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Geological and technological viewpoint on 3D Deposit Model – examples of use in Pniówek Coal Mine

Katarzyna Golda[1], *Lesław* Paszek[1], and *Jarosław* Kulpa[2*]

[1]KWK Pniówek, 18 Krucza St., 43-251 Pawłowice, Poland
[2]Mineral and Energy Economy Research Institute, Polish Academy of Sciences, 7A Wybickiego St., 31-261 Cracow, Poland

Abstract. During the more than 3 years of the "Quality" program at JSW S.A., a geological database has been built from scratch, collecting data from all exploratory boreholes, roadway profiling and the results of chemical analyses in one place – placing particular emphasis on parameters affecting the quality of coke. Working with digital databases requires new competencies for geologists – the ability to efficiently obtain information ready for further processing. As intended, the geological model became the basis for forecasting the quantity and quality of mined coal used in coke production. In the course of the work, a discrepancy became apparent between the geological interpretation of the structure of the deposit – as understood by the assumptions of the geological documentation, and the technological conditions of mining. The article presents resulting changes in the approach to modeling lithology and quality parameters. In addition, examples of the application of the geological database and the geological model in the daily work of the geological department are presented.

1 Introduction

A 3D deposit model from a geological perspective refers to a comprehensive digital representation of a subsurface mineral deposit or geological formation [1]. It integrates various data sources such as geological mapping, drilling data, geophysical surveys, and geochemical analysis to create a spatially accurate and detailed model of the deposit in three dimensions [2, 3]. It allows geologists to visualize the spatial distribution and geometry of mineral deposits, aiding in better understanding the geological structures and processes that control their formation [4]. By incorporating data from drilling and sampling, 3D deposit models facilitate more accurate estimation of the size, shape, and grade of mineral resources. This information is crucial for assessing the economic viability of mining projects [2, 5].

Also, usage the 3D deposit models to identify geological hazards such as faults, fractures, and unstable rock formations, helping to mitigate risks associated with mining operations [6, 7]. The ability to visualize the subsurface in three dimensions assists in planning exploration activities more efficiently, targeting areas with the highest potential for mineralization [8].

* Corresponding author: jkulpa@meeri.pl

3D deposit modelling and Technology 4.0 offer significant benefits to the mining industry and energy supplying [9]. 3D deposit models provide a foundation for integrating and analysing data from various sources, while Technology 4.0 enables more efficient and sustainable mining practices through automation, optimization, and predictive analytics [6, 10]. The synergy between these approaches contributes to improved resource utilization, reduced environmental impact, and enhanced safety in mining operations [11].

The concept of model is widely known and used in the technical literature and there are many interpretations of it. A special example of a mathematical model is a digital deposit model, a computer presentation of a mineral deposit showing selected aspects of the deposit such as its geometry, location or spatial variation of quality parameters [12, 13]. A characteristic feature of models (including digital deposit models) is that they do not need to consider all the elements and relationships present in the studied object or process. In the case of coal deposit models this is shown, among others, in the omission of modeling of faults with very small throws or not paying attention to areas already selected or unprofitable for mining.

A digital model of a deposit is primarily a tool for geologists interpreting and documenting the geological structure of a deposit. Easy and quickly generated spatial visualizations of the deposit show it in a different light and help to better understand the often complex and intricate structure of the deposit [14, 15].

There are many ways to systematize the digital deposit models in the literature, one of which is oriented according to the nature of its structure. It distinguishes two main group-2s: two-dimensional grid (grid) models and three-dimensional block models. In grid models, the dependent variable Z is a function of position, determined by plane coordinates (*X* and *Y*). In a block model, the modeling area is divided into elementary units (blocks), the size of which depends primarily on the geometry of the deposit (its dimensions), the modeling objectives and the degree of dispersion and the amount of available input data. In the preset blocks, interpolation of values is performed using common methods such as linear interpolation, polynomial interpolation, or different varieties of kriging. In addition, for each point it is possible to assign multiple values, which is of great practical importance when modeling polymetallic deposits [16].

Yet another way of dividing digital deposit models is based on the type of data that are used in the models. We distinguish structural models (describing the physical structure of the deposit) and quality models (depicting the variation of quality parameters of the deposit in space) [17]. In case of three-dimensional block models, information on the structure and quality of the deposit are de facto modeled simultaneously. In grid models, information on the physical structure and the variability of quality parameters are interpolated separately, with the structural model playing an overriding role. A structural grid model consists of a set of surfaces separating the modeled structural units of a deposit, where the units are uniquely identified, given rules for continuity or depositional trends. The structural grid model also includes information on tectonic (faults) or sedimentary (partings, washouts, etc.) disturbances. In many situations, however, it requires additional interpretive data from an experienced geologist creating the model, especially in areas with weaker recognition [18].

The quality model is formed by estimating point sample data of deposit quality parameters using commonly used interpolation methods, also based on data from geostatistical analysis [19 – 21].The input data for the quality model are the results of analysis of samples taken from drill core and in situ deposit profiling from mine workings [22]. A characteristic feature of grid quality models is the estimation of the distribution of quality parameter values independently in each structural unit. The quality parameters of the deposit, their value and the accuracy of their estimation, are also of particular importance in the valuation of hard coal deposits, these parameters are components of the sales formulas on the basis of which the revenues of mining plants are determined [23].

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On the basis of the developed digital model of the deposit and the materials and concepts for the planned mining, a three-dimensional model of the planned workings is prepared, along with the schedule of mining works, which for the purpose of economic analysis can be drawn up in several variants [24]. In the case of longwall coal mining, the shape of the mine workings is influenced by several conditions including: the characteristics of the deposit, tectonic disturbances, and natural hazards that introduce a few restrictions on future mining.

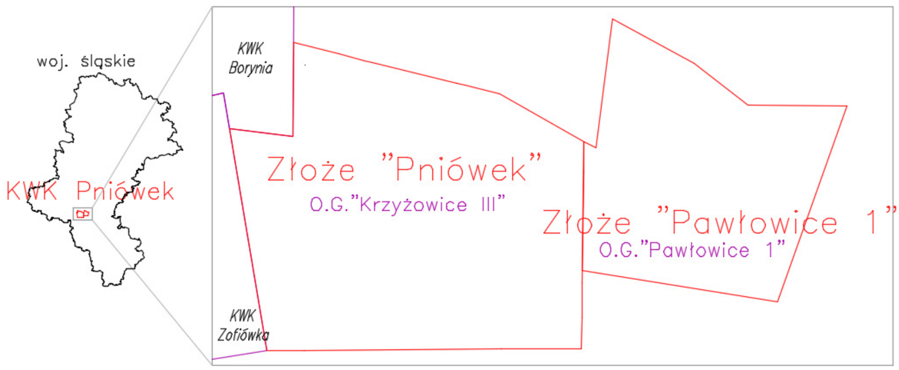

Fig. 1. Location of the Pniówek coal mine and diagram of the boundaries of the exploited deposits.

The KWK "Pniówek" mine is in the Silesian province, mainly within the Pawlowice municipality and the city of Jastrzębie Zdrój (Fig. 1). Exploitation is carried out on two deposits - the Pniówek deposit and the western part of the Pawlowice 1 deposit (since 2013). Due to the geological structure and previous exploitation these deposits differ in seams documented and ones planned for exploitation during the term of the license [25 – 27]. To production planning, one common 3-D geological model has been built, currently covering 30 seams as defined in the Geological Documentation. At all JSW S.A. mines, Datamine's Minescape software was used to build the geological model.

2 Methodology

The basis for building the model was the creation of a digital database of geological data, which until now had been stored mainly in paper form, or on numerical maps maintained individually for each seam. Research borehole profiles (shafts, surface, and underground boreholes) as well as roadway profiling were successively added – which in total now includes more than 130 km of profiling. For importing roadway profiling data in Geolisp roadway geological samples directly from the coal seam numerical map to an established format supported by the Minescape program (Fig. 2).

	A	B	C	D	E	F	G	H	I	J	K
1	HOLENAME	FROM_DEPTH	TO_DEPTH	TOP_ELEV	BASE_ELEV	LITH_CODE	LITH_DESC	SEAM_CODE	SEAM_NAME	STRATIGRAPHY	QUALITY_NO
2	D04100CB2XXX0984	0	0.05	-546.41	-546.46	LI	Claystone			Carboniferous	
3	D04100CB2XXX0984	0.05	1.11	-546.46	-547.52	W	Coal	D04100	404/1	Carboniferous	40000338
4	D04100CB2XXX0984	1.11	1.21	-547.52	-547.62	LI	Claystone	D04100	404/1	Carboniferous	
5	D04100CB2XXX0984	1.21	1.79	-547.62	-548.2	W	Coal	D04100	404/1	Carboniferous	40000338
6	D04100CB2XXX0984	1.79	1.91	-548.2	-548.32	LZW	Carbon Shale	D04100	404/1	Carboniferous	
7	D04100CB2XXX0984	1.91	2.01	-548.32	-548.42	W	Coal	D04100	404/1	Carboniferous	40000338
8	D04100CB2XXX0984	2.01	3.72	-548.42	-550.13	LI	Claystone			Carboniferous	

Fig. 2. Information about boreholes and roadway samples in a fixed format for import into the Minescape Geological Database (GDB).

2.1 Model of coal in seam, or of coal as product?

When importing both boreholes and roadway logs into a database, the key activity is to code the seam, i.e. to tell the program which separations to treat as a given interval for modeling. In the beginning, there was a concept of coding the seams in such a way that the resulting model would reflect the assumptions of the geological documentation, but this approach turned out to be an insufficient solution for the purposes of planning and scheduling.

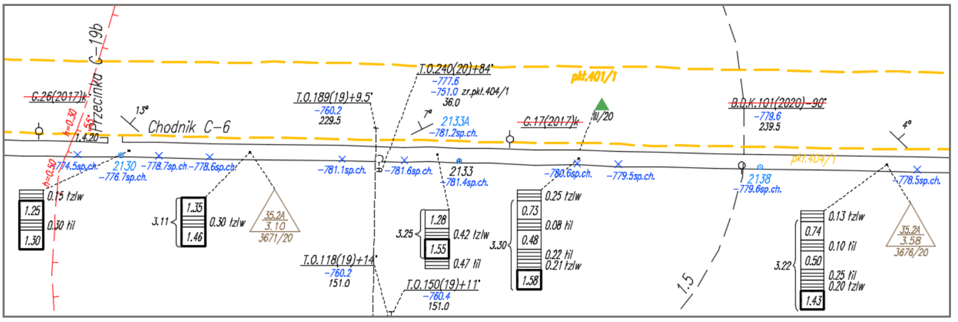

Fig. 3. Part of the map of 404/2 seam (O.G. Krzyżowice III).

Exploitation at the Pniówek coal mine was carried out, among other things, intensively in seam 404/2, which in part C of the deposit is divided into two separate, regular layers – in the eastern direction the main parting increases, within the limits of one projected longwall it can vary from 0.25 to even 1.3 m. According to the limits of the parameters defining the deposit and its boundaries for hard coal, the minimum thickness of hard coal is 0.6 m with overgrowth of up to 30 cm [25]. Thus, where the thickness of the above-mentioned overgrowth exceeds 0.3 m, the remaining coal layers (roof – upper bench) are treated as accompanying, and the documented thickness of seam 404/2 (lower bench) in the map fragment (Fig. 3) throws from more than 3 m to less than 1.5 m. Due to the fact that the seam was to be mined jointly with accompanying layers, it was necessary to include them together in the geological model.

This was resolved by taking advantage of the possibility to model the so-called composite seam, which is divided into two elementary seams (two benches). As a result, one geological deposit is described by three different codes, separately for the composite part (D04200) and for the upper bench (D04210) and lower bench (D04220) – Fig. 4.

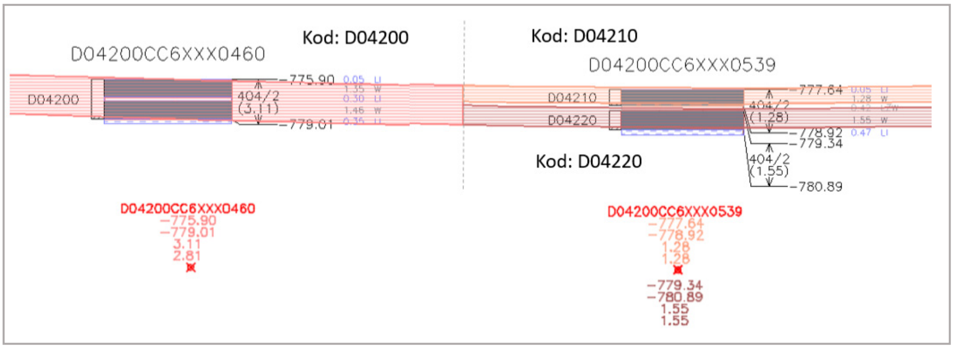

Fig. 4. Method of coding a seam composed of two elementary seams on the example of 404/2 seam.

An example of another problem is the case of seam 360/1 in the PW lot of the Pawlowice 1 deposit, recognized at the time only by boreholes (Fig. 5, left). The seam is accompanied at the bottom by a stated at all. The mine planned to exploit the 360/1 seam together with the above-mentioned accompanying layer to the extent that the longwall complex was technologically capable.

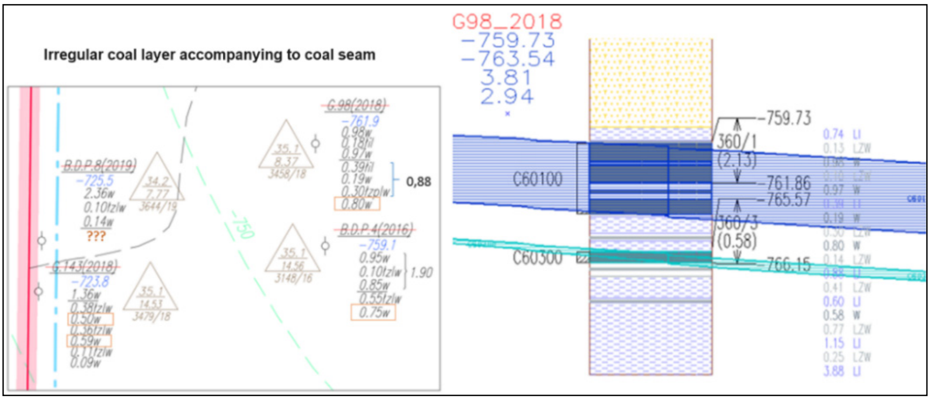

Fig. 5. Part of the map of 360/1 seam (O.G. Pawłowice 1) – borehole exploration, 360/1 seam with the accompanying irregular coal layer at the bottom (left). Method of encoding a compound seam with an accompanying irregular layer (right).

It was decided to take a strictly technological approach - for the purposes of production planning and scheduling, the seam together with the accompanying layer was coded jointly as “C60100”, so that the model interval considered all the coal layers falling within the designed mining height (Fig. 5, right). Thus, the output information from the model is a generalized profile, containing the mining height and including the coal thickness while losing information about the internal structure. However, this approach is much less complicated than introducing additional codes or modeling accompanying layers (as in the case of the seam 404/2). Firstly, in the case of the 360/1 seam, the accompanying layer is very irregular, and secondly, adding more intervals (codes) to the model increasingly complicates the process of building and recalculating it. Currently, to model 30 seams we use 38 codes, and the time for a standard model conversion in a 20x20m grid takes more than 12 hours. In addition, a smaller number of different codes is easier to import into the software used for mining scheduling.

3 Results

The approach to the quality parameters of a deposit in its geological documentation is basically limited to 5 parameters: ash content, total sulfur content, calorific value, coal type and spatial density, which is crucial from the perspective of resource calculation. In contrast, 17 parameters are currently considered for the prediction of coking coal quality, which additionally includes: chlorine and phosphorus contents, as well as dilatometric and petrographic parameters of the coal (Fig. 6).

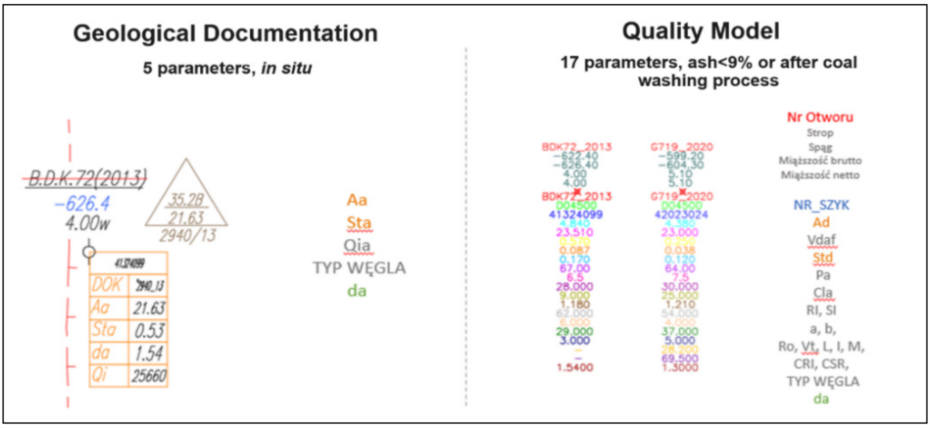

Fig. 6. Comparison of quality parameters included in the geological documentation to those included in the quality forecast for the Company's strategy.

Interestingly, while the geological documentation considers amount of ash values in the dry state. In addition, for forecasting there are used determinations on samples with ash content <9% or after enrichment – which means no in situ forecasting of deposit parameters is performed, but the focus is on forecasting the quality of the potential commercial product.

3.1 Generalized approach to modelling of tectonics

Further differences between the geological view of the deposit and the requirements for production planning and scheduling can be seen in the approach to modeling the deposit's tectonics. The software in use throw and slope, which does not give the possibility of an accurate representation of the tectonics from the documentation – as a result, it is highly generalized in the model, only "signaled", and the user, while working with the model, must be aware that it does not reflect the actual structure of the deposit in the regions of faults, which results in lower reliability (Fig. 7). However, since tectonically undisturbed plots are intended for production planning and scheduling, such simplification of the fault grid is not a problem in practice.

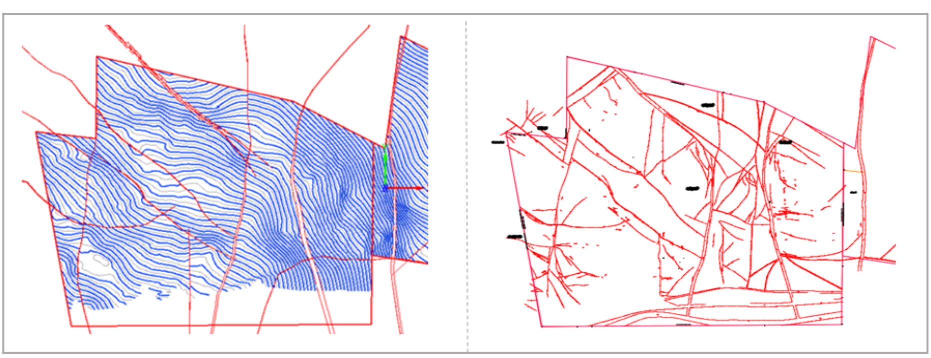

Fig. 7. Modeled structure of 362/1 seam (left), tectonics of 362/1 seam from geological documentation (right).

3.2 Practice of use of the deposit model in work of geology department

The work on the model did not end at the implementation stage - along with ongoing mining, ongoing measurements of coal, its testing – which are successively considered and added to the geological database and the model. The key point is that these routine activities should be streamlined and automated as much as possible, avoiding manual data entry, e.g. in consultation with the laboratory by digitally transferring the results, etc. What's more, having such an amount of data in digital form gives the opportunity for more efficient verification of results, creation of various variant summaries and their further processing, and this already requires additional competence to work with data.

Like digital geological databases, the geological model itself is a repository of information. The Minescape software allows "querying" the model to obtain information on structural parameters (e.g., roof ordinates, floor ordinates, thicknesses), e.g., in the form of a grid of points with the resulting Z-coordinate value, or parameter areas or finished isolines (Fig. 8). In addition, it is also possible to ask questions in the form of expressions and obtain information, for example, about the distance between seams (because of different ordinates of the roof and floor of successive seams) or about the value of the underworking factor (which is the result of the quotient of the distance between the seams and the height of the underworking). Similarly, we can obtain information from the model of quality parameters, for example, by so-called "sampling from polygon" and obtaining statistics for selected areas or export the data in any form (grid/isolines/surface) and analyze them directly on seam maps.

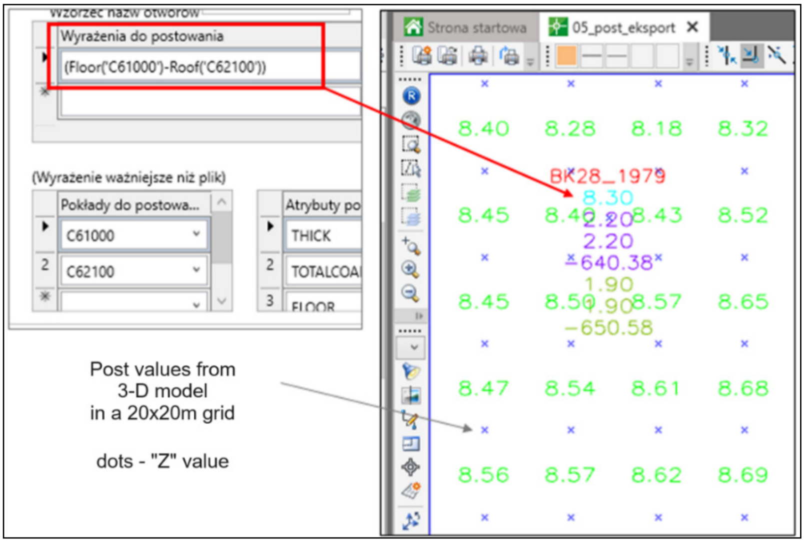

Fig. 8. Scheme of querying the database and model, posting data – here: expression for posting information about the distance between 361 and 362/1 seams floor.

Another classic application is the ability to create cross-sections through the geological model along a preset line, which can be supplemented with profiles of geological boreholes imported directly from the database (Fig. 9). Nevertheless, such a synthetic image can be the basis for further processing – such a cross-section is exported to CAD format, where the adopted profiles of individual lithologies are applied, and can be supplemented with, for example, faults with smaller throws that are absent from the model. The above method of creating geological cross-sections is particularly useful in areas of low recognition, where – in the absence of direct data - the program uses the trends of higher- and lower-lying deposits.

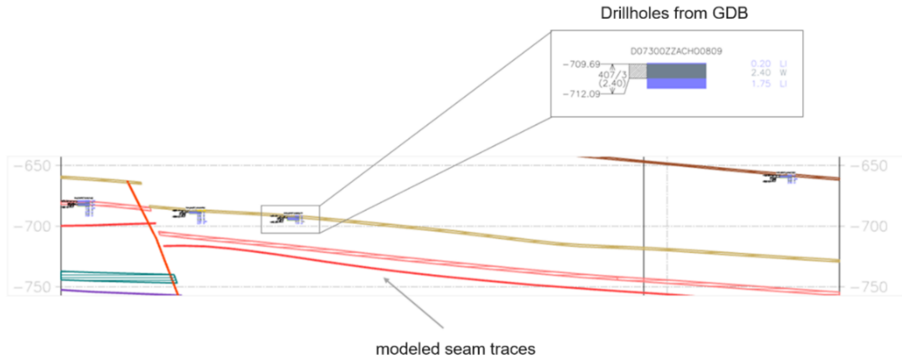

Fig. 9. Cross-section through the geological model along a given line supplemented with headings profiles from GDB (heading 150m from the line).

The last application of the geological model worth presenting is the prediction of the borehole profile, used in the design of exploratory boreholes. Such prediction gives preliminary information about the depth and thickness of expected seams based on the geological model (Fig. 10). It facilitates the design of the depth of the exploratory hole, and then serves as a guide for identifying drilled seams.

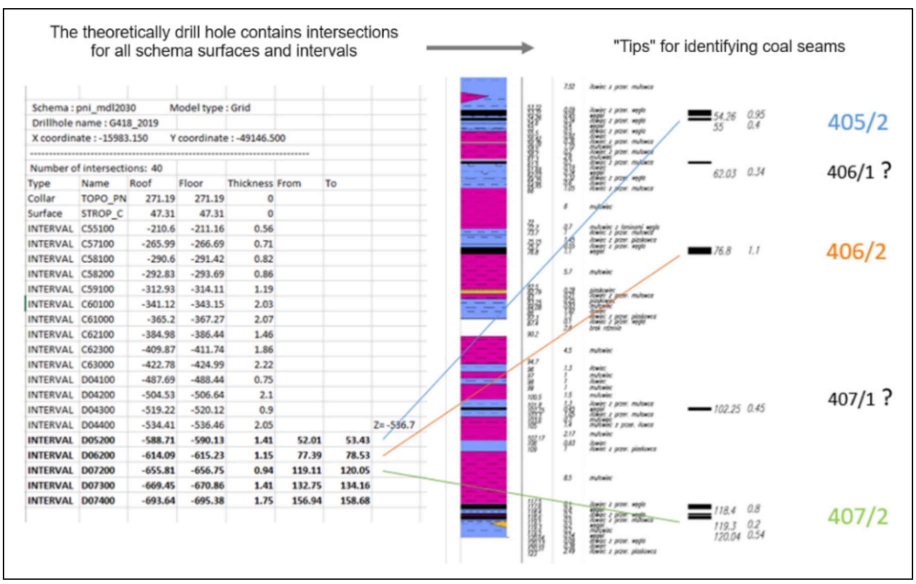

Fig. 10. Report of the planned borehole lithology generated by Minescape according to the given coordinates (left), verification of the report with the profile of the already drilled borehole (right).

4 Discussion

From the perspective of the geological department, the undoubted advantage of implementing the geological model project for production scheduling and coking coal quality forecasting by JSW S.A. was the signal to create a digital geological database, including lithological and quality data. Gathering in digital form the borehole documentation, profiling and chemical analysis results made during the mine's past operations was a tremendously time-consuming task, and one that continues all the time with ongoing operations.

The Geological Model and Geological Database are effective tools for quickly obtaining, analyzing, and presenting information. However, working with such a huge set of digital data is a new challenge in the daily work of a geologist, requiring additional competence, as well as the ingenuity to change previously routine activities.

The way in which a geological model of a coal deposit is built differs depending on its purpose – looking at the deposit for the purposes of production scheduling and product quality forecasting differs from that of geological documentation. In practice, the process of model construction by geologists must be carried out in close cooperation with the production preparation department, which is the recipient of this data.

5 Conclusions

The ongoing integration of measurements, testing, and digital data management techniques in mining operations presents opportunities for enhanced efficiency, accuracy, and decision-making. By leveraging advanced technologies and investing in workforce development, mining companies can realize significant benefits in resource optimization, safety, and sustainability. The work on the geological model extends beyond its initial implementation, with ongoing measurements and testing of coal being systematically integrated into the digital database and model. It is imperative to streamline and automate these routine activities to minimize manual data entry efforts. This can be achieved through digital transfer of results from laboratory tests, thereby enhancing efficiency and accuracy in data management.

The digital format of geological data offers opportunities for more efficient verification of results and creation of various summaries and analyses. With large amounts of data available in digital form, it becomes feasible to conduct thorough analyses, identify trends, and derive insights to inform decision-making processes in mining operations. The Minescape software enables querying of the geological model to obtain information on structural parameters, such as roof and floor ordinates, thicknesses, and quality parameters. This functionality allows for easy access to critical information required for mining operations, facilitating better planning and optimization of extraction processes. The ability to pose questions to the model in the form of expressions allows for the retrieval of specific information, such as distances between seams or underworking factors. This capability enhances the versatility of the geological model, enabling mining engineers to extract relevant insights and make informed decisions based on complex geological data. Managing and interpreting data from digital geological databases and models require specialized competence. Mining personnel need to acquire skills in data analysis, interpretation, and modeling to effectively harness the potential of these technologies for optimizing mining operations.

The utilization of 3D deposit models provides a comprehensive understanding of geological structures within the Pniówek Coal Mine. This includes detailed insights into coal seam distribution, fault lines, and other geological features crucial for efficient mining operations. The integration of geological data into a 3D model facilitates more accurate resource assessments. By visualizing coal deposits in three dimensions, mining engineers can better estimate the volume, quality, and distribution of coal reserves, aiding in strategic planning and decision-making.

While the application of 3D deposit models in the Pniówek Coal Mine demonstrates significant benefits, ongoing technological advancements and continuous data integration pose both opportunities and challenges. Future research efforts should focus on refining modeling techniques, integrating real-time data feeds, and addressing potential limitations to further enhance the efficacy of 3D modeling in the mining industry.

In conclusion, the adoption of 3D deposit models offers invaluable insights into geological structures, resource assessment, mine planning, safety measures, and collaboration efforts within the Pniówek Coal Mine and similar mining operations. By leveraging this technology effectively, mining companies can optimize their processes, improve productivity, and ensure sustainable resource extraction practices for the future.

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