bearing sandstones (R_t) is scarcely higher than that of water-bearing sandstones not containing clay and silt (R_0) particularly if the clay and silt laminae follow the morphology of thin impermeable streaks and bands, thus leading to the formation of anisotropic rock facies. In such cases it is often rather difficult to reveal the presence of productive hydrocarbons and to obtain reliable data on water saturation (S_w) and hydrocarbon saturation (S_{hy}) from the analysis of logs. The problem is further aggravated by the significant volume ratio of clay and silt (V_{cl}, V_{si}) leading to the increase of irreducible water saturation in sandstone (S_{wi}) and even at values of 0.4–0.6 of the latter, water-free hydrocarbon can be produced from the beds.

The system uses the following fundamental principles to solve the problem:

1. The interpretation model accounts for all rock components affecting, to any extent, the geophysical parameters and it accounts for the basic versions of their geometric patterns (dispersed or thin layered). In accordance with this the spatial model of sandstone compositions follows the composition shown in *Fig. 70*. This model also accounts for the adsorption water content in each component (Φ_{ads}). Total porosity (Φ_t) of the rock is represented by the sum of the effective and the adsorption porosities.
2. The interpretation system uses response functions with many variables —in correspondence with the multi-component rock composition—to

---

* Barlai Z.

describe well log parameters. For example, the response function of rock resistivity is as follows:

$$\frac{1}{R_t}=\frac{V_{l,i}}{R_{l,i}}+\frac{1-V_{l,i}}{R_s},$$

where $R_{l,i}$ is the resistivity of impermeable streaks and bands, and R_s is the resistivity of permeable laminae:

$$R_s=\frac{R_w}{\Phi^m}\frac{1+L}{(S_w+L)^2}.$$

Here L is the so called lithological influence factor; which plays an important role in the COMWELL–B.R./ELGI system, since the effects of clays and silts are accounted for by this quantity:

$$L=\left(\frac{V_{cl,sw}}{R_{cl,sw}}+\frac{V_{cl,nsw}}{R_{cl,nsw}}+\frac{V_{si}}{R_{si}}+\frac{V_{sd}}{R_{sd}}+\frac{V_{ca}}{R_{ca}}\right)\frac{R_w}{\Phi}.$$

In this formula R_w is the resistivity of pore water, the macrophysical resistivity of rock components marked in the indices represents the rest of the R quantities. In the Neogene sandstones of Hungary the relative macroscopic resistivities are as follows:

$$\frac{R_{cl,sw}}{R_w}=0.4;\qquad \frac{R_{cl,nsw}}{R_w}=2;\qquad \frac{R_{si}}{R_w}=5;\qquad \frac{R_{sd}}{R_w}=\frac{R_{ca}}{R_w}=50.$$

The response function of the propagation time of sonic compression waves can be constructed in a similar way.

3. To increase the efficiency of interpretation the COMWELL–B.R./ELGI system uses deterministic and statistic interpretation program modules in a hybrid way. It should be noted that the total number of input parameters and mathematical stipulations for the statistical modules exceeds the number of output parameters whereas for deterministic modules these numbers agree.
4. The system uses special calibrations in the interpretation process; the calibrations begin with the cross-plot analysis of input parameters and are continued with the statistical optimization of intermediate parameters (e.g. specific geophysical effects); if there is an opportunity the data of laboratory characteristic values measured on drilled cores are also involved in the optimization of representative values of individual interpretation quantities.
5. The system pays great attention to the determination of fluid saturation: in addition to the determination of water saturation by the usual absolute method the procedure of multiple comparison is also applied in the scope of which the geophysical parameters of the investigated site are compared

with those of so called reference sites where water saturation is accurately known from other information sources.

6. The COMWELL–B.R./ELGI interpretation system determines a wide diversity of output parameters to furnish as much quantitative information as possible to users in evaluating hydrocarbon reserves and qualifying the industrial value of certain reservoir sections when compiling production test and recovery projects, and later for the technological control of production.

   The output parameters include, of course, the volume fractions of rock components and fluid saturations; apart from these there are the hydraulic parameters such as permeability, specific pore surface and capillary properties. For instance, the porosity component filled by adsorption water is calculated by the formula

   $$\Phi_{ads} = L\Phi \frac{R_{ads}}{R_w},$$

   where R_{ads} is the electric resistivity of the adsorption water shell; it should be observed that in the Neogene sandstones of Hungary it varies within the range of $R_{ads}/R_w = 1/8$ and $1/12.5$.

In the course of further improving the COMWELL–B.R./ELGI system endeavours will be made to involve information on all future well logging parameters in the system and to extend it to more and more varieties of reservoir rocks.

2.3.5 Construction of nuclear instruments*

For mineral and water exploration purposes a new type of sonde was developed. The KGϱSP–3–80–32sY sonde with a diameter of 43 mm operates on a single conductor in pulse-type mode and permits 0.1 m +0.4 m potential and gamma-ray logs to be run simultaneously or, after being switched over, it can measure 1.6 m gradient + SP and gamma-ray logs. Thereby, three important fundamental logs can be recorded during a single run.

The working principle of the sonde is illustrated in *Fig. 71.* The electrodes are built in the form of rings over the sonde casing made of insulating material. Within the sonde casing, the electronic cartridge carries out the resistivity, SP and gamma-ray measurements, i.e. sends these data in the form of pulses with three different amplitudes through one conductor of the armoured cable to the surface.

---

* Szentpály M., *Korodi G.*, Nagy M.

The measure point of the gamma-ray channel is placed at the measure point of the 0.4 m potential arrangement, thus the merge of the electric logs to a common depth point on the basis of the gamma-ray log has been substantially simplified.

The block diagram of the sonde is presented in *Fig. 72.*

Natural gamma radition is detected by a photomultiplier mounted on a NaI(Tl) crystal, potential measurement is performed by current generator and measuring amplifiers, the signal of the latter is processed by the voltage-frequency converter. The output pulses of the three channels are forwarded to the surface by an encoder stage built with stepping registers and stores, thus the forwarded pulses are free of coincidence. The eletronic circuitry is built up with integrated circuits of CMOS technology and passive elements of high stability.

Technical parameters of the sonde:

Detectors:		
Gamma-ray channel:	NaI(Tl) 24×70 mm + photomultiplier type FEU–102	
Resistivity channels:	KO36 electrode rings arranged on the sonde casing	
Properties:		
Measuring range of the gamma-ray channel:	0 – 2,000 μR/h	
Dead time:	2 – 3 μs	
Resistivity measurement ranges:		
0.1 m, 0.4 m potential	2 – 2,000 Ωm	(switchable from the surface)
1.6 m gradient	10 – 10,000 Ωm	
SP measurement range:	from – 0.5 to + 2 V	
Supply current:	80 mA ± 2% (stabilized on the surface)	
Supply voltage:	35 V DC	
Pressure rating:	15 MPa	
Dimensions: (sonde casing in assembly)		
diameter	43 mm	
length	about 2,300 mm	
mass	about 15 kg	
Temperature rating:	0 – 80 °C	
Recommended well logging cable:	with loop resistance less than 100 Ω, and capacitance between two conductors less than 0.75 μF	

2.3.6 The MTA 1527–2000 Industrial Rapid Analyser for geophysical applications*

The Industrial Rapid Analyser type MTA 1527–2000, based on experience gained over the past years, was elaborated for the express analysis of elements as well as for solving specific industrial tasks. Apart from determining the components SiO_2 and Al_2O_3, this activation analyser can also determine MnO by means of a new control system. Taking into account the nuclear parameters of silicon, aluminium and manganese, as well as those of other disturbing components in the rock, the samples are put under optimal radiation and measurement conditions where the generated radioisotopes of the samples are measured by high stability GM counters. After the measuring system has been calibrated by corresponding rock standards the quantitative values of the components are determined by a built-in microcomputer using software programs recorded on magnetic discs and printed in tabulated form.

In the X-ray radiometric part of the MTA 1527–2000 apparatus an energy-selective measuring technique is used with proportional detectors. The analysed components are selected from energy spectrum by the joint use of differential filters and electronic discriminators by optimizing the atom-physical parameters of the components. Thus the determination of Fe, Mn, Cu, Ni could also be solved in order to meet geophysical requirements. The whole measuring procedure (changing of samples, transport of samples, replacement of the mechanical filters, modification of electronic parameters) is performed automatically, without intervention from the operator. In actual fact, MTA 1527–2000 combines the NAA and XRF measuring techniques. Interpretation of the measured data is performed by a built-in minicomputer working on-line with the data acquisition channels of the apparatus.

A mobile version of the apparatus (including the sample preparation system as well as the MTA 1527–2000 Rapid Analyser) built into a UAZ type microbus is available for on-site analysis. The activation unit is carried by a special trailer. Current is supplied by a generator independently of the mains. This highly mobile analytical laboratory is able to supply measurement results within 30 minutes of its arrival at the field site.

2.3.7 Pen recorder for well logging purposes**

The APR–4–260K four channel recorder was designed to meet the requirements of up-to-date loggers *(Fig. 73.)*.

The mechanical construction of the recorder has been improved on the basis

---

* *Renner J.*, Siklós A.

** *Flesser N.*, Kántor J., Koronthály L.

of experience gained from earlier types. The instrument works according to the compensograph principle, it has four analog measuring channels and two auxiliary channels *(Fig. 74)*. The maximum writing field of the analog channels is 230 mm. Each of the four channels is able to cover the whole width of the writing field by using four pens of different colours. At the right margin outside the writing field the depth marks and time marks can be recorded by the auxiliary channels. Paper transport is possible in both forward and backward directions, with a velocity of 0–5 mm/s being controlled by the stepping motor of the driving mechanism. Paper transport is adjustable within the scale range of 1:20 to 1:1000. The position of the measuring sonde is given by a 5 digit depth indicator with an accuracy of 10 cm. An integral part of the recorder is the operational unit KFC–4–12, which in addition to the measurement mode selector includes a semi-automatic depth correction circuit, cable speed measuring unit and a compensator circuit. There is a possibility to set the initial depth of the sonde by bursting the depth counter forwards or backwards. The recorder can also be driven according to time thus it permits measurements to be performed with a stationary sonde.

Basic technical parameters:

Number of channels:	4+2 auxiliary channels
Sensitivity of channels:	100 mV/10 cm
Paper transport scales:	1:20; 1:50; 1:100; 1:200; 1:500; 1:1000
Depth marker:	manual
Time marker:	10 s or 1 m
Supply voltage:	12 V DC
Current consumption:	max. 5 A
Dimensions:	19″, system 5E (KONTASET)

2.3.8 Improvement of mechanical construction of sondes*

To meet requirements of modern mineral exploration new sonde constructions have been designed. For caliper measurements in combination with several other physical parameters the standard system of a sonde family has been developed with diameters 36, 43, 60, 76 and 86 mm. The essence of this system is that the measuring arms of the sonde are pressed against the wall of the borehole by a motor driven mechanism.

Our latest product is a dipmeter sonde of 60 mm diameter which incorporates the most sophisticated technology in well logging. Special care was taken in forming the measuring pad which exerts a decisive influence on the measuring accuracy of the sonde. A new plastic was created for the insulation of electrodes. This plastic is extraordinarily wear-resistant and maintains its stability even at high temperatures. A miniaturized core inlet was designed for the connection of electric leads within the mud space.

---

* Cséri D., Kengyel M., *Szalai J.*