GEOPHYSICAL TRANSACTIONS 1984
Vol. 30. No.1 pp. 83–92

COMPUTER LOG EVALUATION IN TERTIARY COAL BASINS

Stanislav MAREŠ*, Jiři KŘESŤAN**

Lignite seams in open-pit mines of the Tertiary coal basins of Northern Bohemia are currently being exploited and geological prospecting and drilling activities are being carried out in new regions in an attempt discover further resources of solid fuels. All boreholes are logged using a relatively wide range of logging methods (formation resistivity log, gamma-ray log, formation density log, neutron-neutron log, caliper log). Logs digitized directly in the field are subsequently processed on an Eclipse C 300 computer. The results of computer evaluation are presented in the form of formation volume analysis in sandy—clayey overburden and in the form of an ash content log in coal seams.

d: well logging, computer evaluation, brown coal exploration, formation analysis, ash-content log

1. Introduction

The North Bohemian Basin is the largest brown-coal basin in Czechoslovakia. It occupies an area of about 800 km^2 and is situated at the foot of the Krušné hory Mountains, between the towns of Kadaň in the west and Ústí n. Lab. in the east. The south-eastern margin of the basin in demarcated by the line connecting the localities Korozluky, Postoloprty and Podbořany. The basemen is formed of the Krušné hory crystalline complex in the northern part and of Upper Cretaceous sediments in the southern part. The character of the sedimentary filling of the basin is given in *Table 1*. The coal seam is formed from one seam of great thickness or is divided by thin clay layers into 2 or 3 parts. The upper boundary of the coal seam is very sharp, but the transisiton to the underlying barren rocks is often gradual. The main coal seam is exploited predominantly by open-pit mining. Additional prospecting by means of boreholes is made i) in front of the working face in order to precisely determine the seam structure and the ash content, ii) in as yet unexploited parts of the basin in order to assess new reserves of brown coal.

2. Logging techniques and calibration of logging instruments

All the prospecting boreholes are logged. In the boreholes in front of the mine faces only density logs (GGL) and caliper logs (CL) are measured; in the boreholes of newly prospected areas the above-mentioned logs are complemen-

* Faculty of Sciences, Charles University, Albertov 6, 128 43 Praha, Czechoslovakia
** Stavebni geologie, n.p., Gorkého nám. 7, 113 09 Praha 1, Czechoslovakia
Paper presented at the 28th International Geophysical Symposium, 28 September—1 October, 1983 Balatonszemes, Hungary

ted by gamma ray logs (GR), neutron-neutron logs (NNL) and resisitivity logs in some simple electrode arrangement (short normal RESN16 with AM electrode spacing 0.4 m and long normal RESN64 with AM = 1.6 m). Borehole logging is carried out using K-500 (Hungarian–made, ELGI) or Prospector 2000 (US–made, Gearhart–Owen Inc.) logging equipment, supplemented by analog-to-digital converters (Czechoslovak-made) [KŘEŠŤAN 1978, MATOUŠEK ET AL. 1978]. Logging data are punched on a tape with a 0.1 m digitization step. Analog logs are recorded on 1 : 100 scale.

All logging tools are calibrated to express all measured data in defined physical units. Density probes (Source ^{137}Cs, activity 10 to 20 × 10^8 Bq, detector to source distance $L = 0.5$ m, the probe with shielded detector pressed against the borehole wall by a steel spring) and neutron probes (source ^{241}Am-Be, activity 110 GBq, $L = 0.5$ m) are calibrated in large blocks of rock of known

<table>
<tr><th rowspan="2">Age</th><th colspan="2">Lithostratigraphic units</th><th rowspan="2">Most frequent lithol. types</th><th rowspan="2">Thickness (m)</th></tr>
<tr><th>Series</th><th>Formation</th></tr>
<tr><td rowspan="4">Miocene
Aquitan. Burdigal. Helvet. Torton.</td><td rowspan="3">producing</td><td>Upper clays and sands</td><td>mostly clays</td><td>up to 250</td></tr>
<tr><td>coal-seam</td><td>brown coal</td><td>30–50</td></tr>
<tr><td>lower clays and sands</td><td>sandy-clayey layers</td><td>up to 100</td></tr>
<tr><td colspan="2">volcanogenic series</td><td>sandy—clayey sediments with pyroclastics, tuffs and tuffites</td><td>20–50</td></tr>
<tr><td>Oli-goecene Middle—Upper</td><td colspan="2">basal complex</td><td>sandstones and conglomerates</td><td>100</td></tr>
</table>

Table I. Geological data on the Neogene North Bohemian Basin [after HAVLENA 1964]

I. táblázat. Az Észak-cseh medence neogén képződményeinek földtani adatai [HAVLENA nyomán, 1964]

Таблица I. Геологические данные Северочешского неогенового бассейна [по ГАВЛЕНА, 1964 г.]

bulk density and porosity; the results of borehole measurements are expressed in g cm^{-3} for bulk density and in % for neutron porosity. The probes for measuring natural radioactivity are calibrated using ^{226}Ra standard of known activity, and the results of borehole measurement are expressed in rate exposure units, pA kg^{-1}. Calipers are calibrated using a set of rings of known diameter; the results of borehole measurements are expressed in mm.

3. Evaluation of logging data and algorithms used

The purpose of logging in coal prospecting is:

a) to delimit the principal lithological types of sediments and to determine the depth of the basement surface,

b) to delimit the depth interval of the coal seam and to determine the ash content and heating capacity.

The digitized logs are evaluated by means of the system of SG programs [Křesťan, Mareš 1977] using an Exlipse C 300 minicomputer [Mareš, Křesťan 1981]. In the first step (editing program) the measured data usually expressed in mV are converted into the defined physical units using the calibrating constants (see above). Logging data are then statistically analysed (statistical programs). Using frequency graphs, frequency plots and Z-plots (see *Figs. 1–3*) the characteristic physical parameters (density DEN, neutron porosity NPOR, natural radioactivity GR and the apparent resistivity RESN) of clays (indices SH), of clean sands (SD), of the formation matrix (MA) and the limit values for the coal (C) and crystalline rocks (B) are determined. Regression analysis takes one of the most suitable mathematical relationships (linear, exponential, logarithmic, parabolic, hyperbolic) between density DEN and ash content AD and between density DEN and heating capacity QD, calculating the correlation coefficients and the corresponding regression constants. An example of statistically determined rock parameters for the Jiřetín coal district in the North Bohemian Basin is given in *Table 2.*

In the main program the following parameters are calculated:
clay content VSH_{GR} from the gamma ray log

$$VSH_{GR} = (GR - GR_{SD})/(GR_{SH} - GR_{SD}), \quad (1)$$

clay content VSH_N from the neutron—neutron log

$$VSH_N = NPOR/NPOR_{SH}, \quad (2)$$

resulting clay content VSH

$$VSH = MIN(VSH_{GR}, VSH_N), \quad (3)$$

effective porosity $EPOR_D$ from the density log

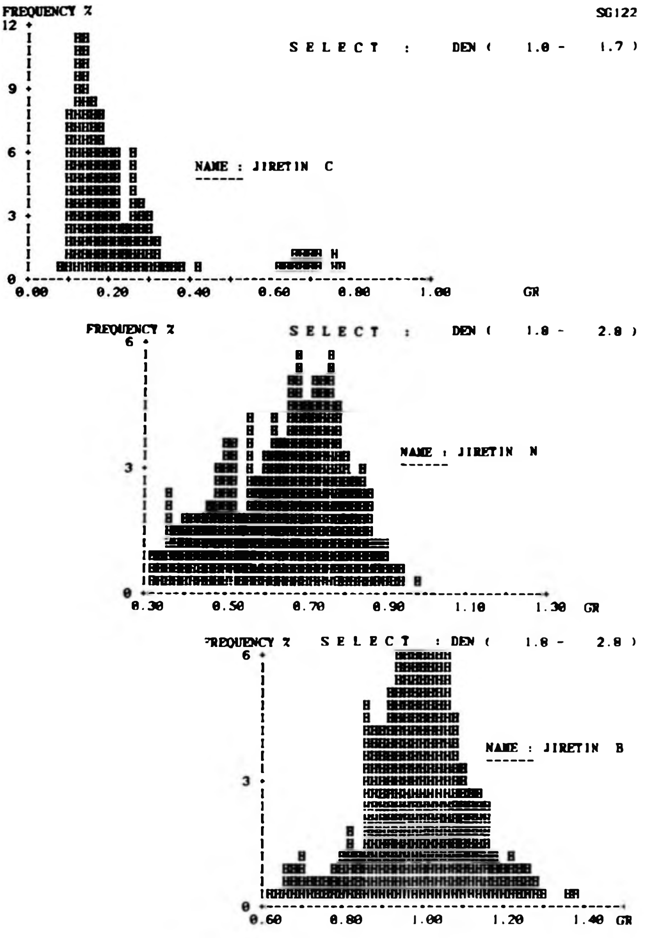

Fig. 1. Frequency graphs of the natural radioactivity GR (pA/kg) for coal (C), Neogene barren sedimentary rocks (N) and crystalline basement — gneiss (B)

1. ábra. A szénrétegek (C), a neogén meddő üledékes kőzetek (N) és a kristályos gneisz fekü (B) természetes radioaktivitásának gyakorisági görbéi (GR, pA/kg)

Рис. 1. Частотные кривые естественного гамма-излучения GR (pA/kg) (для угля (c), неогеновых непродуктивных осадочных пород (N) у кристаллического фундамента — гнейса (B)

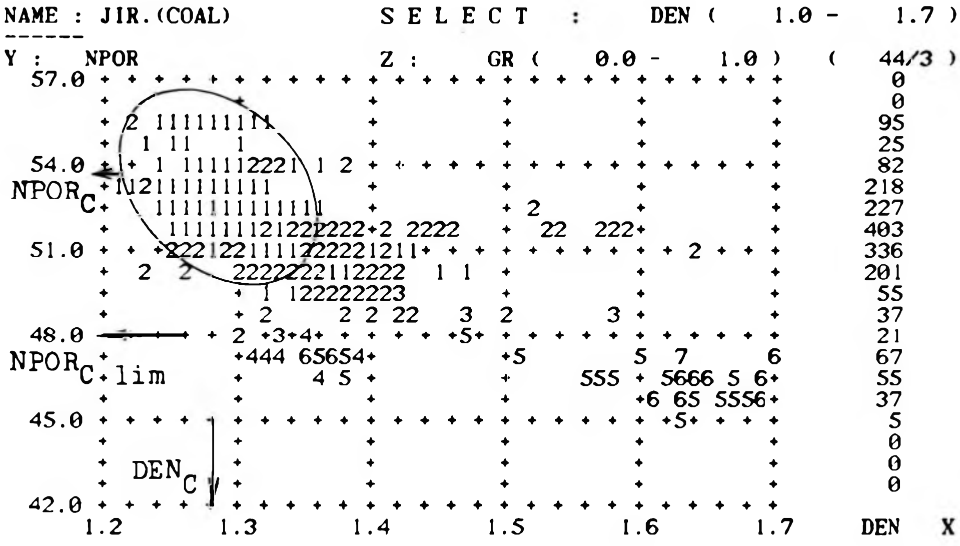

Fig. 2. Z-plot for determination of characteristic and limit parameters of coal ($NPOR_C$ = 53.5%, $NPOR_{C\ lim}$ = 48%, DEN_C = 1.28 g cm^{-3}, $DEN_{C\ lim}$ = 1.75 g cm^{-3} corresponds to ash content AD = 70%)

2. ábra. A kőszén jellemző paramétereinek és határparamétereinek meghatározására szolgáló Z-plot ($NPOR_C$ = 53,5%, $NPOR_{C,\ lim}$ = 48%, DEN_C = 1,28 g cm^{-3}, $DEN_{C\ lim}$ = 1,75 g cm^{-3}, amely megfelel AD = 70% hamutartalomnak)

Рис. 2. Диаграмма Z для определения характерных и предельных параметров угля ($NPOR_C$ = 53,5%, $NPOR_{C\ lim}$ = 48%, DEN_C = 1,28 g cm^{-3}, $DEN_{C\ lim}$ = 1,75 g cm^{-3} соответствует содержанию золы AD = 70%)

$$EPOR_D = DPOR - VSH \cdot DPOR_{SH}, \qquad (4)$$

where $DPOR = (DEN - DEN_{MA})/(DEN_F - DEN_{MA})$,
$DPOR_{SH} = (DEN_{SH} - DEN_{MA})/(DEN_F - DEN_{MA})$,
$DEN_F = 1\ g\ cm^{-3}$ (for the pore space filled with fresh water)

effective porosity $EPOR_N$ from the neutron—neutron log

$$EPOR_N = NPOR - VSH \cdot NPOR_{SH} \qquad (5)$$

resulting effective porosity EPOR

$$EPOR = (EPOR_D + EPOR_N)/2 \qquad (6)$$

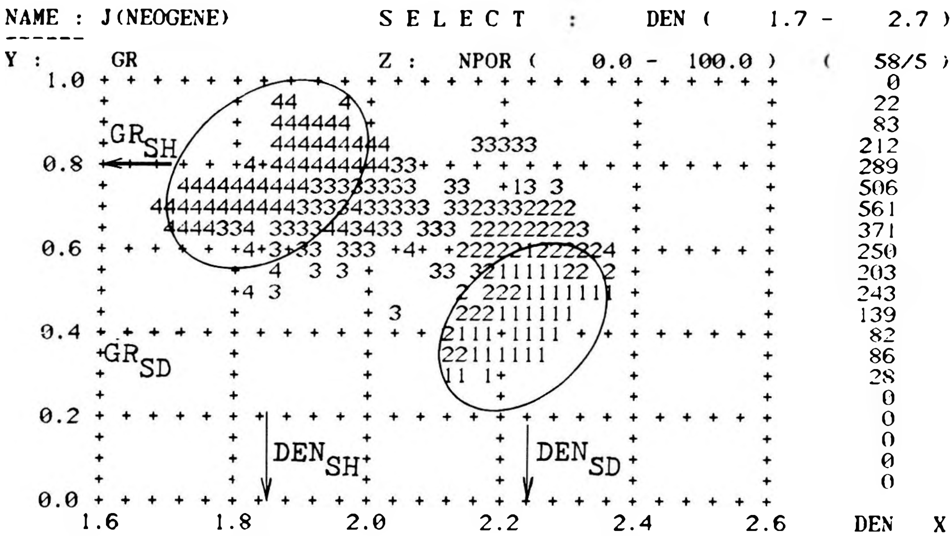

Fig. 3. Z-plot for determination of characteristic values of physical parameters of clays (DEN_{SH} = 1.85 g cm^{-3}, GR_{SH} = 0.8 pA kg^{-1}, $NPOR_{SH}$ = 43%) and sands (DEN_{SD} = 2.24 g cm^{-3}, GR_{SD} = 0.4 pA kg^{-1}, $NPOR_{SD}$ = 15%)

3. ábra. Az agyag és homok jellemzőinek és fizikai paramétereinek meghatározására szolgáló Z-plot (DEN_{SH} = 1,85 g cm^{-3}, GR_{SH} = 0,8 pA kg^{-1}, $NPOR_{SH}$ = 43% illetve DEN_{SD} = 2,24 g cm^{-3}, GR_{SD} = 0,4 pA kg^{-1}, $NPOR_{SD}$ = 15%)

Рис. 3. Диаграмма Z для определения характерных значений физических параметров глин (DEN_{SH} = 1,85 g cm^{-3}, GR_{SH} = 0,8 pA kg^{-1}, $NPOR_{SH}$ = 43%) и песков (DEN_{SD} = 2,24 g cm^{-3}, GR_{SD} = 0,4 pA kg^{-1}, $NPOR_{SD}$ = 15%)

The ash content AD and the heating capacity QD of coal are calculated for DEN = 1.75 g cm^{-3} using the following relations of the above given parameters for the density DEN of coal

$$AD = K_1 \, DEN + Q_1, \tag{7}$$

and

$$QD = K_2 \, DEN + Q_2, \tag{8}$$

where K_i an Q_i are coefficients from regression analysis of the laboratory data (see above).

The results of automatic log evaluation can be given by means of

a) a table from the printer, listing the resulting data with arbitrarily chosen depth step,

b) a table combined with simple graphic presentation of the formation volume analysis in the barren sedimentary rocks and of the ash content in the coal seam (see *Fig. 4*).

Physical Parameter	Characteristic for clay	Characteristic for sand	Characteristic for matrix	Characteristic for coal	Limit for coal	Limit for cryst. r.
Indices	SH	SD	MA	C	C lim	B lim
DEN ($g\ cm^{-3}$)	1.85	2.24	2.50	1.28	1.75	2.26
NPOR (%)	43	15	0	53.5	48	24
GR ($pA\ kg^{-1}$)	0.80	0.40	0.20	0.12	0.54	0.90
$K_1 = 116.48$		$Q_1 = -132.33$		$K_2 = -0.35$		$Q_2 = 30.98$

Table II. Characteristic and limit values of physical parameters of sedimentary rocks, coal and crystalline complex (calculation parameters) and regression coefficients for relations (7) and (8)

II. táblázat. Az üledékes kőzetek, a kőszénrétegek és a kristályos összlet jellemző értékei és határértékei (számítási paraméterek), valamint a (7) és (8) összefüggések regressziós együtthatói

Таблица II. Характерные и предельные значения физических параметров для осадочных пород, угля и кристаллической толщи (расчетные параметры) и коэффициенты регрессии для отношений (7) и (8)

STAVEBNI GEOLOGIE - PVS
P R A H A

PROGRAM SG143

L O G   D A T A   C O M P U T E R   P R O C E S S I N G

BOREHOLE : CN 54   (AREA : 51)   DATE : 5. 4.1983

PROFILE (M)	COMP	DENSITY (G/CCM)	NPOR (%)	GR (PA/KG)	RESN16 (OHMM)	DD (MM)	VSH (%)	EPOR (%)	AD (%)
60	I----I	1.94	42.1	0.71	2.0	4.	77.5	8.9	
	I----I	1.98	41.6	0.75	1.9	4.	88.5	2.8	
	I----I	1.88	43.3	0.75	2.2	9.	87.3	6.8	
	I----I	1.92	45.7	0.70	2.9	10.	75.0	12.5	
	IH30HI	1.51	52.3	0.39	15.7	4:			35.1
	IHHHHI	1.27	52.7	0.18	48.5	-1.			15.7
	IHHHHI	1.27	52.3	0.16	67.2	-1.			15.5
	IHHHHI	1.29	52.4	0.15	56.9	-1.			17.8
	IHHHHI	1.26	52.4	0.16	55.7	-1.			14.6
	IHHHHI	1.27	52.0	0.16	44.8	-1.			15.9
70	IHHHHI	1.31	51.6	0.17	38.6	-1.			19.7
	IHHHHI	1.31	51.8	0.17	34.6	-1.			19.9
	IHHHHI	1.31	51.8	0.17	32.0	-1.			20.3
	IHHHHI	1.34	51.1	0.18	28.0	-1.			23.2
	IHHHHI	1.37	51.4	0.17	21.6	-1.			27.5
	IHHHHI	1.38	50.3	0.20	18.6	-1.			28.5
	IHHHHI	1.34	50.9	0.18	22.3	-1.			23.2
	IHHHHI	1.38	51.3	0.1:	17.7	-1.			28.9
	IHHHHI	1.30	51.7	0.17	26.2	-1.			19.1
	IHHHHI	1.32	51.4	0.19	29.2	-1.			21.2
80	IHHHHI	1.29	50.6	0.19	34.7	1.			17.6
	IHHHHI	1.33	49.9	0.22	34.7				22.2
	IHHHHI	1.37	50.5	0.23	35.2	1.			26.9
	IHHHHI	1.37	50.1	0.24	33.4	1.			27.2
	IH30HI	1.43	49.4	0.26	31.2	1.			34.7
	IH30HI	1.46	44.4	0.32	79.2	1.			37.1
	I.--.I	1.95	39.8	0.56	55.8	5.	41.0	21.9	
	I-..-I	1.99	28.8	0.57	56.8	16.	42.5	14.4	
	I-..-I	2.25	19.7	0.58	96.9	12.	41.2	2.3	
	I....I	2.24	17.0	0.45	157.6	31.	12.5	12.1	
90	I-..-I	2.18	16.7	0.49	168.7	28.	22.5	10.0	
	I....I	2.17	15.6	0.3:	137.5	6.	2.8	18.0	
	I....I	2.24		0.39	141.4	45.	0.3	17.5	
	I....I	2.27		0.38	144.2	68.	0.1	15.6	
	I....I	2.28		0.41	136.1	68.	6.3	12.6	
	I-..-I	2.34		0.52	127.5	68.	29.8	0.7	
	I-..-I	2.31	6.3	0.54	124.2	64.	16.2	4.0	
	I-..-I	2.30	14.4	0.53	130.5	62.	29.9	2.0	
	I-..-I	2.32	14.8	0.48	130.1	54.	20.8	5.0	
	I....I	2.33	15.7	0.42	121.1	5:.	4.0	11.8	
100	I-..-I	2.32	17.1	0.50	118.3	70.	25.3	4.7	

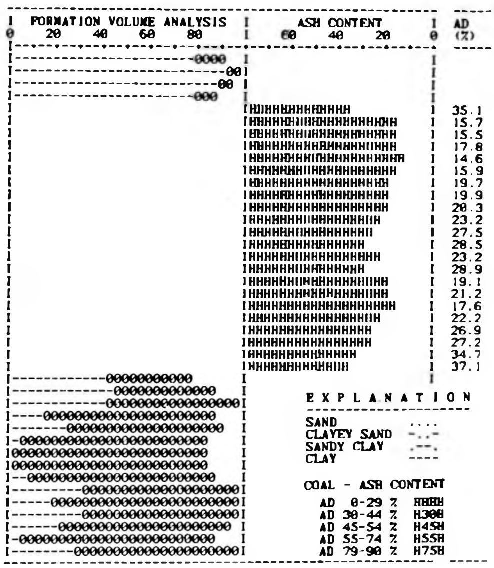

Fig. 4. Listing and schematic graphic representation of logging results from a prospecting borehole in the North Bohemian Basin

4. ábra. Az Észak-cseh medencében végzett kutató fúrás szelvényezési eredményeinek táblázatos és vázlatos grafikus ábrázolása

Рис. 4. Перечень и схематическое графическое изображение результатов измерений в разведочной скважине в Северочешском бассейне *c)* logs showing: i) the formation volume analysis in barren sedimentary rocks, ii) the ash content in the coal seam, iii) two original or transformed logging parameters for better delimitation of the coal seam (*Fig. 5*).

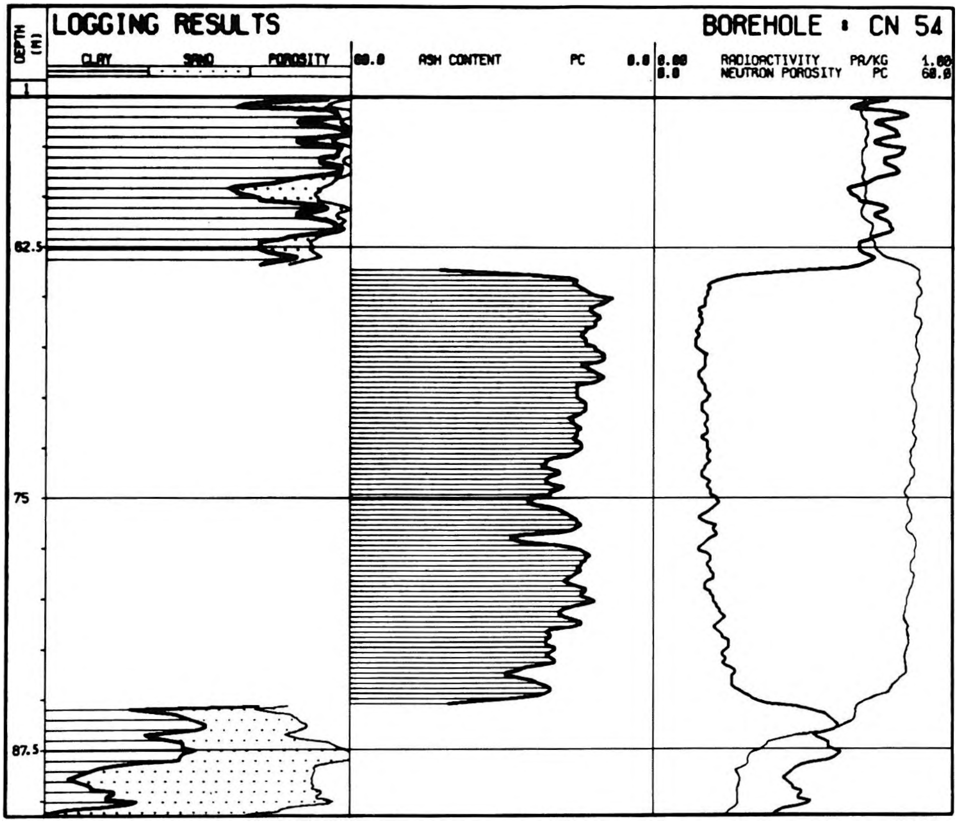

Fig. 5. Graphic representation of logging results from the prospecting borehole given in Fig. 4

5. ábra. A 4. ábrán látható szelvényezési eredmények részletes grafikus ábrázolása

Рис. 5. Графическое изображение результатов измерения в разведочной скважине, указанной на Рис. 4.

4. Conclusions

Digitally recorded logs from prospecting boreholes in brown coal basins are evaluated using the system of SG programs for an Eclipse C 300 minicomputer. Such a manner of evaluation has the following advantages:

1. The time consuming process of manual evaluation can be omitted; the results of computer log evaluation are available to the mining enterprise or the geological service of the prospecting organization in a very short time.
2. The subjective human factor and the unreliability of manual calculations are excluded.
3. The possibility is given for thorough statistical analysis of logging and laboratory data to determine the characteristic and limit values of rock parameters and the corresponding interrelations.
4. Calculation of rock parameters VSH, EPOR and of technological coal parameters (AD with an absolute error not exceeding $\pm 5\%$, QD with a relative error not exceeding $\pm 10\%$).
5. Representation of logging results in a form convenient for geologists. (The most desired form is that combining listing and simple graphic presentation *(Fig. 4)* with a depth step of 0.5 m).
6. Preservation of measured and evaluated data in the external memory of a computer for the future assessment of coal reserves in the area under consideration or for any other integrated evaluation of logging data together with the descriptive geological (lithology, intensity of weathering, density of jointing) and laboratory data (bulk density, matrix density, porosity, moisture content, grain-size distribution, mechanical properties) obtained from core samples.

BIBLIOGRAPHY

Bond L. O., Alger R. P., Schmidt A. W., 1969: Well Log Applications in coal mining and rock mechanics. Soc. Mining Engineers of AIME, 99th Annual AIME Meeting, Washington (Feb. 16–20, 1969), Paper 69-F-13

Christalle H., Steinbrecher D., 1981: Estimation of brown coal quality parameters using well log data. Proceedings of the 26th International Geophysical Symposium, Leipzig, Sept. 22–29

Grechukhin V. V., 1965: Geophysical methods of investigation coal boreholes (in Russian). Moscow, Nedra

Havlena V., 1964: Geology of coal deposits. Czechoslovak Academy of Sciences, Academia, Prague (in Czech)

Krestan J., Mareš S., 1977: The System of SG programs for effective well log evaluation. Paper read at the Geophysical Symposium, Sept. 13–16, Prague

Křestan P., 1978: Digital Recorder DKR-32-MH (in Czech). Natural Gas and Petroleum, XXIII, la. pp. 171–175, Hodonin

Matousek J. et al., 1978: Digital recorder for well logging SG-77 (in Czech). Natural Gas and Petroleum, XXIII. la, pp. 163–169, Hodonin

Mareš S., Křestan J., 1981: Minicomputer processing of log data from Engineering Geological Boreholes. Proceedings of the 26th Geophys. Symp., Sept. 22–25, Leipzig

Schlumberger, 1974: Log Interpretation. Vol. II—Applications, New York

Tixier M. P., Alger R. P., 1967: Log evaluation of nonmetallic mineral deposits. Trans. SPWLA Eightgh Annual Logging Symposium

SZÁMÍTÓGÉPES SZELVÉNYKIÉRTÉKELÉS HARMADKORI SZÉNMEDENCÉKBEN

S. MAREŠ, J. KŘESŤAN

Az észak-csehországi harmadkori szénmedencékben külszíni fejtéses lignitbányászat jelenleg is folyik. A területen intenzív földtani és fúrásos kutatás folyik, további szilárd fűtőanyag-készletek feltárása céljából. Valamennyi fúrásban széles körü szelvényezést végeznek, többek között meghatározva az ellenállás-, gamma-, sűrűség-, neutron- és lyukátmérő szelvényt. A szelvényezési adatok digitalizálását közvetlenül a terepen végzik, egy Eclipse 300 típusú számítógép segítségével. A számítógépes feldolgozás eredményét az agyag-homokkő fedőkőzetben térfogati elemzés, a szénrétegben hamutartalom-szelvény formájában adják meg.

МАШИННАЯ ОБРАБОТКА КАРОТАЖА ПРИ РАЗВЕДКЕ БУРОГО УГЛЯ

С. МАРЕШ, Й. КРЖЕСТЯН

В третичных угольных бассейнах северной Чехии бурий уголь добывается в открытых разработках. В новых районах этого бассейна производятся буровые работы для подсчёта запасов твердого топлива. Во всех скважинах производится относительно широкий комплекс каротажных методов (измерение сопротивления, ГК, ГГК, ННК, кавернометрия). Каротажные диаграммы регистрируются в цифровой форме прямо ха буровой, машинная обработка производится на ЭВМ типа Eclipse С 300 системой программ SG. Результаты машинной обработки представляются в виде крывых отдельных составляющих (глина, песок, пористость) в пустых третичных отложения и в виде кривой зольности углей в угольных пластах.