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Modelling of a multi-seam hard coal deposit using IT tools

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Abstract. With the rising demand for mineral resources, efficient deposit management has become a critical challenge in modern mining. This article underscores the significance of geological modeling in coal deposit management, emphasizing the essential role that digital deposit models play across various mine departments. It outlines the methodology for creating geological models, detailing steps such as data digitization, validation, model construction, calibration, and continuous updates. The article examines three specific deposit modelling software programs (Minex, MineScape, and Carlson) highlighting their unique features and suitability for multi-seam coal deposits. The findings include the development of contour maps, structural and qualitative models, and conducting economic analyses. Additionally, the article discusses the importance of modelling tectonic disturbances and creating qualitative maps for effective deposit exploitation planning. It concludes by emphasizing that the integration of information technology with geological expertise is crucial for precise planning and optimization of mining operations, leading to more efficient and sustainable resource management.

1 Introduction

The rapid acceleration of economic development in modern civilization has significantly heightened the demand for mineral resources [1]. As economies expand and technological advancements continue, the need for these non-renewable resources intensifies, raising concerns about their long-term sufficiency [2]. This escalating demand has put pressure on the mining industry to ensure that these valuable resources are managed and utilized in the most efficient and sustainable way possible [3]. The depletion of easily accessible deposits and the increasing complexity of mining operations further exacerbate these concerns, highlighting the critical importance of adopting advanced strategies for resource management [4].

In response to these challenges, the mining industry is increasingly focused on the rational use of deposits, which is essential for extending the life of mines and ensuring the sustainability of operations [3, 5]. One of the key strategies being employed to enhance the optimization of deposit selection is the development of information systems designed to support decision-making processes [5]. These systems leverage digital tools and advanced data analytics to

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assess various factors such as geological conditions, economic viability, and environmental impact, providing a comprehensive framework for making informed decisions about deposit preparation and extraction [4, 6]. By integrating these technologies, mining companies can improve the efficiency of their operations, minimize waste, and ensure that the exploitation of mineral resources is carried out in a responsible and sustainable manner. [7].

An essential component of the mining company's operational system is the geological modelling of the deposit and the critical role of the mining geologist [8]. The continuous advancement of information technology tools has significantly enhanced the ability to interpret geological data, not only during the initial deposit reconnaissance phase but also throughout its access and exploitation [9]. The geologist's responsibilities in the mining process include collecting, processing, interpreting, and disseminating vital information about the deposit to support the company's operations [8, 10]. As exploration and exploitation of the deposit progress, the volume of geological information increases substantially, necessitating more efficient management strategies [11]. This growing need for efficient data management is further compounded by the shortage of skilled personnel in the geological services of mines in recent years. Consequently, there has been a strong push toward adopting advanced information tools for the modelling and spatial visualization of geological data [12]. These tools are not only helping to bridge the gap caused by personnel shortages but also enhancing the accuracy and efficiency of geological interpretations [13]. As a result, the integration of IT tools into geological modelling has become increasingly indispensable in modern mining operations. This integration ensures that mining companies can make well-informed decisions that optimize resource extraction while minimizing environmental impact [10, 12, 14].

The literature on coal deposit modelling and mineral exploration offers a comprehensive overview of how geological knowledge is increasingly integrated with modern IT tools, which are essential for optimizing mining operations [15]. A foundational work in this field serves as an authoritative resource on the subject, thoroughly covering the formation, composition, and classification of coal [16]. This book goes beyond traditional geological concepts, emphasizing the critical role that digital tools play in the accurate modelling of coal deposits. By focusing on the use of these advanced tools, the book provides readers with valuable insights into how digital models significantly enhance the efficiency and effectiveness of coal exploration and exploitation. It is an indispensable resource for professionals and researchers who seek a deep understanding of the ways in which modern technology can improve geological assessments and mining outcomes. As the demand for precision in mining increases, the insights provided by this work become even more crucial, making it a key reference in the field [17]. A.G. Journel and C.J. Huijbregts provide a foundational exploration of geostatistics, a critical component in the field of geological modelling and resource estimation [18]. The book delves into the statistical techniques necessary for accurate deposit modelling, making it a vital reference for understanding the quantitative methods that underpin modern mining practices. The insights from this text are particularly important for those using IT tools to model complex geological formations, ensuring that resource estimates are both precise and reliable.

Charles J. Moon, Michael K.G. Whateley, and Anthony M. Evans offers a broad overview of the mineral exploration process, including the latest technological advancements [19]. The book covers key areas such as geological modelling, resource estimation, and the integration of IT tools in mineral exploration. It provides practical insights into how modern mining practices are evolving with the adoption of digital technologies, making it an essential resource for professionals in the mining industry who aim to stay at the forefront of technological innovation [20]. The importance of geological modelling in the design and planning stages of mining highlights its critical role in these phases. It is emphasizing how digital models can significantly enhance mine planning and decision-making processes, showcasing the practical applications of IT tools in optimizing mining operations [21]. By integrating digital models, mining companies can achieve more efficient and informed planning, leading to better overall outcomes. This focus on digital tools reveals their essential role in improving the accuracy of geological assessments, which in turn impacts the efficiency and success of mining projects [22]. Understanding these applications helps illustrate how accurate geological models can directly influence operational effectiveness [23]. It provides valuable insights into the transformative effects of technological advancements on mining practices.

The paper focuses on advanced 3D geological modelling techniques, examining both the challenges and solutions associated with modelling complex deposits, such as multi-seam coal deposits [24]. It also reviews the software tools that facilitate these sophisticated modelling techniques, making it highly relevant for those interested in cutting-edge approaches to geological modelling in mining [25]. By addressing these advanced methods, the paper provides a comprehensive understanding of how modern technology can address the complexities of geological deposits. Collectively, it is offered a solid foundation for exploring the intersection of geology, technology, and mining, presenting both theoretical and practical perspectives [24, 26]. The integration of advanced modelling techniques and software tools is crucial for improving the accuracy and efficiency of geological assessments in the mining industry.

The purpose of the research on modelling a multi-seam hard coal deposit using IT tools is to enhance the accuracy and efficiency of geological assessments through advanced digital modelling techniques. The research aims to address the complexities of multi-seam deposits by integrating sophisticated software tools that improve the precision of resource estimation and mine planning. It seeks to evaluate how these IT tools can optimize the management of geological data, leading to more effective decision-making in mining operations. Ultimately, the research aims to contribute to the development of best practices for utilizing digital technologies in the exploration and exploitation of multi-seam coal deposits.

2 Methodology

The deposit model, as a spatial visualization of the deposit, is the basis for proper management of any mining plant. Currently, its role is becoming increasingly important in the Polish mining industry. The digital model of the deposit is a source of information not only for geologists, but also for other departments of the mine such as the mining production planning department, deposit quality control, or departments dealing with natural hazards. The modelling of using the explosive materials involves the integration of advanced digital technologies with traditional mining practices to optimize the extraction of complex coal deposits [27]. IT tools, such as 3D geological modeling software, play a crucial role in accurately mapping the various coal seams and assessing their characteristics, which facilitates more precise resource estimation and mine planning [28]. The strategic use of explosive materials is essential for effectively breaking and accessing these multi-seam deposits, enabling efficient removal of coal while minimizing environmental impact and operational risks [29]. This combined approach ensures that the mining process is both technologically advanced and operationally practical, improving the overall efficiency and safety of coal extraction operations [30].

The correct modelling of a coal deposit is crucial for ensuring both effective access to the deposit and the efficient operation of the mining plant [31]. One of the primary objectives of constructing a detailed deposit model is to document the extent of exploration, providing a comprehensive understanding of the deposit's structure and composition. This information is vital for preparing accurate mining projects that guide the access and development works required to reach and extract the coal [32]. Additionally, the model helps in scheduling ongoing mining operations, ensuring that activities are carried out in a systematic and efficient manner [34]. A well-constructed deposit model also facilitates thorough economic analysis by evaluating the potential profitability of the mining operation [35]. This analysis considers factors such as the qualitative variability of the final product and fluctuations in the raw materials market. By integrating these elements, the deposit model supports informed decision-making and strategic planning, contributing to the overall success and sustainability of the mining company [32, 36].

Current commercially available software allows the creation of three types of models: block, mesh and mixed models [37]. Block models are mainly used for solid deposits and seam deposits of significant thickness. This method of modelling allows to represent the image of the deposit in the form of computational blocks [38]. The size of these blocks depends on the size, structure, complexity of the deposit and the computing power of the computer at the user's disposal. Greater variability of coal deposit parameters forces the user to use smaller and smaller computational blocks, so that the resulting model is as close as possible to the actual deposit [39]. This contributes to the high time consumption of executing the block model when analysing very large and variable deposits [38, 40].

Grid models, on the other hand, are used for seam deposits. Therefore, in the case of modelling coal deposits, they are used most often. They are created by superimposing a grid on the modelled surface. Reference points are most often the locations of boreholes. Interpolation is then used to estimate the value of a given parameter at a grid node. There are many interpolation methods in IT tools [41]. Among the most used are the kriging and inverted distance methods. In addition to these two methods, there is triangulation, the method of least squares or nearest neighbour, among others. A characteristic feature of grid models is that they are independently created and independently visualized and analysed [12]. When creating a digital model of a deposit, however, it should be remembered that while it is necessary, it is only a part of the system that results in the rational and optimal management of the deposit. The model itself must be a source of valid and correct information for other users [42].

For the purposes of this work, 3 deposit modelling programs were used: Minex, MineScape and Carlson. Each of these programs requires the creation of a geological database, and the difference between them is relatively small and based on the adopted calculation systems.

The Carlson program is based on the engine of the well-known IntelliCAD, but it can also be run on the AutoCAD engine. The program allows to create embankment/excavation maps based on design files and field measurements. The user can view the project in 3D view, create cross sections and as-built maps. In Polish conditions, the software is better suited for modelling and design of shallow open-pit deposits, as it does not have the ability to create models of multi-seam deposits.

The Minex tool has an unique technique for modelling a seam deposit that is not available in most popular programs used by geologists. The software has a method for modelling inverted faults and it models the deposit based on the principle of continuity of geological structure, in which faults and the ground surface are a separate resource of information about the rock mass [43].

MineScape is one of the deposit modelling software that is constantly tested, enriched based on user feedback, and maintains its strong position in the world's most complex mining projects. MineScape is a system with wide application in the process of geology modelling and mining design and has gained recognition in Australia, Southeast Asia, North America, Africa, Europe including Poland. The software is being increasingly used in Poland in coal and lignite mines, where it is proving itself as a tool with the ability to model multi-seam deposits with very complex geological structure [44].

2.1 Stages of creating a geological model of a deposit – on the example of a Polish coal deposit

The process of creating a spatial model of the deposit involved four essential steps. First, the data was digitized and then carefully validated to ensure accuracy. Next, the model settings were defined to establish the parameters and constraints for the modeling process. The third step was building the model, followed by a calibration phase to fine-tune the model for optimal results. Finally, the model was updated as needed to reflect any new data or insights. This entire process is represented schematically in Fig. 1.

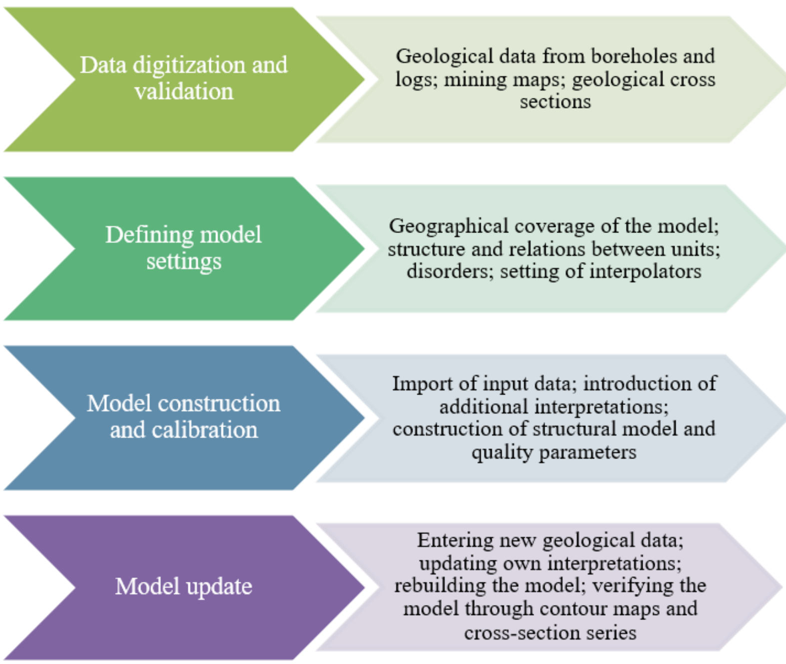
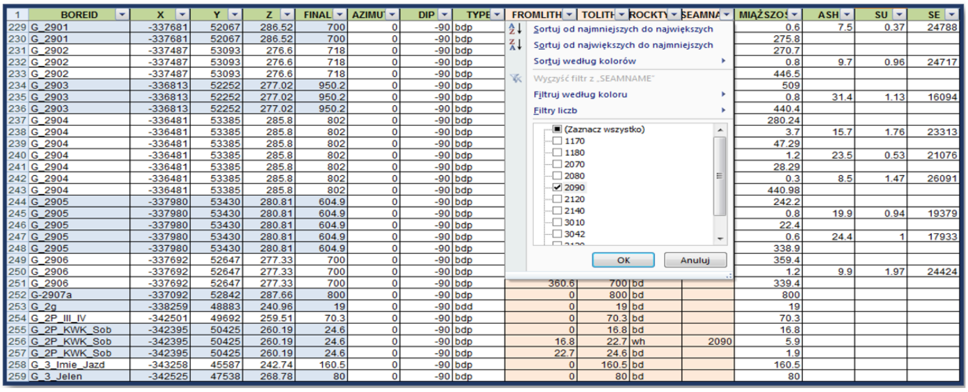


Fig. 1. Stages of creating a digital model of the deposit (own elaboration based on [38]).

The first and one of the most important stages in the entire process was the creation of a geological database. The database consisted primarily of values from surface and underground borehole profiles, boreholes drilled in current mine excavations and the results of qualitative analysis. It could be expanded as needed to include hydrogeological and geotechnical data. The database itself had to be constructed in such a way that it could be easily analysed, sorted and filtered. It was created in MS Excel, which is the most common tool used to create geological databases (Fig. 2).

The database provided a starting point to integrate key areas of mining activity and give a quick multivariate interpretation. The next step was to verify the accuracy of the information in the database and its geological interpretation. Most of the programs already at the stage of inputting batch files give the possibility to verify them, often in the form of error reports. This allows the causes of errors to be quickly captured and their correct values to be entered.



1	BOREID	X	Y	Z	FINAL	AZIMU	DIP	TYPE	FROMLITH	TOLITH	ROCKTY	SEAMNA	MIĄŻSZO	ASH	SU	SE
229	G_2901	-337681	52067	286.52	700	0	-90	bdp					0.6	7.5	0.37	24788
230	G_2901	-337681	52067	286.52	700	0	-90	bdp					275.8			
231	G_2902	-337487	53093	276.6	718	0	-90	bdp					270.7			
232	G_2902	-337487	53093	276.6	718	0	-90	bdp					0.8	9.7	0.96	24717
233	G_2902	-337487	53093	276.6	718	0	-90	bdp					446.5			
234	G_2903	-336813	52252	277.02	950.2	0	-90	bdp					509			
235	G_2903	-336813	52252	277.02	950.2	0	-90	bdp					0.8	31.4	1.13	16094
236	G_2903	-336813	52252	277.02	950.2	0	-90	bdp					440.4			
237	G_2904	-336481	53385	285.8	802	0	-90	bdp					280.24			
238	G_2904	-336481	53385	285.8	802	0	-90	bdp					3.7	15.7	1.76	23313
239	G_2904	-336481	53385	285.8	802	0	-90	bdp					47.29			
240	G_2904	-336481	53385	285.8	802	0	-90	bdp					1.2	23.5	0.53	21076
241	G_2904	-336481	53385	285.8	802	0	-90	bdp					28.29			
242	G_2904	-336481	53385	285.8	802	0	-90	bdp					0.3	8.5	1.47	26091
243	G_2904	-336481	53385	285.8	802	0	-90	bdp					440.98			
244	G_2905	-337980	53430	280.81	604.9	0	-90	bdp					242.2			
245	G_2905	-337980	53430	280.81	604.9	0	-90	bdp					0.8	19.9	0.94	19379
246	G_2905	-337980	53430	280.81	604.9	0	-90	bdp					22.4			
247	G_2905	-337980	53430	280.81	604.9	0	-90	bdp					0.6	24.4	1	17933
248	G_2905	-337980	53430	280.81	604.9	0	-90	bdp					338.9			
249	G_2906	-337692	52647	277.33	700	0	-90	bdp					359.4			
250	G_2906	-337692	52647	277.33	700	0	-90	bdp					1.2	9.9	1.97	24424
251	G_2906	-337692	52647	277.33	700	0	-90	bdp	360.6	700	bd		339.4			
252	G-2907a	-337092	52842	287.66	800	0	-90	bdp	0	800	bd		800			
253	G_2g	-338259	48883	240.96	19	0	-90	bdd	0	19	bd		19			
254	G_2P_III_IV	-342501	49692	259.51	70.3	0	-90	bdp	0	70.3	bd		70.3			
255	G_2P_KWK_Sob	-342395	50425	260.19	24.6	0	-90	bdp	0	16.8	bd		16.8			
256	G_2P_KWK_Sob	-342395	50425	260.19	24.6	0	-90	bdp	16.8	22.7	wh	2090	5.9			
257	G_2P_KWK_Sob	-342395	50425	260.19	24.6	0	-90	bdp	22.7	24.6	bd		1.9			
258	G_3_Imie_Jazd	-343258	45587	242.74	160.5	0	-90	bdp	0	160.5	bd		160.5			
259	G_3_Jelen	-342525	47538	268.78	80	0	-90	bdp	0	80	bd		80			

Fig. 2. Sample geological database made in MS Excel.

The creation and updating of the geological database and its verification are very important parts of the process of creating the deposit model, since the results of further steps depend on the correctness and quality of their execution. In the third stage, proper structural and qualitative models of the deposit were made. Structural models describe the parameters of the deposit (roof and floor), in this case the surface of the coal seams and their thicknesses.

3 Results

For the study, contour maps were created to represent the surface of the floors of selected seams, as shown in Fig. 3. Additionally, contour maps depicting the thicknesses of these seams were also developed. During this stage, a thorough re-verification process was undertaken to ensure the accuracy of the data that had been entered. The verification process also included a careful review of how the data was interpreted. This step was crucial in confirming that the maps accurately reflected the actual geological conditions. Any discrepancies found during re-verification were addressed and corrected. These contour maps served as a foundational element in the overall study.

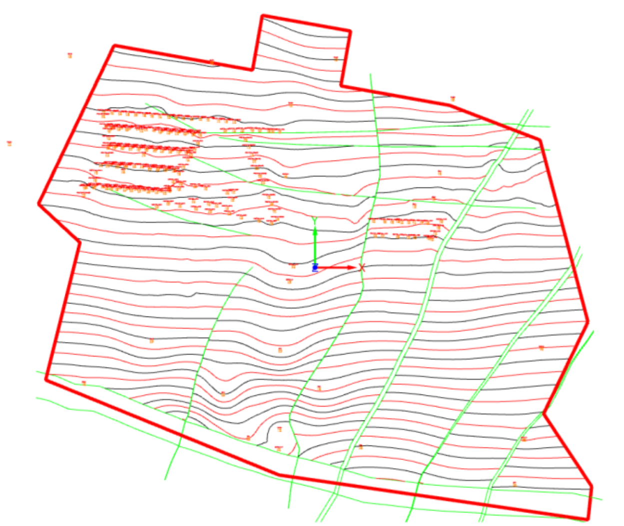


Fig. 3. Example contour map of the floor surface of a selected coal seam, made in MineScape software.

One significant advantage of creating a numerical model of the deposit is the ability to generate a regular set of interpolated values between the point data of the deposit's measurements. This capability allows for the data to be utilized multiple times in various forms, enhancing the flexibility and precision of the analysis. By interpolating between the data points, a more continuous and detailed representation of the deposit can be achieved, which is particularly beneficial in complex geological environments.

With these interpolated values, it becomes possible to create contour maps of the deposit's surface features, such as the roof or floor of the seams. These contour maps can be generated for any specific cutting of the contours, providing detailed insights into the geometry of the deposit. The model allows for the determination of the slope of the seams, which is a critical factor in selecting and adjusting the appropriate mining method. This ability to tailor the mining approach based on precise slope information can significantly improve operational efficiency and safety. The authors created maps of the floor in the form of a surface, as illustrated in Fig. 4.

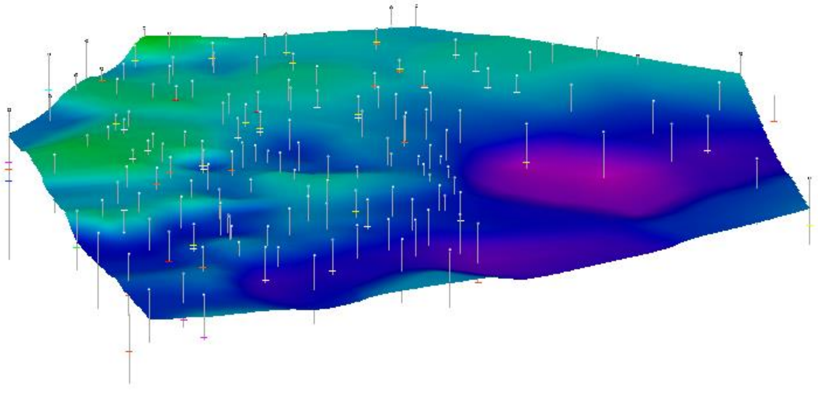


Fig. 4. Coal seam floor surface, made with Minex software.

These surface maps provide a three-dimensional perspective of the deposit's features, offering a more comprehensive understanding of the geological structure. Furthermore, a summary of three example coal seams, along with the terrain surface, is presented in Fig. 5. This summary serves as a valuable reference for comparing the seams and assessing their characteristics in relation to the surrounding terrain, thereby aiding in more informed decision-making during the mining process.

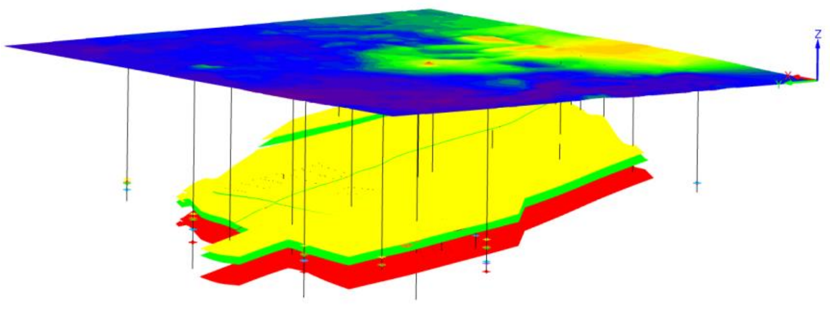


Fig. 5. Examples of floor surfaces of three coal seams with surface boreholes and ground surface made in MineScape software.

This way of depicting the surface of the deposits makes it easier to convey basic information about the deposit to those without sufficient knowledge of geology. Undeniably, among the most difficult of the tasks was the modelling of tectonic disturbances. This is the most complicated and time-consuming activity. In addition, the analysed deposit was characterized by a very complex tectonic structure. To model the tectonics of the deposit, one needs information about the throw of the fault, its azimuth and degree of inclination of the fault surface, as well as knowledge about the age of individual faults. For the study, only faults with a throw of more than 20 meters were selected for tectonic interpretation. The result of an example model of the seam floor surface considering tectonics is shown in Fig. 6 below. In the process of modelling the tectonics of the deposit, the experience of the geologist and a very good knowledge of the studied deposit are very important.

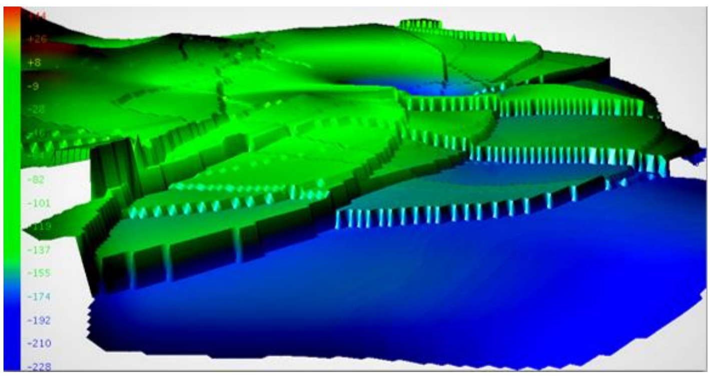


Fig. 6. Area of the floor of the coal seam taking into account faults with a throw of more than 20 m made in the Carlson program.

In managing the deposit, the quality of the exploited mineral is of paramount importance, as it directly influences the value and usability of the extracted resources. To ensure that the mining process targets high-quality material, several key quality parameters were meticulously mapped. These parameters include the sulphur level, expressed as a percentage, which is critical in determining the environmental impact of coal combustion. The ash level, also represented as a percentage, was mapped to assess the amount of non-combustible residue present in the coal, as shown in Fig. 7. Another crucial parameter that was mapped is the calorific value of the coal, measured in kilojoules per kilogram (kJ/kg), which indicates the energy content of the coal. By mapping these quality parameters, the management can make informed decisions to optimize the extraction and processing of the deposit.

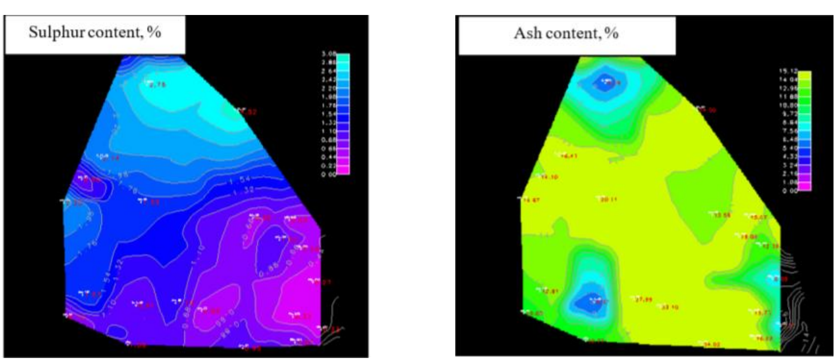


Fig. 7. Gradient maps: sulphur level [%] and ash levels [%], for a selected coal seam, made in Minex software.

Many geological modelling tools are equipped with a statistical module that provides the capability to perform basic statistical analyses on quality parameters that describe a given deposit. These tools enable users to analyse data efficiently, offering insights into the distribution and variability of key parameters. One of the key features of these statistical modules is the ability to visualize the results through histograms, as illustrated in Fig. 8. These histograms provide a clear graphical representation of the data, making it easier to interpret the distribution and identify any trends or anomalies. The ability to quickly generate and review statistical information allows for more informed decision-making, tailored to the specific needs of the moment. This flexibility and immediacy are crucial in dynamic mining environments, where rapid adjustments may be necessary.

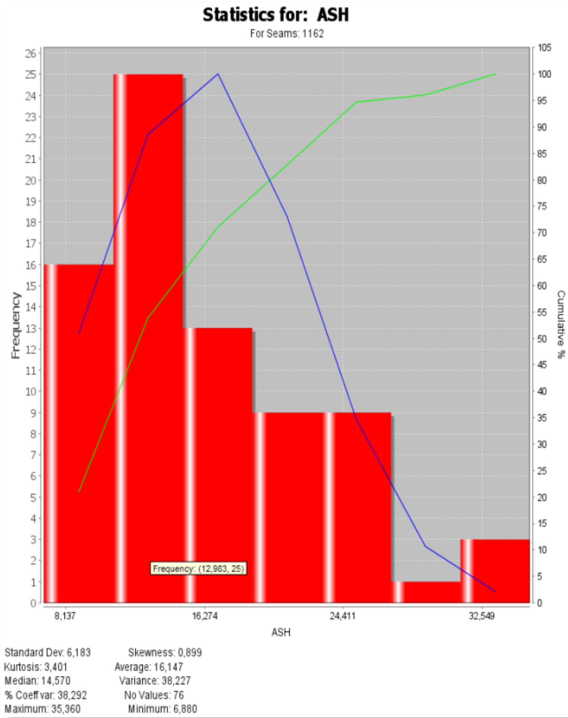


Fig. 8. Example histogram of ash level [%].

The steps described above allow the creation of resultant data and reports for mine services as well as to meet the requirements of mining authorities. Examples of required documents include profiles and geological cross sections. Computer tools allow the creation of cross sections (Fig. 9) through selected surfaces, in any direction, including along polygonal chain.

One significant advantage of geological modeling tools is the ability to display text data or symbols directly on cross sections and geological profiles. This feature enhances the clarity and detail of the visual representations, making it easier to convey important information relevant to the task or problem at hand. By overlaying key data points or symbols, users can quickly identify critical features or anomalies within the geological structure. This visual integration of data helps in better understanding the spatial relationships and geological characteristics of the deposit. Fig. 10 illustrates how this capability can be effectively utilized in geological analysis.

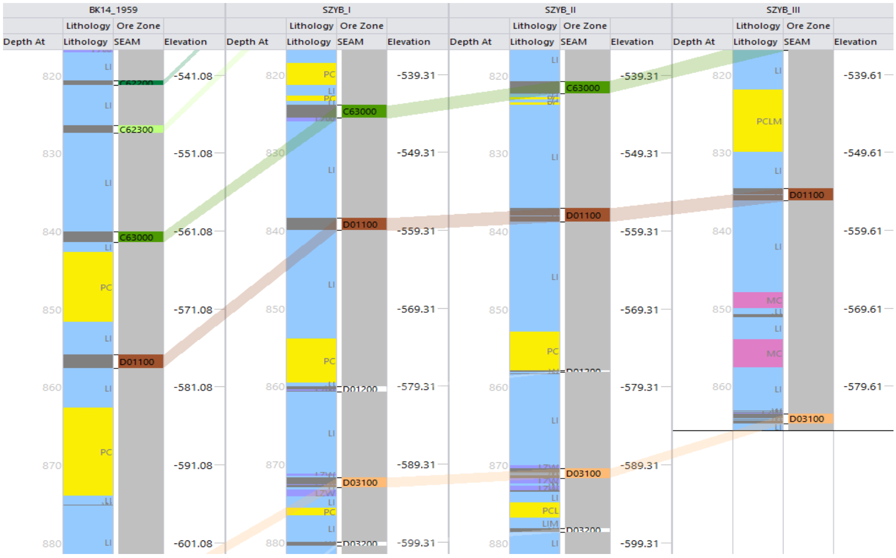


Fig. 9. Example of a geological cross-section through a selected section of the deposit, made with MineScape software.

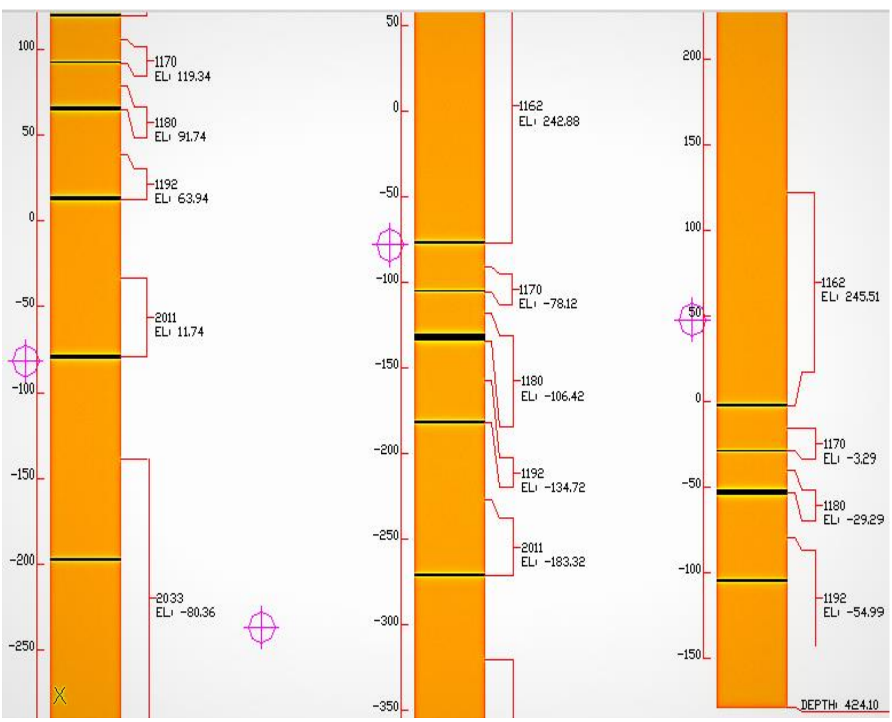


Fig. 10. Examples of geological profiles with ordinates of coal seams floor, made in the Carlson program.

The ability to quickly and easily generate reports that account for various parameters of the deposit is a significant advantage in managing mining operations. These reports enable ongoing monitoring and assessment of the deposit's conditions and quality, ensuring that any changes are promptly identified and addressed. By incorporating multiple parameters into these reports, a comprehensive overview of the deposit can be achieved, aiding in more informed decision-making. An example of such a report, which focuses on the quality parameters within a modelled deposit, is shown in Fig. 11. This example demonstrates how these reports can be used to visualize and analyze the key characteristics of the deposit, providing valuable insights for effective management.

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1
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 18-Mar-24                     BRZESZCZE_2024 PROJECT        VERSION 8.100
+_________

                                QUALITY COMPOSITING              Page:    1
+                                                                _____

                Quality Statistics for Compressed Data Samples
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Quality	Number	Total Length	Minimum	Maximum	Average
AA	785	1543.76	0.520	49.030	9.077
CH4	111	55.50	1.50	79.70	22.80
DA	638	1250.02	1.150	1.950	1.317
QIA	784	1541.76	13494.000	31982.000	29014.710
S	765	1506.47	0.170	3.600	0.438
TWN	50	73.42	32.10	34.00	32.76
WA	632	1263.40	1.500	8.500	3.155
TOTAL	2425	2860.65			

Fig. 11. Report generated using MineScape software.

Contoured structural and qualitative models contain all the necessary information to provide an accurate description of the coal deposit located in the analysed area. Such a geological model is used by subsequent users of the integral deposit management system. In the first instance, it is transferred to the employees of the mining production planning and scheduling departments.

4 Conclusions

The scheme for creating a geological model presented in the article shows its role in the various stages of the operation of a mining plant. The above-described advantages of having a digital deposit model are not the only ones. Made correctly and accurately, the deposit model is also used to calculate the resources in individual parcels, as well as in the entire deposit.

Deposit modelling has many advantages. One is the standardization and centralization of geological information, which translates into a common coordinate system, the normalization of lithostratigraphic designations, and having a single geological database for the entire deposit. Another plus is quick and easy access to diverse geological information in the form of maps, sections, profiles and statistical data, resulting in better management of geological resources. However, the most important benefits of the digital deposit model include the availability of information necessary for the optimal and rational management of the deposit, namely for the planning and design of mining works, scheduling of access and exploitation works, and for support during the operation of the deposit.

Obviously, the implementation of a digital deposit model at mining companies involves a number of difficulties. First and foremost is the lack of awareness with the role of digital deposit modelling for optimal deposit management. The trend toward automation and computerization is just emerging in Polish mines. As a result, there is a lack of experience in deposit modelling in the conditions of Polish underground mines, which automatically entails a shortage of qualified personnel. In addition to the high cost and labour in the initial stages of implementation, there is also a reluctance to make organizational changes in mining companies.

The rapid development of computer science allows for a wide range of choices of appropriate software for the type or construction of the deposit. However, one continues to encounter the same problems arising from the programs used repeatedly. At first glance, most programs have a complicated and chaotic user interface and a high degree of complexity in basic model operations. Another nuance is usually the instability of the work, especially for deposits with large areas and very good recognition. The low quality of visualization and output materials forces the user to process them in additional programs such as Bentley MicroStation. However, one of the most serious problems is the insufficient adaptation of the programs' assumptions to Polish realities.

A digital deposit model is a tool that allows geologists, mining engineers and financial analysts to accurately analyse and evaluate a deposit. With advanced technology and software, deposit modelling allows geological and engineering data to be collected, analysed and visualized. A production schedule built based on a digital deposit model provides a database that is key to evaluating the economic viability of a deposit. With advanced modelling technologies, investors can make more informed decisions, which contributes to the success of mining projects.

Summarizing the role as well as the advantages and disadvantages of a digital deposit model, it is important to mention the characteristics of a good model. First of all, the choice of software should be suited to the intended design goals. Gathering as much representative data as possible determines the accuracy and reliability of the deposit model. In addition, a well-made model enables efficient and effective work on the data. Throughout the entire process of modelling the deposit, it is also important to remember to update it systematically as the work progresses. A deposit model that has the above-mentioned features improves proper management of the deposit.

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