

## Interactive program system for application of modern evaluation of coal deposits and their parts under complicated conditions

František Staněk<sup>1</sup>, Josef Honěk<sup>2</sup>, Kerstin Hoňková<sup>2</sup> and Jan Jelínek<sup>1</sup>

### *Interaktívny programový systém pre aplikáciu moderného hodnotenia uhoľných ložísk a ich časti v komplikovaných podmienkach*

*In the contribution methodical procedures of modeling and assessing of coal deposits, applied in the frame of the solution of the (Grant Agency of the Czech Republic) project No 105/03/1417 entitled „Interactive program system for application of modern methods of evaluation of coal deposits and their parts under complicated conditions“, are presented. The development of the computer technology as well as the new results in the domain of scientific geoinformatics have enabled an application of new modeling procedures and subsequent assessing of coal seams. Above all, the procedures in the sphere of the statistical data processing, geostatistics, selection and the application of a proper interpolation method, the graphic elaboration of maps and the 3D visualization of modeled coal seams and further procedures facilitating the selection of in-seam balanced thickness as well as identifying and correlating of coal seams are concerned. The program system formed in this way is conceived for applying to all types of coal deposits occurring in the Czech Republic.*

**Key words:** coal seam modeling, calculation of coal reserves, mathematical procedures of assessing deposit attributes, methods of evaluation of coal deposit, automated program system

### Introduction

The contribution deals with methodical procedures applied to a newly developed program system for the model of coal deposit formation and its subsequent assessing. The program system was developed within the frame of the project of the Grant Agency of the Czech Republic (hereafter GAČR) N° 105/03/1417, entitled „Interactive program system for application of modern methods of evaluation of coal deposits and their parts under complicated conditions“ (hereafter *IPSHUL*). The system is applicable for all types of coal deposits in the Czech Republic. In reality individual coal basins considerably differ especially by their general geologic structure, depth of depositing, level of exploration etc.; the *IPSHUL* was adapted to the elaborated characteristics of selected coal basins of the Czech Republic.

Generally, the coal deposits of the Czech Republic are structured, (in view of methodology and procedure), into two main groups. In the first group, there are coal basins with a small number and usually a greater thickness of coal seams, a lower depth of depositing of coal seams, and a simpler tectonic development. Members of this group are the North Bohemian brown coal basin as well as the South Moravian lignite coalfield, for which the *IPSHUL* has been primarily formed. Especially in peripheral parts of these coal basins the areas occur with a greater number of thicker dirt bands, dividing the seam into independent benches. However, the principal nature of the coal seam structure has (from the surface point of view) an overall basin validity. Another type of coal deposit is presented by coal basins with a great number of coal seams of prevalingly unstable nature. The coal seams frequently thin out, having a lens-shaped development and splitting into two or more subseams (benches). These variations have a local and rapid nature. The coal seams with a stable development are exceptional from the overall coal basin point of view. Among such basin types, the Lower Silesian coal basin and the selected area of the Upper Silesian hard coal basin rank, for which the developed system of evaluation of coal deposits was adapted later.

### Methods of evaluating reserves of coal deposits in the Czech Republic

A main difference between the methods for the assessment of coal reserves is perceived by assessing the volume of the the deposit body and the values of observed deposit attributes in a defined domain or eventually a block (Schejbal, 2001). The applied method of the assessment of the reserves, the statistical and spatial distribution of deposit variables, the morphogenetic type of the deposit and the system of exploration of the deposit are decisive for the procedure of assessing the mean values of the deposit variables. In course of past years a number of methods of assessing the reserves of solid mineral raw materials were proposed and practically used. Among the most popular methods, the arithmetic mean method (for geologic or mining blocks), the polygon method (Boldyreff method), the triangle method, the geologic

<sup>1</sup> Doc. RNDr., František Staněk PhD., Ing. Jan Jelínek, Ph.D., HGF VŠB-TU Ostrava, 17. listopadu, Ostrava-Poruba, 708 33

<sup>2</sup> Doc. Ing., Josef Honěk CSc., Ing., Kerstin Hoňková PhD., Opavská 150, Ostrava-Pustkovec, 708 00  
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section method, the contour method and the statistical method (Schejbal, 2003) can be ranked. The first two ones of the above-mentioned classic methods (method for geologic or mining blocks, polygon method) were previously applied with the preference for practical calculations of coal reserves.

Current procedures of assessing coal reserves, used for the interactive program evaluation of coal deposits, are based on the discrete modeling. They use segmenting the deposit object into a plane or a spatial network of elementary plane or spatial units representing basic structural units of assessments. This potential set of structural units is then transformed according to the level or degree of exploration (i.e. according to the scope and reliability of the knowledge), according to required technical-economical criteria of utilization, permissibility to mining (free reserves or bound reserves) or eventually to further criteria into appraisal of reserves of particular categories. For assessing the values of deposit attributes of particular elementary units we apply interpolation methods described further in the text. An example of such procedures is the *IPSHUL*.

### Mathematical procedures of assessing deposit attributes

A basis of the complex processing of data for a coal deposit (most frequently a calculation or recalculation of reserves is concerned) is the formation of a model of the coal deposit, which is the best comprehending the real situation. Best apart from determining the total coal reserves according to various criteria, it is necessary for many purposes to know both the deployment of raw materials and their indices.

For *IPSHUL*, mathematical procedures, especially the procedures of mathematical statistics and geostatistics and other selected kinds of function interpolation, were applied.

### Mathematical statistics and geostatistics

Differences between the classic mathematical statistics and the analysis of geodata by means of statistical and geostatistical procedures result from properties of geological objects and from real possibilities of their investigation. As mentioned by Schejbal (2001), practically all evaluations are based on inhomogeneous data files (consequence of various data carriers – samples), which represent very frequently mixed statistical distributions. The magnitudes, by which the investigated objects are characterized, are often not statistically independent. Geological bodies are featured by participating of both structural and incidental components in a spatial distribution of values. Moreover, the geological bodies can be investigated only in a limited extent due to their problematic accessibility and also due to cost requirements of geological work. The above-mentioned aspects influence the possibilities and procedures of statistical and geostatistical analysis of geodata. Therefore, we are confronted with certain problems and especially with limitations, which have to be respected during the analysis.

One of principal tasks of statistical analysis and selecting further methods of elaboration is the study of nature of statistical distributions. Only when based on a correct description of distribution, it is possible to assess statistical characteristics and to realize a further processing. It is a well-known fact that the empirical distributions of a majority of magnitudes describing geological bodies do not comply with a commonly considered normal distribution, but they have a not symmetrical distribution (predominantly positive, but also negative) – most frequently a lognormal one. However, a normal distribution is the basic prerequisite for applying many mathematical procedures. Without an adequate approach to „skewed“ data, it is impossible to perform for instance geostatistical analyses or assessments, because the best linear assessment is obtained from experimental values governed by the normal Gauss distribution (Vizi, Timčák, 2002).

The lognormal distribution is one of many possible distribution types of a set of values. In case of coal seam modeling, the values of particular deposit attributes are interpolated from irregular deployed exploration points into a regular grid of points. As linear mathematical procedures are concerned, it is necessary that input data are distributed normally. In order to bring the coal seam model to reality as close as possible, it is needed to apply normally distributed input values of particular deposit attributes for interpolation. In case that the input data file does not comply with the normal distribution, the so-called graphic (quantile) transformation of the input file can be performed by means of cumulative frequencies (empirical distribution functions, see Deutsch 2002) so that the resultant file has a standard normal distribution (with the zero mean value and standard deviation 1).

In a program solution of *IPSHUL*, the quantile transformation of input data into the standard normal distribution (hereafter SND) is performed in case when other than the normal distribution has been detected by a statistical test. Subsequently, the interpolation by a selected interpolation method is performed and the values of grid are transformed back with the use of cumulative frequencies (empirical distribution functions). The graphic transformation in its essence is the assignment of corresponding quantiles of both types of distributions. In Fig. 1a and Fig. 1b, the values corresponding to selected grids of ash content  $A^d$  of Dubňany seam of the South Moravian lignite coalfield, which have been interpolated by the kriging

method (linear isotropic model) from original values and from the values transformed into SND, are indicated. The absolute values of differences of these grids are represented in Fig. 1c.

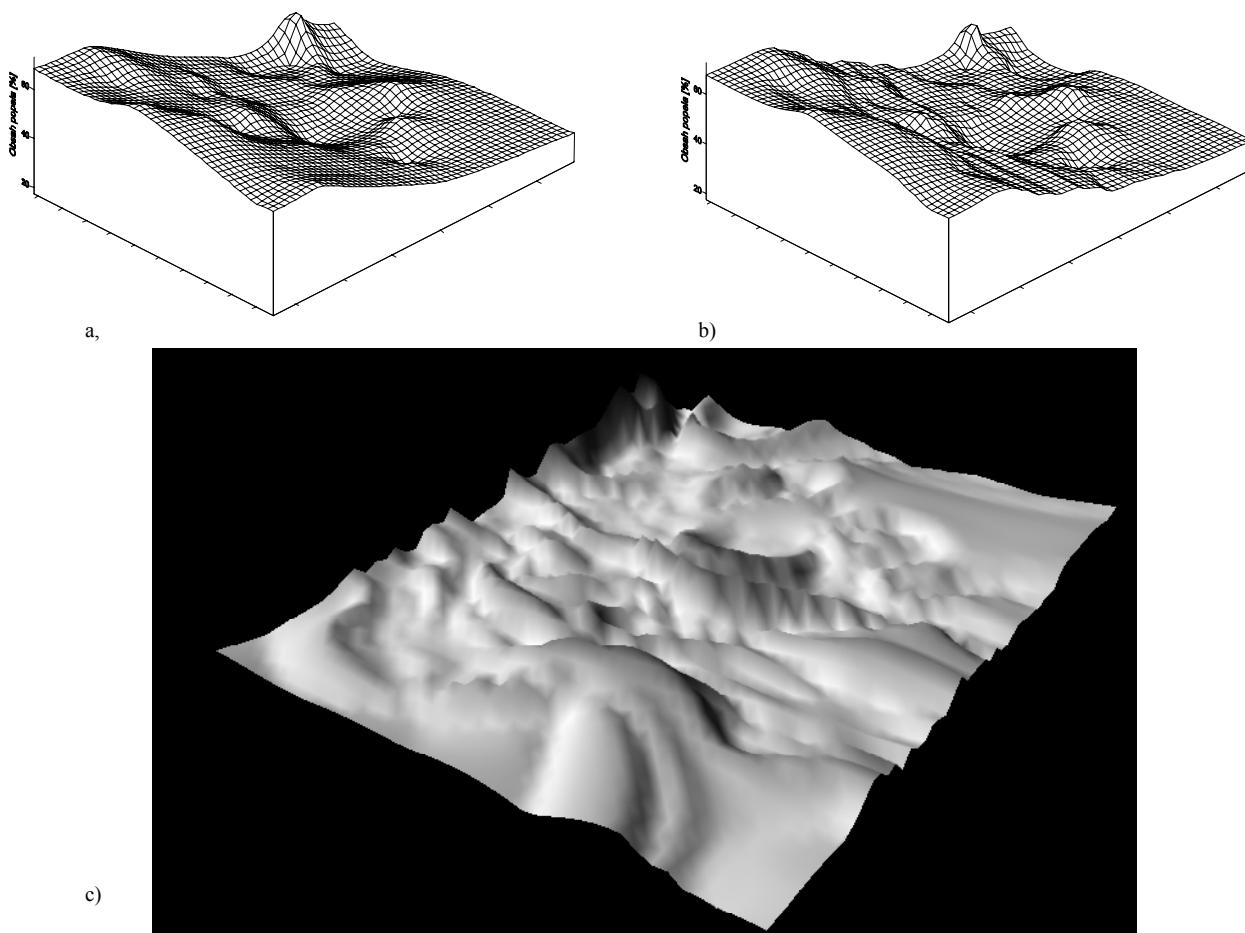


Fig. 1. Kriging method – a) grid formed from original values; b) grid formed from transformed values; c) representation of grid of differences of absolute values of grids formed from original and transformed values.

The geostatistical structural analysis of particular attributes of coal seam solved in the *IPSHUL* system is performed in the Surfer software environment. The results of geostatistical structural analysis are then applied for the interpolation of particular attributes of coal seam when forming a coal seam model.

### Interpolation of functions

With the use of many practical methods of calculation of reserves, a spatial model is transformed into a series of plane models (Staněk, 1999a). Usually the values within a regular grid of points are generated in such models as the basis for a subsequent interpretation of empirical values. Only the samples from a zone of influence, the shape, and size of which are determined according to the continuity and the anisotropy of the field, enter the calculation of a given point.

The selection of the interpolation method has a considerable impact on the resultant deposit model as well as on quantity of calculated raw material reserves. The application of an improper interpolation method leads to an unreal model of the deposit (Staněk, 1999a). The most frequent interpolation tasks occurring in practical applications can be structured into three principal groups: the group of statistical methods, group of geostatistical kriging methods and the group of continuous or smooth surfaces methods.

The Grid program objects of the Surfer software are used for gridding by *IPSHUL*. For the interpolation of deposit attributes, the following methods are suitable:

- inverse distance to power method,
- kriging,
- minimum curvature method,
- modified Shepard's method by which the inverse distance is connected to the power method with the adjustment by the least square method,
- natural neighbor method,
- nearest neighbor method,

- radial basis function method,
- triangulation with the linear interpolation method.

For making a choice of adequate interpolation method easier, the module of the so-called cross validation method is used by *IPSHUL* where for a point of known value, a calculation of local estimate based on other values is performed. This value, calculated in the point where a real value is known, is the result. Thus it is possible to determine the error of estimate in a given point and subsequently the error in all points (Deutsch, 2002; Staněk, 1999b). A testing is performed for the final set of interpolation methods with various parameters.

### Discrete models of natural objects

Both the classic automated mapping systems and the CAD (computer-aided design) software are unable to perform a complex modeling of geologic surfaces or even a less complex modeling of geological bodies disturbed by complicated tectonic faults (Mallet, 2002). For these reasons, Mallet during the development of his research project *gOcad* in 1989 proposed a quite different strategy using a discrete modeling of natural objects. In the frame of this discrete approach, the geometry of modeled objects has been defined by means of a finite set of nodal points in the 3D space, while their topology has been modeled by means of the interconnection linking of these nodes. Contrary to classic CAD methods, based on continuous functions (polynoms), the presented approach is based on the discretization of the object similarly as in the finite elements technique, which is used for the solution of partial differential equations. Each object is modeled by a set of interconnected points describing both the geometry and other properties of objects and, for the interpretation of geometry and properties of complex data, a discrete smooth interpolation is applied. In case of geological applications, it is necessary to pay a special attention to the discrete methods of modeling as well as to the geostatistical methods.

*IPSHUL* is based on the formation of plane discrete models of particular coal seams. From the geological point of view, a correctly performed identification and correlation of coal seams in the deposit is assumed.

## Main aspects of modeling coal deposits

### Database of deposit data

The database of *IPSHUL* is based on the conception of relational deposit database realized within the GA ČR project entitled „The development of system for loading and evaluation of data on coal resources and its utilization for analyses of usability of these resources after year 2000“, completed in 1998 by IGI HGF VŠB-TU Ostrava (Schejbal et al., 1998). The aim of the database is to encompass all data necessary for performing a coal reserve calculation. The data in the database allow to create a spatial model of coal seam body as well as models of selected attributes of coal seam, to divide a coal seam model into partial calculation blocks, and to determine the quantity of reserves in blocks with a simultaneous classification of reserves. The modeling is performed on the basis of data from the so-called balanced seam thickness in place where the coal seam is penetrated by a borehole, i.e. from coal seam sections selected with regard to assigned criteria, defined under conditions of utilization. The limit parameters of coal seams are most frequently the minimum thickness [m] and the maximum ash content  $A^d$  [%]. A balanced section in the coal seam is limited very frequently by further criteria as, for instance, the “condition of peripheral sample”: the extreme parts at the „roof“ or “base“ of a defined coal seam section characterized by the ash content, exceeding the contractual limit ash content value, cannot be included in the coal seam. From the above-mentioned follows that the database for the calculation of reserves has to contain both primary data obtained by the deposit survey and the data derived from them.

The database was compiled by using the MS Access software. It consists of a number of tables, which are structured into two parts:

- system (code) part,
- data part.

The system part is mainly represented by code tables, which form a fixed part of the developed system including their data records. Above all, lists of admissible values by means of which deposit data are coded and thus they are stored in a uniform way. In other tables, the coefficients and contractual values used in mathematical calculations and many complementary data required for the automated processing of data are stored. Although the tables of the system are already filled-up, they remain partially opened for users during their work with the system. The database and thus also the system can be adapted in this way to specific conditions of particular coal basins or their partial areas, and to the purpose of calculation of reserves. For instance, a user can expand according to his needs into further types of rocks or lines,

forming boundaries of calculation blocks (new records can be created). Equally, he can complement with new conditions of utilization including values of limit parameters and prepare different criteria for eventual variant solutions of calculation of reserves, which are offered by the program.

Proper deposit data are stored in tables of the data part. Numerical data are preserved in the original form, descriptive information data are coded almost in full extent by means of data from the system part.

The data part was divided into two thematically and structurally different files designated as “the descriptive part” and “the graphic part”. The graphic part focuses on data of line or polygon type, the descriptive part cumulates numerical and textual data.

In the descriptive part of the database, the main share of data is formed from results of chemical-technological analyses and logs of boreholes with petrologic descriptions of rocks. For an uniform storage of terms of rocks, the principles of universal system of graphic representation of rocks, transition rocks and coal, developed in the past, were applied (Honěk et al., 2003).

The main elements of graphic part of database are plane or spatial objects defined and stored in the database by means of coordinates of vertexes of lines or polygons. The data are thematically structured into several groups: surface objects, underground objects, deposits and other contractual objects, Z - contour lines of seam base, tectonics, safety pillars, mined-out, areas according to the level of exploration and “others” (washout, outcrop etc.). Internal organization of data within each group is uniform and based on a simple partial structure formed by a trio of relational tables: by a code table with all admissible types of objects in a given group, by a list of all existing objects in a given group and by a table with coordinates of existing objects. The elementary structure of three interconnected tables is used for almost all objects with modifications being performed according to needs resulting from the nature of data of particular types at the level of data fields. Except of surface and underground mining objects and delimitative polygons (for instance a boundary of the deposit), all the other objects of the graphic part of database are linked with a proper coal seam. The code of coal seam, based on which the input data for the reserve calculation are filtered by the application, is filled in a table containing a list of objects of a given type.

The database is organized so as to be universally applicable for all types of coal deposits in the Czech Republic. Most tables are structured uniformly for all coal types, only among tables with the necessity of different structure depending on the type of coal (e.g. chemical–technological analyses), suitable alternatives exist. By simple substituting some tables with a different structure, the modifications of database for lignite, brown or hard coal are formed.

### **Identification and correlation of coal seams in IPSHUL**

When modeling coal deposits, the individual coal seams, or eventually particular benches of coal seams, are identified and correlated by processing the borehole data from the database. Selection of the balanced thickness of a coal seam in the borehole and detecting mean values of deposit parameters in these depth intervals within the graphic environment is enabled by the application developed as a part of the *IPSHUL* system. The proper identification and correlation are performed by the deposit geologists according to their concept on the base of following various graphic outputs developed from the data of the deposit database:

- petrologic logs of boreholes,
- detailed logs of coal seams,
- geologic sections.

These outputs are compiled using a special method of a graphic representation of rocks, transition rocks, and coals (Honěk et al. 2003), implemented into the software developed by Staněk (2003).

### **Modeling of internal attributes of deposits**

One of the most important conditions of reliable modeling of a coal deposit at all levels, which are apprehensible by the realized system of observation, is the detection and description of structure of fields of plane variables, by which the coal deposit is characterized. Usually, values in a regular grid are generated as a basis for the subsequent interpretation of empirical values.

It is necessary to pay a special attention to tectonic faults. In case of minor tectonic faults, where in a projection particular floes of coal seam are not too much shifted, it is possible to create a non-tectonic model of the coal deposit (South Moravian lignite coalfield). In case of a deposit with more conspicuous displacements of tectonic floes, in which equally reverse faults can occur (the Upper Silesian Basin), it is necessary to perform a spatial transformation of particular floes before modeling internal attributes of the deposit, i.e. „straightening“ into the original state.

### Forming of discrete model of coal deposit and its evaluation

From the technical point of view, the programming of particular modules was performed within the operation system MS Windows with the use of the Visual Basic software. In the system, objects of modern programming software in fields of the statistical data processing, geostatistical structural analysis, interpolation methods, graphic plotting of maps, and the spatial 3D depicting modeled coal seams were used. By means of the Visual Basic, for instance MS Access, MS Excel, Surfer or Arcview applications are interconnected.

The particular modules of *IPSHUL* were tested on case studies of selected coal basins. The processing took place according to particular coal seams or eventually coal benches, with a possibility of alternative change of parameters of utilization conditions, when selecting balanced positions in the borehole and when forming the coal seam (or coal seam bench) model and at a subsequent calculation of coal reserves.

#### Procedure of first-stage processing of coal basin

*IPSHUL* performs a first-stage processing of the deposit model in the following steps:

1. Selection of necessary values from external databases or eventually introducing of further values into deposit database;
2. Testing of reliability of data, eliminating erroneous data by means of optional logic limits;
3. Graphic representation of borehole logs in the territory of interest with the application of a new method of graphic representing data stored in the database;
4. Identification and correlation of coal seams or eventually particular benches of coal seam.

#### Procedure of processing a coal seam or a coal seam bench

The procedure of processing a coal seam follows immediately the first-stage processing of the deposit model and is realized by the following steps:

1. Determination of balanced thickness of coal seams or of coal benches in boreholes according to defined conditions of utilization, storing calculated geological and technological parameters into the database. The selection of balanced intervals of the coal seam is preceded by complicated selection explicit parameters for particular depth sections because such data can be gained from various types of samples (segments, slides, segment slides, checking analyses etc.).
2. Selection of data in exploring points of the area of interest (boreholes, shears) from the deposit database and their graphic representation together with values of technological and geological parameters in the modeled coal seam (e.g. depicting technological logs of the coal seam).
3. Statistical analysis and the geostatistical structural analysis of particular magnitudes performed for further decision-making about the method of modeling the coal seam. The selection of a proper interpolation method.
4. Formation of a basic model of the coal deposit from the data of information points (boreholes, shears) stored in the database.
5. Plotting of contour maps of modeled magnitudes of the coal seam, including depicting of tectonic situations, mined-out areas, safety protective pillars, contractual man-made restrictions (for instance boundaries of the coal deposit) and further important information.
6. Basic model is structured into independent floes by detected tectonic lines. According to lines defining other geologic phenomena (washout, outcrop), to contractual boundaries (boundaries of deposit, safety pillars), to technological limitations e. t. c., the coal deposit will be structured into smaller units – geological or mining calculation blocks.
7. Calculation of reserves of the coal seam or coal seam bench in the area of interest.
8. Compilation of textual synopses of coal reserves with structuring according to the method of evaluation of the deposit, for instance according to the level of exploration, balanced quality and the permissibility to mining.
9. Formation of maps of coal reserves complying with a traditional concept.
10. Modern presentation of the coal seam model – conversion of particular map types to the GIS environment with utilization of its possibilities.

#### Principle of interactive program evaluation of coal reserves under geologically complicated conditions

This procedure was specially adapted to the geologically complicated conditions of the Upper Silesian hard coal basin. A complicated Hercynian development was manifested by the irregular development of coal seams, their lateral steadiness, variable thickness, coal quality and the tectonic faulting. Among other factors, which aggravating calculation of coal reserves belong a great mining depth of coal seams, and a small

number of documentary points. The above-mentioned elements cause problems not only for a mutual correlation of coal seams and tectonic faults but also when selecting a proper interpolation method for their modeling.

The calculation procedure is performed separately for individual tectonic floes (unless the area of interest is tectonically faulted, then the area could be considered as a single tectonic floe) by means of the following steps:

1. Due to structuring of coal seams into floes it is necessary to adapt the system to this reality. The proposed system enables to calculate coal reserves not only for the whole coal seam, but it divides the seam into blocks based on the tectonic structure, which is modeled for the whole selected coal seam. It is possible to model the tectonic structure based on intersecting lines of faults with the coal seam, on the borehole data and on the data from other sources (e.g. mine maps). Each boundary line is divided into segments depending on the mutual crossing. Boundary points of partial lines lie on the crossing with other lines. Thus, combining arbitrary parts of fault lines is possible. Moreover, the user has a possibility to insert into system new dividing lines or to omit partial parts of fault lines and so to create a new tectonic or other limitation on the concrete hard coal seam. Polygons separated in this way will be designated subsequently and their boundaries will be stored in the database.
2. In the subsequent step, a project of coal seam base for polygons (tectonic floes) formed will be modeled by the system. The user will select a method of depicting of the modeled coal seam base from the standard offer of the applied Surfer program and assesses visually whether the modeled coal seam base corresponds to his concept of real appearance. The goal is to achieve a model which would most truly represent the reality. Wherewith the accuracy of the model and subsequent calculation of reserves depends on the quantity and density of input data, on the one hand, and on the choice of a proper interpolation method, on the other hand. If the model does not correspond to the reality, the user can add accessory points, which together with input values from the database would help to model a more accurate course of coal seam base. This process is repeated until the user is fully satisfied with the model.
3. When calculating coal reserves, the formed interactive system relates all attributes of coal seam to a true seam thickness. Ideally, where a tectonically intact coal seam with a constant true thickness is deposited in the horizontal position, the modeling of attributes and coal seam base is easy. In the Upper Silesian Basin the situation is considerably more complicated. The coal seams are frequently deposited monoclinaly, folded or locally dislocated. The amplitude of dislocation in faults differs, wide fault zones of failure occur, and the course of fault surfaces and the orientation of floes are complicated. Therefore, a program module transforming the modeled structure surfaces into the horizontal position was developed. The so-called „rectifying“ of the coal seam base works on the principle of finding the center of a tectonic floe or a given block, from which the coordinates of each grid point are recalculated. At the same time, the coordinates of documentary points are transformed into a new coordinate grid. If it is necessary to add into calculation the values from adjacent tectonic floes, the boreholes from a given zone of influence are selected (according to the distance from the peripheral polygon of the area of interest). The transformation of their coordinates is performed based on the type of the tectonic line (shift in the direction x and shift in the direction y) and according to the structure map of the modeled floe as well as according to the structure map of the tectonic floe, to which the transformed borehole belongs.
4. In transformed coordinates adapted in this way, a calculation of all attributes of coal seam and evaluation of coal reserves are performed. Based on given conditions of utilization, the peripheral polygons of blocks of coal reserves are determined according to required categories of utilization conditions together with mean values of observed attributes of coal seam. IPSHUL enables to specify coal reserves equally by the methods rarely used in the Czech Republic.
5. The following operation performs a backward transformation of all model parameters into original coordinates including calculated peripheral polygons. The process of „rectifying“ is used for joining up separated tectonic floes and is based on the information about the direction of displacement and the height amplitude of fault.
6. The result is depicted by means of contour and reserve maps in the original area of tectonic floes. A total calculation process can be optionally repeated on any other proposed polygons or tectonic floes. The system enables joining of coal reserves of particular tectonic floes and plotting of a map.
7. Individual types of maps created in this way (maps of boreholes, contour maps, maps of coal reserves) are exported to the GIS environment for an eventual further adaptation and elaboration. The resultant coal reserve sets are printed. The user is able to create further variants according to changed limit conditions of utilization (passing to point 4).

## Methods of evaluation of coal deposits by the developed interactive program system

By *IPSHUL*, the assessment of coal deposits is offered by following methods:

a) **International Classification of In Seam Coals [12]**

The international classification of in seam coal enables to classify coal with a view of characteristics of coal deposits, not for commercial or trade purposes. This classification is rarely used in the Czech Republic. The designation of coal types by this classification as well as boundaries defined between the types do not correspond entirely with the division of coal in the Czech Republic so far. The classification is based on three characteristics. When evaluating coal, it is necessary to take into consideration three characteristics:

1. *Rank (degree of coalification)*

The categorization of coal rank is organized in two ways to enable a comparison between the conventional group terms ranging from lignite to hard coal including anthracite and the hierarchical order of low-, medium- and high-rank coals. The conventional terms are approaching some other national systems, which are based on chemical, thermal or rheological properties. The lower limit boundary between peat and ortho-lignite (low rank C coal) is at a 75 % water content  $W_{tr}$ . The upper boundary between meta-anthracite (high degree of coalification A – high-rank A coal) and semi graphite is 0.8 % hydrogen content. Between these limits, the following main divisions are delineated: lignite, subbituminous (brown coals), bituminous (hard, black coals) and anthracites or alternatively low-, medium- and high-rank coal categories. Between them, in a hierarchical sequence, low coalification coals (low-rank coals) incorporating in their conventional sequence lignites and brown coals (subbituminous coal), medium coalification coals (medium-rank coals) incorporating in conventional series black or hard coals (bituminous coals), and finally high coalification coals (high-rank coals) incorporating in their conventional sequence anthracite coal types (Anthracite) are delineated.

All three main coalification degree groups (rank groups) are further structured into subgroups designated in conventional series Para, Ortho, Meta, per and in hierarchical series A, B, C, D. For classifying low coalification degree coals or Low-Rank Coals (Lignite and Brown Coals) the combustion heat or the gross calorific value  $Q_s^{af}$  [MJ.kg-1] is applied. For a more detailed classification of black (hard) coals and anthracite, the vitrinite mean random reflectance  $R_0$  [%] is used.

2. *Petrologic composition*

The petrologic composition is represented by results of maceral group analysis according to the ČSN ISO 7404-3 Standard. The percentage content of the following maceral groups is determined: the vitrinite group (V), the liptinite group (L) and the inertinite group (I) without minerals. If it is possible, a macroscopic description of coal with the application of lithotype terms is mentioned, namely bright, intermediate and dull coals.

3. *Grade of coal*

The quality of coal depends on the quantity of inorganic impurity in coal represented by the percentage ash content at the water-free state (ash content mass percentage)  $A^d$  [%]. For humic coals, the upper grade limit is  $A^d = 80.00$  %. Rocks with the ash content above the upper grade limit are not covered by the classification. The limit for discerning coal from rock, according to the ash content is  $A^d = 50.00$  %. Above this limit, transition carbonaceous rocks are classified, for instance coaly clay. For sapropelic coals the upper limit is 50 %  $A^d$ , which separates a sapropelic coal from oil shale. A comparison between qualitative terms (grade description) and petrologic equivalents (petrologic description) is given in tab. 1.

Tab. 1. A comparison of the grade description with the petrologic description

$A^d$ [%]	Grade description	Petrologic description
0-10	high grade coal	pure coal
10 – 20	medium grade coal	coal
20 – 30	low grade coal	coal with inorganic (e.g. clay) admixture
30 – 50	very low grade coal	ashy coal (e.g. clayey dull coal)
50 – 80	carbonaceous rock	coaly rock (e.g. coaly claystone)
>80	rock	rock



b) **International Codification System for utilizing Low-Rank Coal Utilization [14]**

The codification system for low-rank coal (brown coal), i.e. coal with  $Q_s^{af} < 24$  MJ.kg-1 and  $R_0 < 0.6$  % is intended to be applicable for run-of-mine coal and washed coal from particular seams, or for blends of coal from several coal seams. The evaluation is based on the following four parameters: the gross calorific value  $Q_s^{daf}$ , the total moisture  $W_t^r$ , the ash content  $A^d$  and the total sulfur content  $S_t^d$ . There is an eight-digit code number and for each parameter a single two-digit number is defined. The code number can be complemented with results of analytic investigations of further supplementary parameters (e.g. volatile matter content  $V^{daf}$ ). If the value of some parameter is not determined or available, a partial (incomplete) coding is performed, i.e. for a couple of figures the „xx“ characters are substituted into the code number.

c) **International Codification System for Medium- and High-Rank Coal [13]**

The codification system for medium- and high-rank coal (brown coal with  $Q_s^{af} \geq 24$  MJ.kg-1 or coal with  $Q_s^{af} < 24$  MJ.kg-1 and  $R_0 \geq 0.6$ ) is intended to be applicable to run-of-mine coal and washed coal from particular seams or for blends of coal from several coal seams. This evaluation of coal is based on the following eight parameters: the mean random reflectance of vitrinite  $R_0$ , the histogram value of reflectance of vitrinite, the composition of maceral groups I, L, the crucible swelling number SI, the volatile matter content  $V^{daf}$ , the ash content  $A^d$ , the total sulfur content  $S_t^d$  and the gross calorific value  $Q_s^{daf}$ . There is a 14-digit code number and to each parameter a single figure or a couple of figures are adjoined. The code number can be complemented with supplementary parameters (e.g. determinations of carbon and hydrogen content).

The compilation of complete code numbers of black or hard coal in the Czech Republic is not always realizable. Values of all code parameters were determined only exceptionally in the past. Above all, the determination of the mean random reflectance of vitrinite and the histogram value of the reflection are missing. Therefore, in most archive analytic results, only a partial (incomplete) coding can be carried out.

d) **Classification of Hard Coals by Code Numbers [15]**

During the past period in the Czech Republic, the classification of hard coal by code numbers was used for evaluating hard coal, which was designated also as an international coding system for the specification of commercial groups. The characteristics of coal, in view of the coke production, is indicated by a three-digit code number. By the first code number, the volatile matter content  $V^{daf}$  is indicated (in lower coalification, the coal gross calorific value  $Q_s^{af}$ ). The second code number indicates the crucible swelling number and the third one indicates the cokeability, i.e. the swelling properties according to the results of the dilatometric test. Coal types according to the code numbers are classified into commercial groups designated by the Roman figures and capitals.

e) **Evaluation of coal reserves in compliance with the mine Law**

According to the level of exploration – probable coal reserves, proved coal reserves.

According to the conditions of utilization – balanced coal reserves, non-balanced coal reserves.

According to the permissibility of mining – free coal reserves, bound coal reserves.

## Conclusion

In the present paper, the methodical procedure of modeling of a coal deposit as well as the process of its subsequent evaluation by a developed interactive program system is described. The created system was prepared from the methodical and programming point of view to evaluate main coal basins of the Czech Republic in a uniform modern way. The methodical background described in the article gives a prerequisite to avoid errors caused by the application of improper or even inadequate procedures of evaluation of coal deposits.

In the system of evaluating a coal deposit, plane discrete models of particular coal seams are applied, to perform detailed calculations under complicated geological conditions in particular modules of the program system. The procedure of classification of coal reserves proceeds not only in accordance with methods used in the Czech Republic but also with European and international classifications.

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