# 2 METHODOLOGICAL AND INSTRUMENTAL RESEARCH

### 2.1.1 Role of the SDS–3 program package in ELGI's seismic processing*

Since 1981 the processing of seismic data has been carried out on our RYAD–35 machine (see Annual Report for 1981) by means of the SDS–3 program package. This program package was developed by the Central Geological Expedition (CGE) of the Ministry for the Petroleum Industry of the USSR, in cooperation with geophysical institutions of other socialist countries. The basic task of the package is to process seismic reflection data on RYAD computers under the OS operation system. The program can treat data of arbitrary field geometries. The following main possibilities are provided by the system for the seismic interpreter:

*Control of the processing of a selected sequence of seismic traces.*

Control parameters:

— type of common coordinate
    SP (shot point)
    OP (observation point)
    DP (common depth point)
  trace gathering can be made with respect to any of these coordinates;
— the selected interval of the section (INTX) and step size (DX);
— definition of the SP–OP distances $L_i$ for the traces to be processed;
— time range (INTT);
— sampling rate (DT: 1,2,4,8 ms);
— data format (FTR: I2, I4, R2, R4).

*The main programs enable the selected sequence of traces to be subjected to many procedures, the principal ones being:*

— creation of set of traces, "seismograms", gathered with respect to SP, OP or DP;
— gathering of selected traces within seismograms;
— gathering and subsequent summation of sequences of traces of identical shot point–geophone distances;

* Tímár Z.

— trace gather and summation by taking into account the coherency;
— trace gather and summation by taking into account reflector dip;
— coherency- and dip analysis;
— special „repetitive main programs" for quick look testing of the control parameters of subroutines, with trace selection and summation;
— velocity analyses for coherent noise wave trains;
— subtraction of the coherent noise from common shot point seismograms;
— 2D filtering**
— summation with respect to given or automatically determined velocity functions, over arbitrarily selected parts of the profile and in a given time window;
— automatic improvement of the static corrections on common SP or common OP sections;
— automatic improvement of the static corrections on common depth point seismograms;
— computation and print-out of vertical and horizontal frequency spectra;
— creation of trace gathers with respect to common reference points and, if necessary, their phase corrective summation, wavelet-shape correction or both;
— computation of velocity spctera from a vertical or horizontal set of traces;
— elimination of multiple reflections;
— enhancement of the coherent events on the time section;
— linear or weighted Kirchhoff migration;
— Wave equation migration (2D and 3D)***

*The system's subroutines that can be called during the execution of the main programs perform the following tasks*

— editing (removing of arbitrary parts of the traces);
— „kill", (i.e. erasion of whole traces), polarity reversal, notch filtering;
— print-out of the amplitude vs. time behaviour, execution of the static and dynamic corrections, inverse dynamic correction;
— computation of frequency spectra for each trace;
— automatic amplitude control;
— normalization of the trace amplitude levels with respect to maximal amplitude, average amplitude or average energy, and inverse normali zations;
— corrections of the amplitudes for surface effects;
— true amplitude recovery to compensate spherical and inelastic losses;
— amplitude control according to a prescribed function;

** Programs written by the GEOSOFTWARE Cooperative of the Geophysical Exploration Enterprise, Hungarian Oil and Gas Trust.

*** Developed in ELGI.

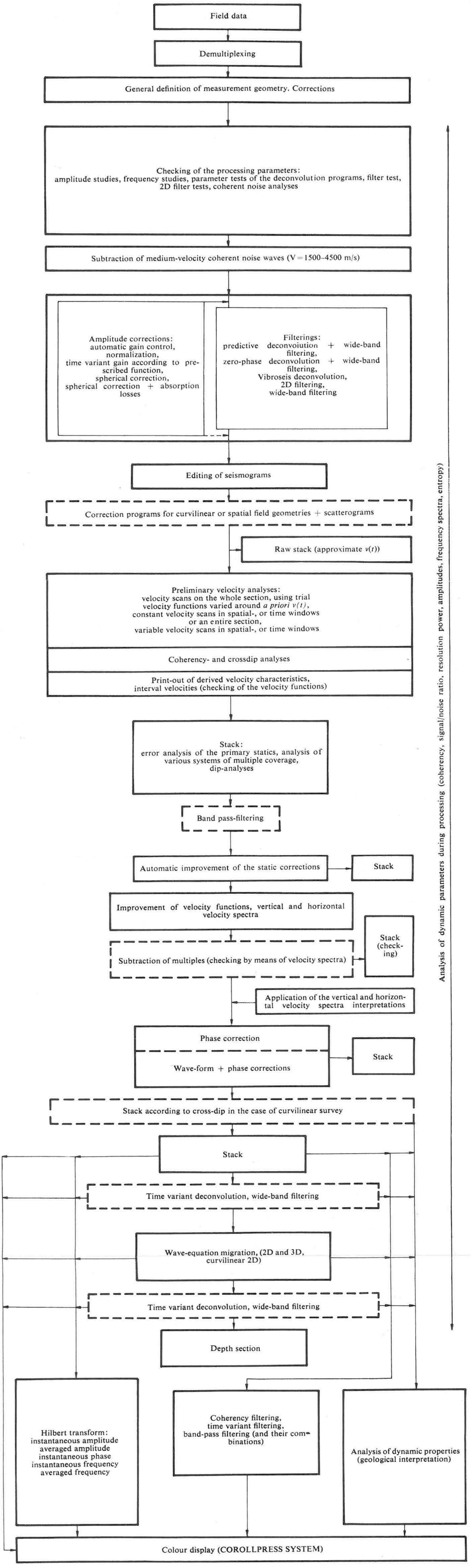


*Fig. 39.* Flow-chart of standard SDS–3 processing as applied by ELGI

— keeping track of the dynamic parameters (coherency, S/N ratio, resolving power, entropy) along selected horizons throughout processing;
— VIBROSEIS[R] deconvolution**;
— time- and space-variant band-pass filtering;
— time- and space-variant deconvolution (predictive, spike or zero-phase);
— Hilbert transformation for the computation of instantaneous amplitudes and its smoothed version, of the instantaneous frequency and its smoothed version, and of the instantaneous phase;
— correction programs for curvilinear and spatial measuring geometries***;
— display of curvilinear field geometries and depth point distributions (scatterograms)***;
— nonlinear stack taking into account coherencies and crossdips, for curvilinear measurements***;
— computation of time slices*** (for 3D measurements).

*COROLLPRESS programs*

— colouring with respect to amplitude strength***;
— colouring with respect to apparent frequencies***;
— coloured scatterograms***;
— coloured time slices***;
— colouring of time sections with respect to dip or coherency***.

Even a short enumeration of the possibilities of the SDS–3 package demonstrates its usefulness for the interpreter; actually, there are more than 200 procedures that can be utilized to solve processing- or methodological tasks. After the necessary extensions of the computer centre (interfacing of the array processor, see our Annual Report for 1982) we have been able to define the standard graph of processing *(see Fig. 39)*, by taking into account the wide range of tasks to be solved. As a first step of processing we study the characteristic features of the individual seismograms and define the optimal sequence of procedures and parameters for an improvement of the field data. We always make amplitude- and frequency studies, and determine by tests the type and parameters of the necessary amplitude regulation (as a rule, we apply true amplitude recovery); we decide whether there is a need for deconvolution and select the band-pass filter parameters. If necessary, we also make noise-wave analysis and apply appropriate programs for the subtraction of these waves. Next come deconvolution and band pass filtering with the selected parameters. After editing we make a velocity analysis and compute the first raw stack *(Fig. 40)*. Then follows the automatic improvement of the static corrections. The efficiency of this step can greatly be improved by proper band-pass filtering, "tuned" to the signals. The accuracy of the obtain-

[R] Registered trademark of CONOCO.

ed velocity functions is further improved by velocity spectra, the multiples if any can also be subtracted. As a final stage of this processing sequence, before stack but after the elimination of the residual static and dynamic errors, we can further improve the efficiency of summation by multichannel wave-form- and phase-correcting programs (optimal multichannel filtering) *(Fig. 41)*. We finally carry out wave-equation migration and enhance the useful signals by coherency-filtering *(Fig. 42)*. The program package*** of the COROLLPRESS colour plotter provides a mean for the different kinds of displays of the seismic sections, coloured with respect to amplitude and apparent frequency and for the coloured representation of the instantaneous amplitude-, frequency-, and phase sections obtained via the Hilbert transform *(Figs. 43, 44)*. The spectra below the figures show the variations of the presented parameters along the time-window indicated in Fig. 44. It is hoped that the PGR program package (Prognoza Geologicheskogo Razreza = Prediction of Geologic Properties) purchased from CGE in 1983 and to be introduced in 1984 will further increase our processing capabilities. Details of and first results obtained by this new program system will be reported next year.

### 2.1.2 Input of the ESS–01–24 field records to the RYAD–35 computer*

The ESS–01–24 type digital engineering seismic equipment, developed by ELGI, has found a wide range of applications: its 16 Kword memory of 16 bit words, its summing capability, 20–2000 Hz frequency range and small weight maked it a universal seismic instrument. Its range of applications has further been improved in 1983: e.g. a newly realized computer peripheral makes it possible to directly read the cassettes containing the seismic material recorded by the ESS, so that these data can directly be entered to the flow of standard seismic processing. The improvement in the quality of these materials due to software techniques and the sophisticated ways of visualization are extremely helpful to the interpreter geophysicist.

The new peripheral of the computer is the PK–1 type cassette tape drive. For cassette reading the control unit of the ES–6022 type punched-tape-reader was modified and extended, though obviously it can still be used to control a conventional punched-tape input. The PK–1 cassette reader is interfaced by a special hardware unit which models—both physically and logically—the inteface of an FS–1501 punched-tape reader towards the ES–6022. This unit also takes care of the control of the cassette recorder, as well as of the blockwise reading, decoding and transformation of the stored information, as synchronized by the control signals generated by software in the control unit.

* Holczer P., Széphelyi E., Dianiska L., Csercsik F.

The internal buffer memory makes the information transmission toward the channel independent of tape speed, i.e. the equipment can be used in multiplex mode. The data transfer rate is 12,000–40,000 Baud. The interface unit receives the data from the cassette in blocks and similarly transmits them. The block size can be 1–2–4 Kbyte, data blocks shorter than the selected buffer length are automatically supplemented by the interface unit by 'oo' characters. Because of its small size and low consumption (LSI, MSI circuits), the interface unit can be housed in the ES–6022, from which it also gets its power supply.

*Software support*

The control of the interface unit and the reception, checking and decoding of the data are realized by a specially designed program which transforms the original FSO data format of the cassette into more user-friendly format meeting FORTRAN–IV conventions, and it writes these data onto magnetic tape.

Reading of the cassettes is done in two steps: first the reading proper of the data from the cassette, then—leaving a possibility for manual intervention—correction or omission of erroneous data.

The reading of a single side of a cassette takes some 30–60 minutes therefore the program had to be made restartable. After each successfully copied record (1 header + 24 data blocks), the essential information characterizing this record is written onto a magnetic disc. In case of malfunction or unexpected events the program can be restarted: it automatically rewinds the magnetic tape, moves it to its proper position, then continues the reading of data.

The program is written in PL/1 and FORTRAN–IV, it requires less than 128K memory and only two peripherals, the ES 6022 for the input cassette and the ES 5017 for the output reel. The outline sketch of the PK–1 interface is shown in *Fig. 45*.

### 2.1.3 Seismic data acquisition and processing system based on the VT–600 (VT–6000) computer*

As a result of several years of R&D we are proud to announce a new geophysical processing centre, based on the VT–600 (VT–6000) mini computer. The development of the system has been a joint effort with the VIDEOTON Company within the framework of projects defined by CMEA's INTERMORGEO and OMFB (Hungarian State Office for Technical Development). Keeping in mind geophysical applications, the basic VT–600 (VT–6000) configuration has been supplemented with the following peripherals:

* Kereszti F., *Komjáthy J.*, Lazarovits Gy., Méri T., Molnár Imre, Molnár István, Páhi L., *Rácz I.*

— for real-time applications the SDA seismic data acquisition unit, produced by ELGI (see Annual Report for 1980, p. 69) was directly interfaced to the computer as an input unit (i.e. the data acquisition unit serves in such cases as a computer peripheral, it can be controlled and also tested by software instructions);

— we interfaced our COROLLPRESS–4 colour plotter as a geophysical output peripheral, each interface can serve—alternately—two devices, as required by the geophysical task. Most of the systems are supplemented by several optional *off-line* COROLLPRESS–4 plotters;

— our new floating-point geophysical special processor (Annual Report for 1982, p. 101) is also interfaced as a peripheral—for acceleration of the most frequently occurring algorithms in the VT–600 (VT–6000)-based real-time and express systems. Because of its full-precision floating-point arithmetics and its large operative memory the capabilities of the device have greatly been increased compared with its earlier version;

— seismic programmers will certainly appreciate that, similarly to the RYAD–10 system, we have again the means for hardware-demultiplexing in the form of a specially interfaced disc;

— since the magnetic tape drive interface of the original VT–600 (VT–6000) configuration cannot deal with more than 64 Kbyte continuously recorded data, it could not be applied to read field-recorded seismic data. The interface has been modified so that it can continuously read long records from magnetic tape through alternating buffers.

As for conventional peripherals, the geophysical system contains—besides disks and tape drives—line printers, a console display and several terminals for operators, floppy discs and—for the non-mobile variant—a large disc as well, for program development. For off-shore puposes, the quasi field-proof systems are manufactured by VIDEOTON. An outline of the system is shown in *Fig. 46*. For the VT–600 (VT–6000)-based geophysical complex, the VIDEOTON Co. have modified and supplemented the original operating system to handle geophysical peripherals, ELGI elaborated most of the tests for these peripherals, as well as a Marine Real-Time Data Acquisition and Preprocessing Package and a "Seismic Express Processing System".

*Marine Real-Time Data Acquisition and Preprocessing Package*

Input:

— parameters defining field geometry and controlling the processing, from terminal;

— seismic records from the SDA.

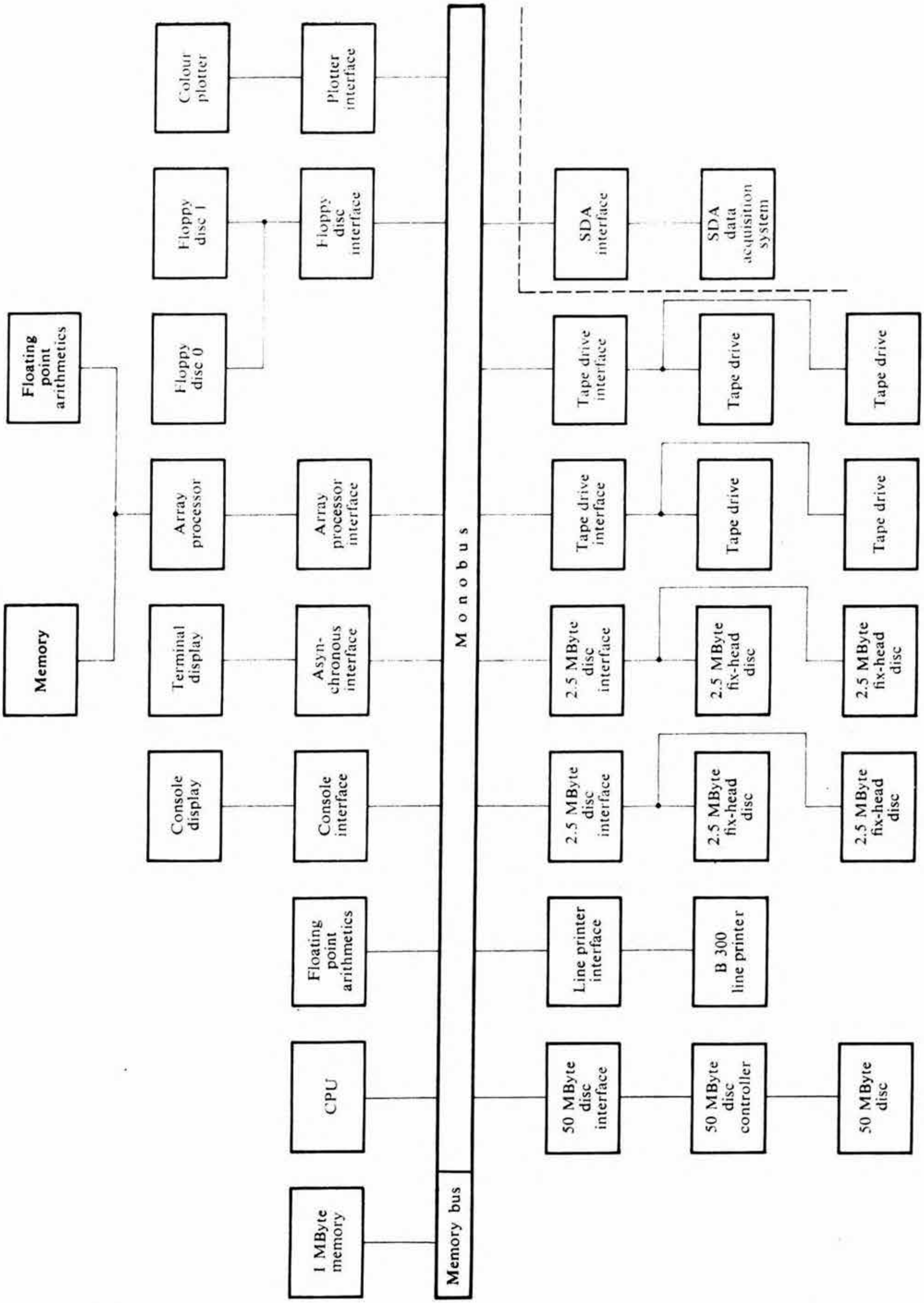


*Fig. 46.* Flow-chart of the seismic real-time preprocessing system based on the VT–600 (VT–6000) computer

Output:

— trace sequential seismograms on magnetic tape for subsequent detailed processing;
— single-channel or stacked time section displayed by the colour plotter.

During the continuous functioning (which usually lasts several days) individual measurement cycles can be initiated:

— as controlled by the navigational computer;
— in equally spaced time instants, provided by the VT–600 (VT–6000)'s real-time clock;
— individually controlled by software.

The package can process 24- or 48-channel seismic data of 2 or 4 ms sampling rate, containing at most 4000 data/trace. Parameters for the setting of the SDA equipment, data defining the processing sequence and any messages and instructions for the operator should be entered, or appear on the same terminal, which makes supervising much easier. During measurement the parameters can be updated, new procedures can be inserted into the processing sequence or others deleted. The presently available procedures, in their usual order of execution are:

— write on magnetic tape;
— trace zeroing;
— MUTE;
— dynamic correction;
— stack;
— deconvolution;
— band-pass filtering;
— scaling;
— plotting.

*The Seismic Express Processing System*

The system is similar to out earlier Express System, written for the RYAD–10 (Annual Report for 1982). During the development of the new system it was a principal requirement that all internationally recognized seismic formats up to 256 channels should be tractable and the definition and description of the process-control parameters be simple. Of course, the advantages of ELGI-made peripherals (special processor, COROLLPRESS, etc.) are also fully utilized. The system must be applicable for the on-site processing of the seismic data of far-away expeditions and still has to preserve all friendly features of the VT–600 (VT–6000) operating system.

The system can process seismic data of 1/8–16 ms sampling rate, of maximum 256 channels and no longer than 8000 data/trace. At present, the following procedures are available:

- — magnetic tape I/O programs;
- — interpretation of the measurement geometry;
- — MUTE;
- — KILL;
- — polarity reversal of given traces;
- — decimation;
- — static correction;
- — dynamic correction;
- — stacking;
- — band pass filtering;
- — deconvolution;
- — scaling;
- — on-line or off-line COROLLPRESS colour plots with respect to amplitude or frequency;
- — velocity analysis;
- — automatic static correction;
- — migration.

The sequence of procedures is arbitary, the results of any phase can be written onto magnetic tape and further processed at a later time. The algorithms are executed either by the VT–600 (VT–6000) arithmetics or by the floating-point special processor. The application of the special processor reduces processing times by a factor of five — ten.

### 2.1.4 Instrument development for in-mine seismics*

In 1983, our R&D activities for in-mine geophysical instrumentation led to the completion of the development of the firedamp-proof digital seismic equipment (SSS–I), to be utilized in mines. The new type of instrument was developed according to a program authorized by the Permanent Commission for Coal Mining of the CMEA, in direct Soviet–Hungarian cooperation. The Soviet participant of the project was the Ukrainian subsidiary of the VNIMI (All-Union Mining Research Institute). In Hungary, the developmental work was carried out by ELGI, in cooperation with the Central Mining Development Institute and the Mecsek Coal Mines.

The following were the main objectives of the development:

- — firedamp-proof construction;
- — portable basic units;

* Czifra F.

— semiconductor memory for summing signals of consecutive records;
— low power consumption (built-in power supply);
— wide frequency pass-band for the high-resolution refraction- and reflection measurements;
— a quick-look visual check of the measured data;
— data recording on magnetic tape for further processing.

The SSS–I type in-mine seismic equipment consists of the following main parts, shown in *Fig. 47:*

— amplifier unit (1), containing 12 identical amplifiers provided with low-cut and high-cut filters, a 12 channel analog multiplexer, a 10-bit A/D converter;
— control unit (4), containing a microprocessor-based central control unit, a semiconductor memory as well as peripheral controls for the amplifier unit (1), for the display unit (2), for the cassette storage (3) and for the control panel (5);
— the display unit (2) is a 12-channel oscilloscope for on-site check of the seismic record quality, the seismic wave pattern appears as a still picture;
— the magnetic cassette storage unit (3) records the digital information coming from the equipment on a Philips commercial cassette;
— control panel (5), contains the manipulating- and indicator elements to adjust the parameters and modes of operation of the instrument.

The different modes of operation realize three main functions (see the functional outline sketch in *Fig. 48*):
*Control.* Checking of the amplitude- and phase identity by means of high-accuracy test-generator (4). In Mode 1 the control is restricted to the interior electric circuits of the equipment; in Mode 2, the seismic cable and the seismometers are also checked.
*Recording* (Mode 4). The source of energy is—because of the dangerous environment due to firedamp—the pop of a hammer. The recording process is started by an impulse sent from the signal transmitter mounted on the hammer (2). From the seismometers the signals are led to the 12-channel amplifier (5), the amplifications can separately be adjusted for each channel, in the 24–108 dB range, in 12 dB steps.
The following kinds of filtering can be applied:

low-cut: 62.5; 125; 250; 500 Hz
high-cut: 250; 500; 1000; 2000 Hz.

The analog multiplexer (9) scans, in turn, the outputs of the amplifiers and connects them to the input of the A/D converter (11). The resolution of the A/D is 10 bits (including sign). Sampling rates, record lengths and bandwidth are related in the following way:

| Sampling rate | Record length | Frequency range |
|---|---|---|
| 1 ms | 2.048 s | 62.5–250 Hz |
| 1/2 ms | 1.024 s | 62.5–500 Hz |
| 1/4 ms | 0.512 s | 62.5–1000 Hz |
| 1/8 ms | 0.256 s | 62.5–2000 Hz |

From the output of the A/D converter the time-multiplex signals are led through the recording DMA interface (13) into the semiconductor memory (18). To improve the signal-to-noise ratio and to increase the useful signal amplitude, records made by subsequent pops can be summed; the summation and the repeated storage of the recorded data are also taken care of by the recording DMA interface. The equipment can add maximum 64 records; its memory capacity is 2,048 words/trace. The data recorded are continuously displayed by CRT (8). The data are sent to the screen by peripheral control unit (16). The screen cannot display more than 1/4 of the total record length a time; the visualization of an entire record can be realized only by leafing, as controlled by the change of the parameters on the control panel.

*Data recording on magnetic tape.* Data recording is made in the standard way, in an 800 bpi phase encoded (PE) format. Mode of Operation 5 serves to write data from the memory to the magnetic tape. The whole record length, half of it, or a quarter of it can be written out and, consequently, we get 6, 11 or 21 records, respectively, on a single side of the cassette. Data are recorded on magnetic tape in a prescribed, block-wise format in file organization, the seismic data are trace sequential. There are several auxiliary programs connected with tape recording and data transfer: search on the magnetic tape (for a given record number; for BOT or EOT, Mode 6); loading of records from tape to memory (for checking or analysis purposes, Mode 7); labelling of cassette (Mode 8), overwriting of the last record (Mode 9).

The instrument has its own power supply, its cased parts operate from chargeable NiCd batteries. Its classification of protection against firedamp is Sb-n/Ex $i_a$I (Hungarian Standard MSz 4814). One of the prototypes has carried out long-lasting experimental measurements in different coal mines of the Donets Coal basin in the USSR.

# 2.2 GEOELECTRIC METHODOLOGICAL AND INSTRUMENTAL RESEARCH

## 2.2.1 Hydrocarbon exploration by means of geoelectric methods*

In CH deposits the pore space of the reservoir rocks is filled—instead of by low-resistivity brine—by high-resistivity oil or gas. Thus, in principle, the deposits should directly be detectable by resistivity measurements. In practice, however, the high-resistivity layer does not present itself on the sounding curves because of its small thickness in relation to its depth.

Recently several observations have been published proving that the geoelectric properties of the sedimentary cover of CH deposits may change, even up to the surface; some authors speak about radiometric anomalies. While no general consensus has been reached as to the geochemical processes causing these changes or the necessary material-, primarily gas-transport phenomena and their causes; the most widely accepted explanation claims that the following phenomena take place in the reducing environment below the water table and in the overlying oxidizing medium:

$$
\begin{array}{llll}
 & O_2 \longrightarrow CO_2 & \longrightarrow & CaCO_3 \\
CH_4 + & \nearrow & + Fe^{2+} \rightarrow & FeS_2 \\
 & SO_4^{2-} \rightarrow CO_2 + H_2S & & \\
 & & + O_2 \longrightarrow & S
\end{array}
$$

Besides these, more complex decomposition phenomena may also take place (disintegration of the silicates and aluminium silicates and development of secondary minerals).

These phenomena can cause the following alterations in the electric parameters:

*a)* The epigenetic pyrite increases the IP parameter of the rocks over the CH deposit, the process creating pyrite can also cause a resistivity decrease.

*b)* At the same time the $CaCO_3$ and part of the secondary minerals fill the pores and thus could lead to a resistivity increase.

The resultant of the contradictory processes is further affected by a number of other geologic, to say nothing of climatic factors so that it cannot be definitely stated that a CH deposit would always be characterized by resistivity

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* *Erkel A.,* Csörgei J.

highs or lows. It is still very likely, however, that resistivity or IP anomalies would mainly occur at those places where there are reasonable geologically fair conditions for an upward migration of hydrocarbons.

A case history is presented here based on IP measurements and frequency soundings in Hungary, over a 700–750 m deep gas lens of about 1.5 km diameter, situated in Upper Pannonian formations. The reservoir rock is a sandstone layer of 200–300 Ωm specific resistivity and 5–10 m thickness, interbedded in a medium of 3–5 Ωm specific resistivity; it forms a very gently dipping arch of 30–35 m amplitude. Conventional well logs have not provided any hints, besides the resistivity increase, to changes in physical properties. The 700 m deep, high-resistivity sandstone lense of only a few metres thickness cannot be directly detected by conventional geoelectric prospecting methods. Consequently, we applied a very dense spatial sampling rate, both in the IP and MFS measurements, and over the barren and the productive media as well, in order to continuously trace the changes of physical properties both horizontally and vertically.

*Figures 49* and *50* present an IP section and characteristic multifrequency sounding curves. To give a feeling of the very dense sampling of the frequency sounding, it would suffice to say that between 1 and 30 Hz the resistivity and phase values were determined for 104 distinct frequencies.

The CH deposit is in the depth range corresponding to the frequencies 1.1–2 Hz ($H_{\text{eff}}$=400–900 m) of the sounding curves. It is the task of data processing to reveal the subtle resistivity changes in this interval between the barren and productive formations, and to plot them section-wise as residual anomalies. From the IP measurements (with AB=1600 and 2400 m electrode distances) we could determine the differential polarizability (i.e. the derivative with respect to time of the decay curve), and the parameters of a single exponential term best fitting the decay curve. *Figure 51* shows the IP values measured with AB=2400 m and the resistivity sections constructed from MFS. By matching these results with borehole data the following conclusions can be drawn:

- an IP anomaly appears near the gas/water contact, possibly due to epigenetic pyritization;
- in the resistivity sections the gas lens is situated in a wide zone of resistivity-low, the smaller relative maxima probably indicate minute gas lenses situated beside and above each other in a shifted position with respect to each other.

*Figure 52* shows the distribution of the $\varrho_{E_x}$ values along the profile. Below the coarse-grained, high-resistivity Holocene–Pleistocene cover one observes a monotonous decrease of the apparent specific resistivities in the 400–900 m depth-range. The traditional way of interpretation could not be used to determine the layers of different specific resistivities and the layer boundaries so we proceeded in the following way. We split the resistivity section to two components: the regional component is first computed from the sounding data by means of the formula

$$\hat{\varrho}(x, H_{\text{eff}}) = a_K(x) H_{\text{eff}}^K + a_{K-1}(x) H_{\text{eff}}^{K-1} + \ldots + a_0(x),$$

where $x$ is distance measured along the profile, $H_{\text{eff}}$ the effective depth, $K=10$, and $a_i = b_{i,N} \cdot x^N + b_{i,N-1} x^{N-1} + \ldots + b_{i,0}$ ($N=5$). Then the residual anomaly is calculated; this is the difference between the regional values and the measured values, and it is depicted in percentages on the section. In Fig. 52 we plot the measured, the regional and the residual $\varrho_{E_x}$ values; in *Fig. 53* we show the measured, the regional and the residual values for the resisitivity computed from the ratio of the magnetic and electric components ($\varrho_{E/H}$), and for the phase angle between the $E$ and $H$ components, respectively.

On all presented residual sections there appear a larger double anomaly-pair between points 0 and 15, and a smaller one, between points 20 and 27, at the same location as the IP anomalies.

In *Fig. 54* we plotted the contours of the gas lenses constructed on the basis of the IP anomalies obtained with AB lines of various lengths. For the smaller penetration depth of 400–500 m, no anomalies relating to the presence of gas lenses appear but this is not the case in the vicinity of borehole Mh–20. The contour obtained with the greater penetration of 600–800 m follows the gas/water contact known from borehole data, except in the southwestward direction. On the basis of the IP data we can assume a further, smaller, enclosed gas lens around borehole Mh–3. Of course, these statements are entirely qualitative and hypothethical unless the results obtained in the vicinity of boreholes can be extended to the whole field.

As a conclusion of our experiences obtained to date it should be stressed that for successful prospecting of non-structural CH deposits one has to increase the accuracy of conventional geoelectric methods and to develop novel, computerized procedures instead of the available ways of interpretation.

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### 2.2.2 Effect of topography on the frequency-sounding made by the Maxi-Probe EMR–16 equipment*

The instrument measures the ratio of the absolute values of the vertical ($H_z$) and horizontal ($H_r$) magnetic field strength components (under ideal conditions—when the surface is a horizontal plane—the inducing coil is horizontal, i.e. the source can be taken as a vertical magnetic dipole, and the points of measurements are in the plane of the inducing coil).

The coil system of the receiving antenna is set up vertically by means of a box level, while the transmitting coil is spread on the surface. Consequently, the receiving coil system makes an angle $\Phi$ with the normal of the plane corresponding to the average dip of the surface while—because of the roughness of the terrain—the resultant dipole moment of the transmitter coil is not exactly perpendicular to this plane ($\Theta \neq 0$). The geometrical relationships are shown in *Fig. 55.*

Since in electromagnetic phenomena we only have to distinguish between the components perpendicular to and parallel with the surface, let us choose the normal of the average plane of the terrain as the $Z$-axis of the coordinate system, and denote the magnetic field strength components which are due to the perpendicular and parallel components of the transmitter dipole, with respect to the surface, by the superscripts $V$ and $H$, respectively. Making use of the formulae describing the vertical and radial components, respectively, of the magnetic field due to vertical and horizontal dipoles over an n-layered model, we obtain the expressions

$$H_z^V = \frac{M}{4\pi}\left\{\int_0^\infty J_0(\lambda r)\lambda^2 e^{\lambda-(z+h)} R_0(\lambda)\, d\lambda - \frac{1}{R^3} + \frac{3(z-h)^2}{R^5}\right\}, \tag{1}$$

$$H_r^V = \frac{M}{4\pi}\left\{\int_0^\infty J_1(\lambda r)\lambda^2 e^{-\lambda(z+h)} R_0(\lambda)\, d\lambda + \frac{3r(z-h)}{R^5}\right\}, \tag{2}$$

$$H_z^H = \frac{M}{4\pi}\left\{-\int_0^\infty J_1(\lambda r)\lambda^2 e^{-\lambda(z+h)} R_0(\lambda)\, d\lambda + \frac{3r(z-h)}{R^5}\right\}, \tag{3}$$

$$H_r^H = \frac{M}{4\pi}\left\{-\frac{1}{r}\int_0^\infty J_1(\lambda r)\lambda e^{-\lambda(z+h)} R_0(\lambda)\, d\lambda + \right.$$

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* *Kardeván P.*, Prácser E.

$$+\int_0^\infty J_0(\lambda r)\lambda^2 e^{-\lambda(z+h)}R_0(\lambda)\,d\lambda-\frac{1}{R^3}+\frac{3r^2}{R^5}\Bigg\} \tag{4}$$

where $M$ is the dipole moment;

$R_0(\lambda)$ is a kernel function depending on the parameters of the layers, which can be determined by means of recursion,

$J_0$, $J_1$ are Bessel functions of the first kind, of zeroth and first order, respectively,

$R=\sqrt{r^2+(z-h)^2}$,

$z$ is the height of the transmitter, $h$ that of the receiver, above the surface (in the present case $h=0$).

Taking into account the vectorial decomposition of the dipole representing the transmitter and, further, that both the magnetic component which is perpendicular to the surface as well as the parallel component induce voltages in both receiving coils, the field-strength ratio between vertical and horizontal components will be given by

$$R^m=\frac{H_z^V\cos\Theta\cos\Phi-H_r^V\cos\Theta\sin\Phi-H_z^H\sin\Theta\cos\Phi+H_r^H\sin\Theta\sin\Phi}{H_z^V\cos\Theta\sin\Phi+H_r^V\cos\Theta\cos\Phi-H_z^H\sin\Theta\sin\Phi-H_r^H\sin\Theta\cos\Phi}. \tag{5}$$

If

$$\Theta=\Phi=0, \quad \text{then} \quad R^e=\frac{H_z}{H_r}=\frac{H_z^V}{H_r^V}.$$

The case $\Theta=\Phi\neq 0$ cannot be realized in practice. According to field experience however, the transmitter can always be placed such that the direction of the dipole moment would only slightly deviate from the normal of the average plane of the slope, i.e. $\Theta\approx 0$ can be assumed. Then, for a uniform slope, the following relationship holds between $R^m$ measured for a transmitting dipole which is approximately perpendicular to the surface and $R^e$ that would be measurable for a horizontal plane surface:

$$R^m=\frac{R^e-\tan\Phi}{R^e\tan\Phi+1}.$$

The absolute values of the above complex quantities are related by

$$|R^e|=\frac{(R_a^m)^2+\tan^2\Phi+2R_a^m\tan\Phi\cos R_f^m}{1+(R_a^m)^2\tan^2\Phi-2R_a^m\tan\Phi\cos R_f^m}, \tag{6}$$

where

$$R^m=R_a^m e^{\{iR_f^m\}} \quad \text{and} \quad \Phi=\arc\tan\frac{\Delta H}{r}.$$

Since the instrument can also measure the phase angle $R_f^m$ between vertical and radial magnetic components, $|R^e|$ can directly be computed by Eq. (6) ($\Delta H$ is determined by means of levelling). The main advantage of this is that *the topographic correction is valid for any kind of subsurface, it can be carried out without numerically computing the integrals (1)–(4).*

For the geometric arrangement treated above and for $\Theta=0$, $\Phi=$varying, the response curves $R^m(f)$ with respect to the homogeneous half-space are shown in *Fig. 56*, as functions of frequency $f$.

For positive and negative values of $\Phi$ the response curves will also be characterized by a shift depending on the angle of the slope in the range of interpretable $R^e$ values. These results are in agreement with the investigations of SINHA [1980].

## Reference

SINHA, A. K. 1980: A study of topographic and misorientation effects in multifrequency electromagnetic soundings. Geoexploration, **18**, 2, pp. 111–122.

# 2.3 WELL LOGGING INSTRUMENTAL AND METHODOLOGICAL RESEARCH

## 2.3.1 Computer processing of dipmeter logs of hydrocarbon exploration wells*

In 1982, the Hungarian National Oil and Gas Trust purchased a dipmeter with a processing program system from Dresser Atlas. ELGI was commissioned to adapt the software, to process Hungarian logging results and to develop the program package.

The program package compiled for Dresser Atlas' Interdata 8/32 computer was adapted to an R–35 computer. At the first stage of operation, experimental processing was performed in order to compare the results with the results of a run performed in the Houston Center of Dresser Atlas. The comparison showed them to be in very good agreement. After the trials, all the materials relating to the Hungarian measurements—amounting to some 4200 metres of diagrams— were processed.

The basic idea of dipmeter logging and processing is that shifts between microresistivity curves measured on the four pads of the sonde are characteristic of the dip of beds. The first step in processing is the correlation by pairs of microresistivity curves recorded on magnetic tape. From shift values determined in this manner and from the measured orientation data the dip of a given bed can be determined for a given depth point.

Two linearly independent shifts of the curves are sufficient for the dip determination. From measurements made with a four-arm sonde, 13 linearly independent pairs of curve shifts can be selected; thus, the measurement contains excess information. The original program system selects the best of them on the basis of certain quality criteria.

The KZONA program compiled in ELGI using redundant information determines statistically by cluster analysis the most probable dip values. In the program execution the depth interval to be processed is divided into zones. For each dpeth point within a zone all possible dip values are calculated and the obtained spread is classified by a cluster algorithm. The marked clusters are assigned to a successive order of ranks on the basis of the number of elements, and their scattering. The program computes the dip only at those depth points

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where at least one out of 13 dip values falls into one of the clusters described as good.

*Figure 57* shows a plotted result of the original program system. The plot illustrates the magnitude and direction of calculated dips for each depth point by the so called arrow representation. The same depth interval with dip values calculated by the KZONA program is shown in *Fig. 58.*

### 2.3.2 Development of the coal qualification program system*

The program system compiled for a HP 9825A computer was further developed. The program system calculates the elastic parameters from the acoustic $\Delta t$-log and nuclear density log ($\varrho$): Young's modulus, the shear modulus, bulk modulus and Poisson's ratio.

The knowledge of elastic parameters is of considerable importance primarily in the roof and floor of coal seams. The centre of the algorithm is a table containing the $V_p/V_s$ values of the most important rocks, where $V_p$ is the propagation velocity of longitudinal waves and $V_s$ of transverse waves.

The value of $V_p$ can simply be calculated from $\Delta t$ while, with a knowledge of lithology, the value of $V_s$ can be determined from the above mentioned table. If $V_p$, $V_s$ and $\varrho$ are known the elastic parameters can unambiguously be determined. The foregoing is illustrated in *Fig. 59.*

Another field of development is the detailing of coal deposits marked off by the lithology program. In its present version the program system performs the detailed division of coal seam sin relation to ash content or caloric value. The algorithm is founded on a table built in the program with the following values:

| denomination | ash content [%] | caloric value [kJ/kg] |
|---|---|---|
| brown coal | <20 | >16,800 |
| brown coal with clay | 20–35 | 10,500–16,800 |
| coal-bearing clay | 35–50 | 4,200–10,500 |
| clay with coal traces | 50–65 | — |
| organic coloured clay | >65 | 2,000–4,200 |

The result of processing on the basis of ash content is shown in *Fig. 60.*

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### 2.3.3 Adaptation of the ASOIGIS system*

During 1983 "The Automatic Processing and Interpretation System of Geophysical Well Logging" (ASOIGIS) was adapted for the R–35 computer of ELGI. This system was designed under the guidance of the Ministry for the Petroleum Industry of the USSR within the framework of the CMEA. The system is designed to automate well-log processing in order to increase the reliability and quality of results by using third generation computers. A further aim is to furnish geological and geophysical information relying on the data bank.

The processing flow-chart of the ASOIGIS system is presented in *Fig. 61*. The basic concepts of the organization of processing are as follows:

- uniform data base, single data entry, possibility of later re-processing;
- structure of the data base does not depend on the actual task and processing programs;
- data stored in the data base and their descriptions are independent, thereby offering the advantage of data entered earlier remaining unchanged even when the handling programs of the data base are altered;
- handling, copying, compression and other operations can be performed with the aid of special system programs;
- processing is carried out on the level of the temporal data base, which stores the required information only while the given task is being performed;
- the processing programs may enter into contact with the temporal data base through special service programs only;
- connection between user and data base is realized through special languages controlling display, handling and processing of data.

At its present level the system is available with more than seventy programs which handle the data base or perform geophysical processing.

Of these programs procedures can be organized for the given task, including either complete or partial tasks. When they are run automatically there is a possibility to review individual partial processes and to determine parameters for the subsequent step.

The program system was designed with the purpose of processing the logs of hydrocarbon-producing wells; however, the structure of the data base permits the data storage for any type of drillings. The majority of processing programs also ensures interpretation of various types of exploration boreholes after information on useful minerals and geological build-up have been entered into the data base.

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Mention should be made of the following programs of processing:

— preparing function relations;
— normalization processes;
— automatic depth correlation;
— correction of nuclear logs;
— correction for cycle skipping on acoustic logs;
— correction of SP logs;
— correction of induction logs;
— correction of laterolog curves;
— determination of true resistivity;
— automatic marking of bed boundaries;
— statistical lithological interpretation;
— determination of clay content;
— determination of porosity by several methods;
— determination of water saturation by several methods;
— determination of oil saturation by several methods.

Results obtained with the program system in a hydrocarbon-producing well are presented in *Fig. 62.*

### 2.3.4 Nuclear and electric apparatus design*

To modernize traditional loggers the KFU series of surface units was designed. This is an updated version of the old-fashioned system of nuclear surface panels. The current version has higher stability, reduced consumption and dimensions using Eurocards constructed with active semiconductor elements of the second and third generation in accordance with IEC recommendations *(Fig. 63).*

The universal KFU surface units and the pulse-type sondes developed in ELGI permit the following logs to be recorded:

— gamma-ray log;
— gamma–gamma (density) log;
— compensated gamma–gamma (calibrated density) log;
— neutron–neutron (porosity) log;
— compensated neutron–neutron (calibrated porosity) log;
— temperature (graduated in °C);
— caliper (graduated in mm);
— borehole profile;
— flow-meter diagram;

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— mud density;
— photoelectric gamma log;
— X-ray radiometric log;
— energy-selective recording of gamma radiation (on 4 channels at most);
— spectrum of gamma radiation;
— normal resistivity 0.4 m (16″)+1.6 m (64″);
— lateral resistivity 1.8 m (6′)+SP;
— mud resistivity;
— CCL.

Of the measurements listed above four types can be performed simultaneously at most depending on the chosen sonde. One of the main features of the KFU units is that only a single-conductor armoured cable is needed for the simultaneous operation on four channels.

The incorporated processor is used to calculate compensated density and porosity, as well as to perform further simple calculations, e.g. the four basic operations.

The processor is realized on a single Eurocard which is being developed with the purpose of performing other calculations.

The block diagram of the KFU–4–12 surface unit is shown in *Fig. 64.*

In the case of energy-selective gamma measurements the pulses with amplitudes proportional to the measured energy of radiation are forwarded on a further conductor of the cable to the input of a PRA–4 Pulse Height Analyser which allows four energy windows to be set. Such measurements require a cable with at least 3 conductors.

For simultaneous recording of technical and nuclear measurements combined sondes have been designed. The benefit of these types of sondes is that correction for borehole effects (e.g. density measurement corrected for borehole diameter) can be introduced, information can be processed with a processor (e.g. determination of borehole volume from borehole profile measurement), and the wall of the borehole can be followed more accurately. In addition to these advantages, other technical improvements are provided: in particular the possibility of opening and closing of caliper arms within the well. Three main types of the sonde family combined with a motor-driven caliper have been developed.

*i)* Sondes combined with 3-arm caliper
Parameters to be measured: — hole diameter
— temperature
— gamma ray

*ii)* Sondes combined with 1-arm caliper or pad type caliper detector system
Parameters to be measured: — density compensated for borehole
— hole diameter
— gamma-ray

*iii)* Sondes combined with 4-arm caliper (profile gauge with 2×2 arms)
Parameters to be measured: — X–Y hole diameter
— temperature
— continuous mud resistivity

The electronic scheme of the scombined sondes is illustrated in *Fig. 65* by means of the block diagram of a KGGGC–4–80–60 sMPY sonde. This sonde is capable of the simultaneous measurement of

— compensated density
— hole diameter
— gamma ray.

The characteristic features of the sonde family are as follows: *(i)* the caliper arms with the built-in density measuring detectors are pressed against the wall by a spindle and spring mechanism driven by an electric motor which is controlled from the surface; *(ii)* sondes are manufactured with diameters of 36 or 60 mm; *(iii)* the maximum working temperature is 150 °C; *(iv)* they are operated on a single conductor armoured cable; *(v)* the operation of their electronic system free of dead time and coincidence arrors is ensured by downhole divider stages with AMPLITUDOMULTIPLEX* selective storage.

### 2.3.5 Digital apparatus design**

Within the scope of this project the first model KD–80 of the MOLE (Microprocessor Organized Logging Equipment) system has been constructed. The main purpose of this project was to satisfy present and future requirements of well logging techniques utilizing computer technique. The achievements so far are that *(i)* the growing diversity of measuring techniques does not complicate the construction and handling of the measuring system; *(ii)* there is no need to use an independent surface unit for each logging method, and in addition, the execution of traditional measurements is also rendered simpler; *(iii)* more precise data are obtained from the measurements partly by improving and automatically checking the measuring process, partly by using calibration data; *(iv)* simultaneously with the measurement, physical parameters corrected with borehole data are recorded and express-interpretation is performed in the field.

The basic configuration of the MOLE system *(Fig. 66)* contains the following units:

— measuring unit with analog input;
— measuring unit with pulse-type input;

* Hungarian patent No. 173355 — 30. 01. 79/22. 04. 76.

** *Horváth F.*, Josepovits Gy., Szongoth G.

— depth handling unit;
— control unit;
— analog recorder;
— transitional data store.

The basic configuration of the MOLE system enables the following logs to be run:
Electric measurements (with the analog input measuring unit)

— resistivity with 10 and 40 cm normal sonde + SP;
— resistivity with short lateral sonde + SP;
— resistivity with 40 and 160 cm normal sonde + SP;
— resistivity with long lateral sonde + SP;
— focused current measurement with three electrodes;
— induction log;
— induced polarization;
— microresistivity;
— mud resistivity.

Nuclear and pulse-type measurements (with the pulse-type input measuring unit)

— gamma-ray;
— density (with a sonde having 4 channels at most);
— photoelectric gamma;
— neutron porosity;
— neutron activation;
— caliper;
— temperature;
— flowmeter.

In depth data handling the unit performs depth correction, shifts the recorder, displays the depth number and logging velocity and provides other warning signals (e.g. end of logging interval). The control unit includes the data transfer processor and fast arithmetics to introduce primary corrections, it gives numerical indications for selecting the measuring range and performs D/A conversion. To realize analog recording of logs any ELGI designed pen-recorder or camera can be attached to the system.

The task of transitional data storage is to store data of several logs (e.g. caliper, mud resistivity) for the total time of logging runs in order to introduce correction for hole effects, to play back logs with other scale or dynamics and to perform other kinds of processing.

The MOLE system can optionally be expanded by spectral gamma measuring unit, acoustic unit, CRT dispaly, magnetic tape transport, standard serial data output.

The electronic construction of the system is backed up by a microprocessor which is controlled by fixed programs. Partial programs controlling calibration, measurement, calculation and recording for each type of logs are started by pushing a single button.

### 2.3.6 Nuclear geophysical analyser*

Ast he results of research over the past years and experience of oceanographical expeditions we have created the MTA 1527–HFD Integrated Nuclear Geophysical Analyser.

In addition to the measuring unit for determining the main components by activation, an X-ray radiometric measuring equipment with gas cooled semiconductor detector was also incorporated in the analyser in order to study useful mineral components.

The measuring system, the automatic changing of samples, the acquisition, interpretation and display of measured data are all governed by the control unit based on a Z80 microprocessor. Characteristic X-ray radiation arriving from the rock sample is sensed by the gas cooled semiconductor detector.

Signals of the detector after amplification and signal shaping go to the A/D converter, from where they are forwarded to the memory of the Z80 microprocessor. After the measurement is completed, the computer in automatic mode of operation compares the unknown spectrum of the analysed sample with standard spectra stored in the computer's memory and determines percentage compositions by programmed interpretation algorithms. The results of measurement are recorded in print and visualized on the display.

The equipment is able to perform individual and combined interpretation of complete spectra obtained from the X-ray radiometric measuring site. All data can be stored on the background store of the system (magnetic tape, floppy disc) for subsequent processing.

The integrated equipment was used to make a detailed analysis of iron-manganese nodule samples collected in the course of expedition work. We have investigated the reproduction accuracy of the measuring system and have determined the minimum concentration value that can be revealed by the equipment in routine operation. The reproduction accuracy for certain elements in absolute per cent is as follows:

Mn $\pm 0.06\%$, Fe $\pm 0.09\%$, Ni $\pm 0.013\%$, Cu $\pm 0.02\%$, Sr $\pm 0.003\%$.

When analysing other rock types it was also reaffirmed that the accuracy achieved by the analyser surpasses the accuracy of wet chemical analyses.

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