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Research paper

3D representation of geological observations in underground mine workings of the Upper Silesian Coal Basin

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ABSTRACT

The purpose of the paper is to present the possibilities of the three-dimensional representation of geological strata in underground (access) workings in a hard coal deposit in the SW part of the Upper Silesian Coal Basin, using CAD software and its flagship program AutoCAD. The 3D visualization of the results of underground workings' mapping is presented and illustrated on two opening out workings (descending galleries). The criteria for choosing these workings were based on their length and the complexity of geological settings observed while they were driven. The described method may be applied in spatial visualization of geological structures observed in other deposits, mines and existing workings (it is not applicable for designing mine workings), also beyond the area of the Upper Silesian Coal Basin (USCB). The method presented describes the problem of the visualization of underground mine workings in a typical geological aspect, considering (aimed at) detailed visualization of geological settings revealed on the side walls of workings cutting the deposit.

1. Introduction

Mapping underground mine workings means following their definition and presenting rock complexity revealed by the mine workings in a graphical form.

Methods of mapping individual mine workings differ, because they include mapping of vertical access workings (shafts and staple shafts), horizontal access workings (dog headings), roadways driven in coal and extraction mine workings (mainly longwalls).

Results of mapping are entered into geological logs which are a basic mapping document and are usually very specific for given workings, but currently they usually cover one seam or level. Geological information obtained through mapping is used to update information about the main coal seam and level maps. Basic and special geological cross-sections are employed to prepare special geological maps (e.g. isopach maps, i.e. lines of equal thickness in a seam). This information is also the base to identify seams and assess deposits.

Preparing data from mapping underground mine workings provides proper recognition of the deposit structure, which is crucial for designing and conducting safe mining operations (Dudek, 2013; Winkler, 2002; Winkler, Michalak, Jaszczyk, & Bojara, 2007). The scope of the work usually includes: determining actual parameters of seam structure (thickness, strike direction, dip direction and angle), reconstruction of fold structures (recognising the style of structural folding), determining fault displacements (strike direction and fault plane dip angle, stratigraphic throw and separation of the fault, influence of the fault on designing and maintaining mine workings: detecting the moment of approaching the fault while driving a working, determining displacement direction in the area across the fault), determining the course of geological disturbances (changes in the thickness of seams and layers, seam splits and erosive wash-outs) (Duźniak & Gabzdyl, 1991; Nieć, 1982, 2012).

Graphic structures, projection rules, trigonometric equations, dependences, nomograms, theorems and lists (profiles, maps, cross-sections, diagrams, models) were a great help to realise them (if it was not possible directly in a working).

Development of IT tools made it possible to document geological phenomena in a digital form, enabling the preparation and interpretation of all the aforementioned materials (Maciaszek, Wąsacz, & Szewczyk, 2015). In a digital recording there is no data simplification and generalisation, resulting in the description of a phenomenon losing its accuracy and resulting from the complexity of the geological structure of multi-seam deposits. Today's

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software, to a varying degree dedicated to mining and deposit geology, is equipped with techniques which enable 3D images of various objects (single ones) or sets of them to be obtained (Kecojevic, Willis, Wilkinson, & Schissler, 2005; Maciaszek, Gawałkiewicz, & Gawałkiewicz, 2010). These capabilities are also applicable to mine workings, existing or ones being designed (treated as an object or a set of objects). On today's software market there are many programs specifically dedicated to creating 3D models, yet the sheer number of options and modules available means that there are significant costs of purchasing licences and then further subscriptions.

For many years, the Polish hard coal mining industry has been successfully using CAD software and its flagship – Autodesk's AutoCAD program. The options within this program together with available overlays and the possibility to exchange data with other applications suit the specific conditions of Polish hard coal deposits and meet (even combine together) most of the requirements posed by geological and survey services, i.e. by both mine surveyors and geologists. They also enable a 3D approach to geological and deposit issues (Marcisz, Ignacok, Knapik, & Ostrowska-Łach, 2017; Probierz, Marcisz, & Ignacok, 2017).

This article presents a fraction of AutoCAD's 3D capabilities in the representation of geological units in (access) mine workings in a hard coal deposit in the SW part of the Upper Silesia Coal Basin. The authors are aware of many software packages which are used for the 3D graphical representation of rock strata. Additionally, it is known that there are also many programs capable of this and the same is true with the modelling environment (CAD, GIS). The method presented in the article approaches the problem of modelling underground mine workings in its typically geological aspect, paying attention to (aiming at) a detailed analysis of a geological structure revealed in the sidewalls of mine workings driven through the deposit.

2. General characteristics of the study area

The study area is located at the SW slope of the main trough of the USCB (the largest element of the basin's geological structure in terms of area), between the Jastrzębie saddle and the Gorzyce-Bzie-Czechowice regional fault (Fig. 1).

The lithostratigraphic profile of the study area is constituted by bed-rock formations (Precambrian, Cambrian, Devonian and Lower Carboniferous rocks), Upper Carboniferous formations making up the productive series (Fig. 2, Table 1) and overburden strata – constituted by Miocene and Quaternary deposits. In the study area, the productive formations of the Carboniferous are represented by Paralic Series (Namurian A), the Upper-Silesian Sandstone Series (Namurian B-C) and the Mudstone Series (Westphalian A-B).

The Carboniferous formations generally dip towards the NE direction with an angle from several to ten or more degrees (the steeper dip angles, exceeding 15°, are observed in the S part of the studied area). Within the deposit, both continuous tectonic forms

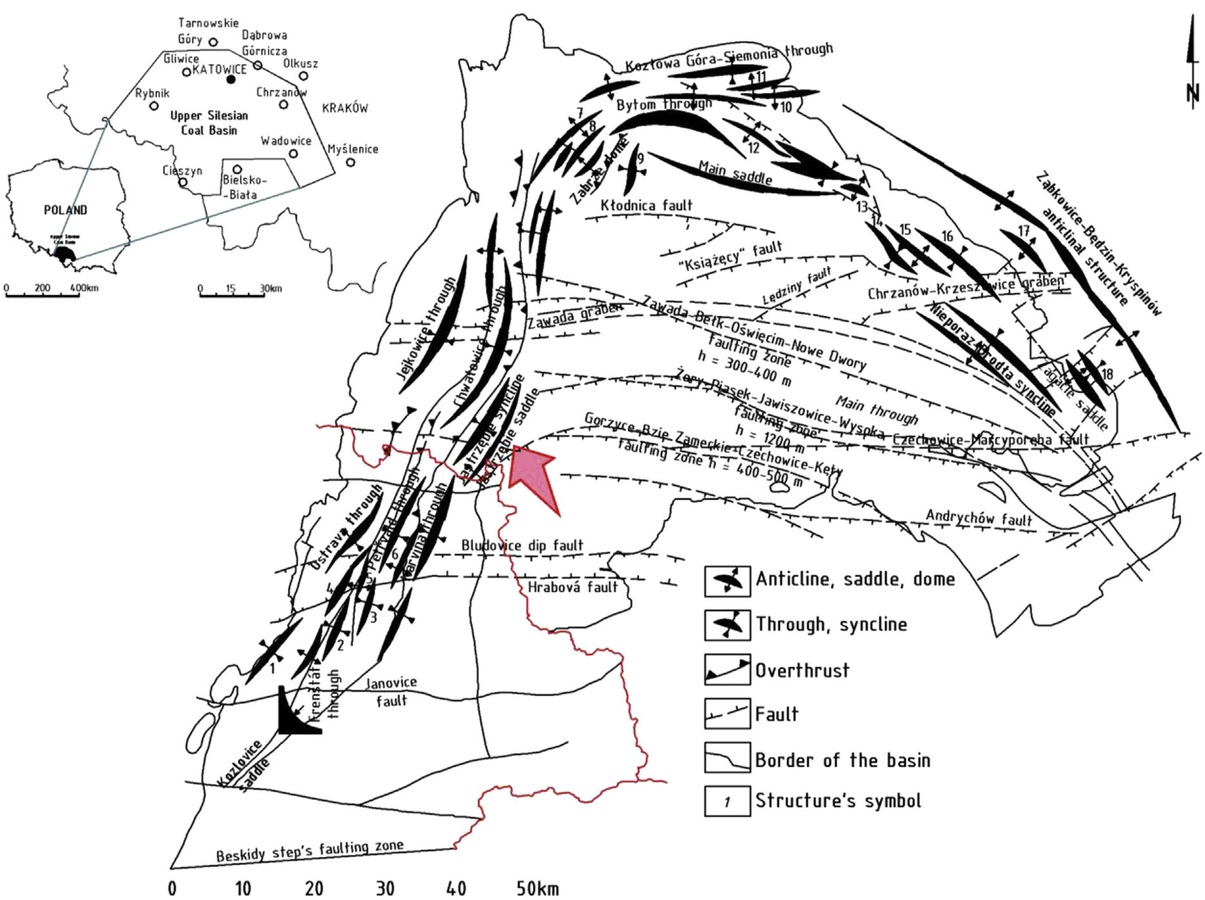

Fig. 1. Location of the study area against the background of the USCB tectonics, after (Probierz, Marcisz, & Sobolewski, 2012).
1 – Příbor trough, 2 – Stařice trough, 3 – Svinov trough, 4 – Paskov saddle, 5 – Michałkowice saddle, 6 – Orlova fold, 7 – Sośnica-Knurów fold, 8 – Concordia trough, 9 – Ruda syncline, 10 – Malinowice trough, 11 – Sarnów saddle, 12 – Grodków saddle, 13 – Maczki dome fold, 14 – Długoszyn-Wilkoszyn syncline, 15 – Ciężkowice-Trzebinia saddle, 16 – Siersza trough, 17 – Miękinia antycline, 18 – Nowa Wieś Szlachecka trough (only the structures marked by numbers have been explained).

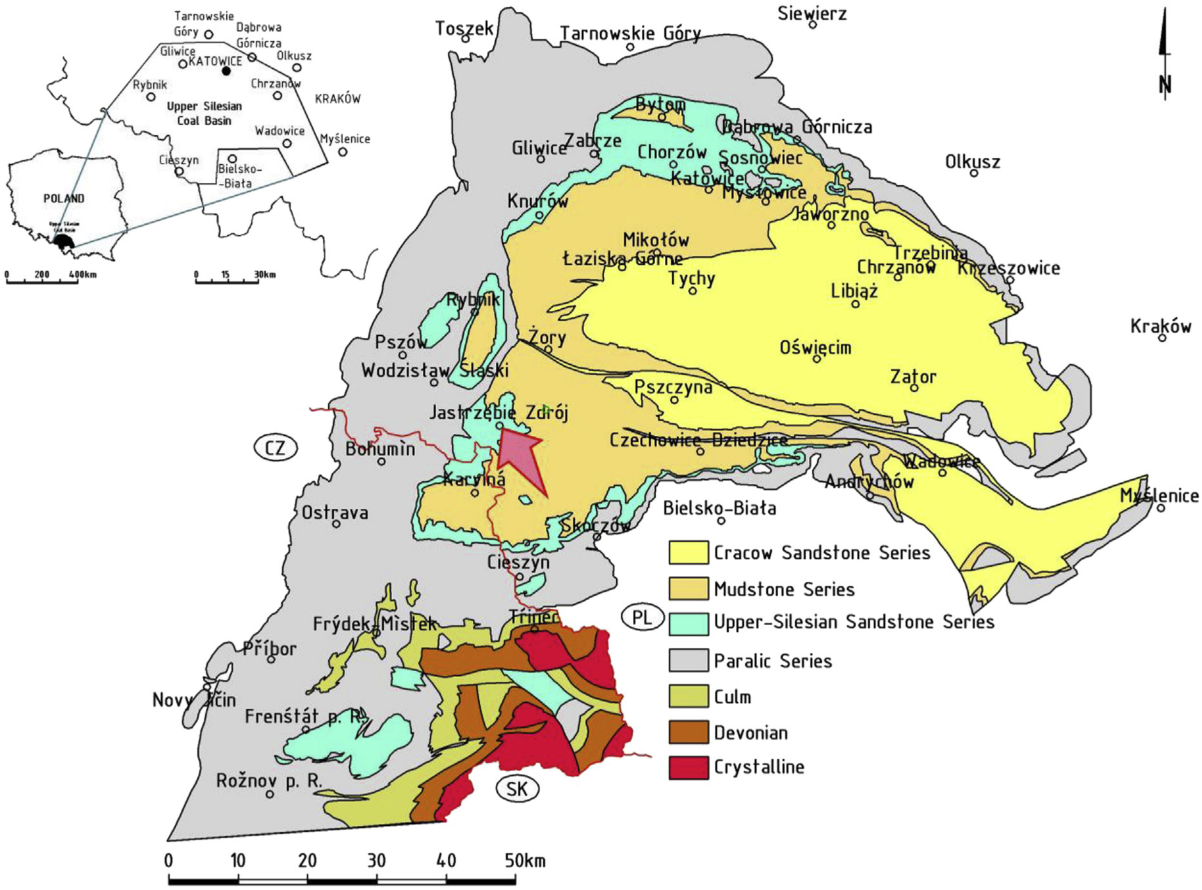

Fig. 2. Location of the study area against the background of the USCB geological sketch (Probierz et al., 2012).

Table 1
Chronostratigraphical division of USCB (Probierz et al., 2012).

Chronostratigraphic division after International Commission on Stratigraphy (2013): Eonothem/Eon	Erathem/Era	System/Period		Series/Epoch	Stage/Age	Heerlen 1935 Chronostratigraphic division: Eonothem/Eon	Erathem/Era	System/Period	Series/Epoch	Stage/Age	Substage	Orogenesis
Phanerozoic	Paleozoic	Carboniferous	Pennsylvanian	Upper	Gzhelian	Phanerozoic	Paleozoic	Carboniferous	Upper (Siles, Silesian)	Stephanian	C	
					Kasimovian					Stephanian	B	
										Stephanian	A	Astrurias
				Middle	Moscovian					Westphalian	D	Leon
										Westphalian	C	
				Lower	Bashkirian					Westphalian	B	?
										Westphalian	A	
										Namurian	C	
										Namurian	B	Ore Mountains
				Upper	Serpukhovian					Namurian	A	Sudeten
				Middle	Visean				Lower (Dinant)	Upper Visean		
				Lower	Tournaisian							

after Polish Geological Institute after A. Kotas, W. Malczyk, Z. Dembowski (1972, 1995): Complex	Litostratigraphic division		Age, million years / Limiting horizons	Another stratigraphic divisions: after T. Bocheński and S. Doktorowicz-Hrebnicki (1952)	for continental sediments after S. Stopa (1957, 1967, 1977)	for Czech part of basin after M. Dopita (1967)
		Kwaczała arcose			Stratigraphic gap	
		Stratigraphic gap				
Coal Ortomolasse	Cracow Sandstone Series	Libiąż Beds	307 — seam 119	Libiąż Beds	Libiąż Beds	
					Chełm Beds	
		Łaziska Beds	— seam 209	Łaziska Beds	Łaziska Beds	
	Mudstone Series	Orzesze Beds	312 — tuff horizon	Orzesze Beds	Orzesze Beds	
		Załęże Beds	— seam 401		Załęże Beds: Dębieńsko com.; Żory complex; Świerklany com.; Borynia complex	Doubrava Beds
						Sucha Beds: Upper
	Upper Silesian Sandstone Series	Ruda Beds *sensu stricto*	318 — seam 406, 407	Ruda Beds	Ruda Beds *sensu stricto*	Sucha Beds: Lower
		Zabrze Beds	— seam 501	Saddle Beds	Zabrze Beds	Saddle Beds
		Jejkowice Beds	— seam 510	Poruba Beds	for Dąbrowa region*	Stratigraphic gap
Coal Paramolasse	Paralic Series	Poruba Beds	Gaebler (sea horizon)		Grodziec Beds	Poruba Beds
		Jaklovec Beds	Barbara (sea horizon)	Jaklovec Beds		Jaklovec Beds
		Hrusov Beds	Enna (sea horizon)	Hrusov Beds	Flora Beds	Hrusov Beds
		Petrkovice Beds	polishing slate hor.	Petrkovice Beds	Sarnów Beds	Petrkovice Beds
			328 — Stur			
Flysh		Zalas Beds			Malinowice Beds	Kyjovice Beds
						Hradec Beds
						Moravice Beds

* after S. Doktorowicz-Hrebnicki (1935); 117–920 (PL) and 009–962 (CZ) – coal seams numbers; (symbol) – sea horizons

and numerous faults are observed both in the E-W and the N-S directions.

In the N part of the studied area, the Gorzyce-Bzie-Czechowice regional zone of faults is located (Fig. 1). The zone's width is approximately 60–100 m and its throw is 650–800 m. It is most likely comprised of two large faults with thrusts of 200–400 m accompanied by smaller dislocations. It is most likely a bedding-plane thrust, step fault zone with S thrust direction.

Three water-bearing strata related to Quaternary, Neogene, and Carboniferous formations exist in the studied area. The main water-bearing stratum is located in the Dębowiec formation lying directly on the roof of the Carboniferous formations.

3. Materials and methods

The 3D approach to mapping the geological information of underground mine workings is presented based on two selected existing access workings (inclines). The workings were chosen for their length (1950 and 2010 m respectively) and the complexity of their geological structure observed while under development.

It ought to be emphasised that the described method can be applied for the spatial visualization of the geological structure observed in other deposits, mines and existing mine workings (it is not applicable for designing mine workings), also outside the area of the USCB.

The actual visualization process was preceded with analyses of mine documentation.

The proper models were created on the basis of the results of 388 "underground" geological mappings as well as sketches and notes taken by mine geologists (Fig. 3), which were verified on-site and by underground tests.

At the stage of visualization with AutoCAD, all 388 entries of geological units from geological logs were arranged to create (1:1 scale) digital profiles of sidewalls in each of the mine workings (Fig. 4). The profiles were made in the form of a section, presenting the course of individual lithological layers, their thickness, dip angles and directions as well as geological disturbances (wash-outs) and faults. It may be assumed that in such a way 2D hand-made sketches of the profiled mine workings were obtained.

Full 3D visualization of mine workings accessing the deposit, together with detailed lithology of layers they go through was obtained through the adaptation of a 2D sketch. It was done using the method of fitting 2D profiles of sidewalls to the shape of support in a given mine working (Fig. 5), which is also the method of 3D visualization provided by options within the AutoCAD program.

4. Results and discussion

The presented 3D image of geological units in underground mine workings enables the full visualization of both the coal seam and its surroundding rocks and tectonics (both plicative and disjunctive) with their basic parameters (Fig. 6). It is possible mainly thanks to 1:1 scale visualization and the option of a full turn (by 360°) of any fragment.

The above images show that the 3D processing of data, obtained by mapping underground mine workings, enables detailed analyses of the structure of a deposit for designing and maintaining rational and safe mining operations as mentioned in the works of (Dudek,

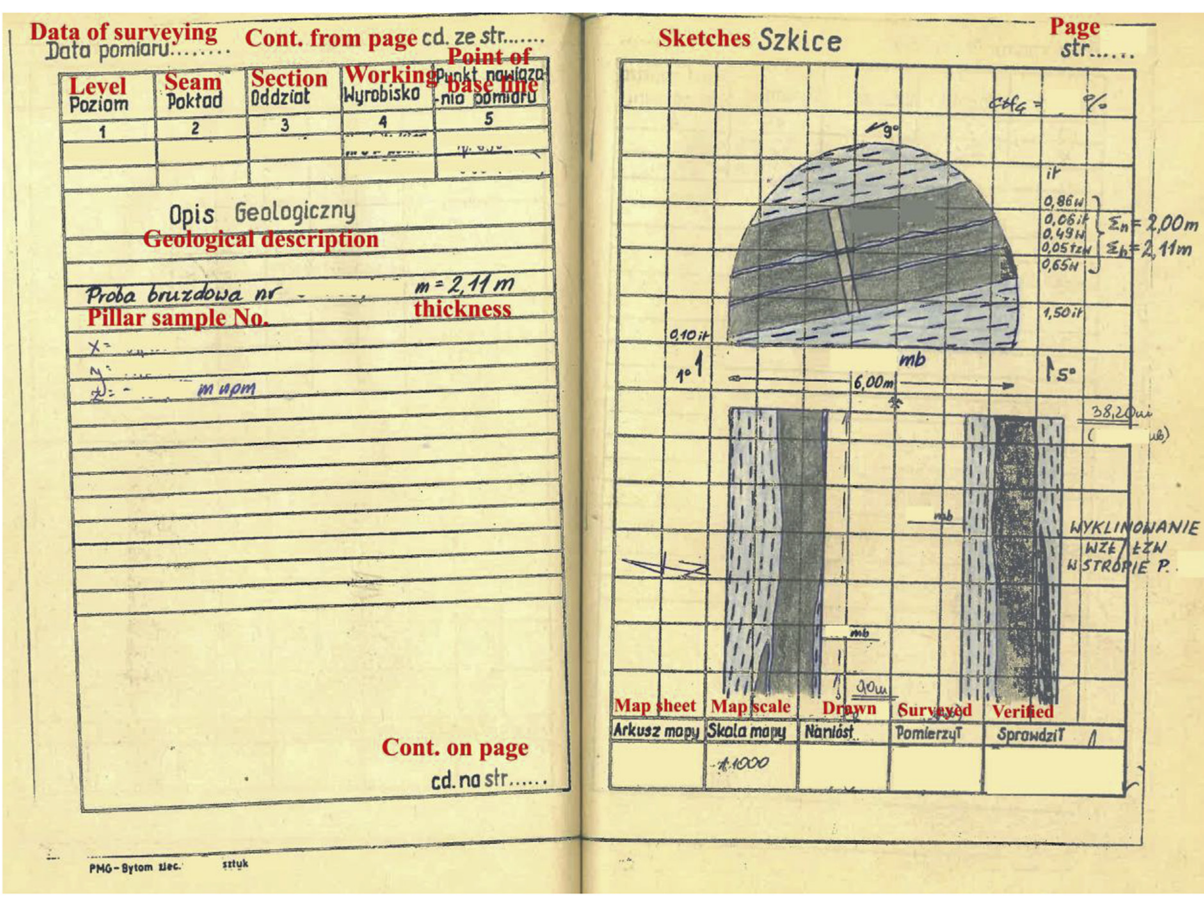

Fig. 3. Traditional mapping of an underground mine working in a geological log.

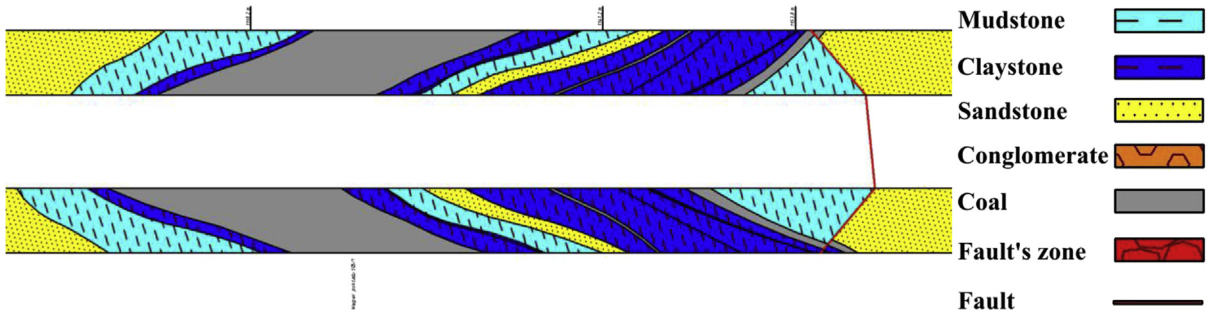

Fig. 4. Fragment of a 2D digital profile of both sidewalls in one of inclines.

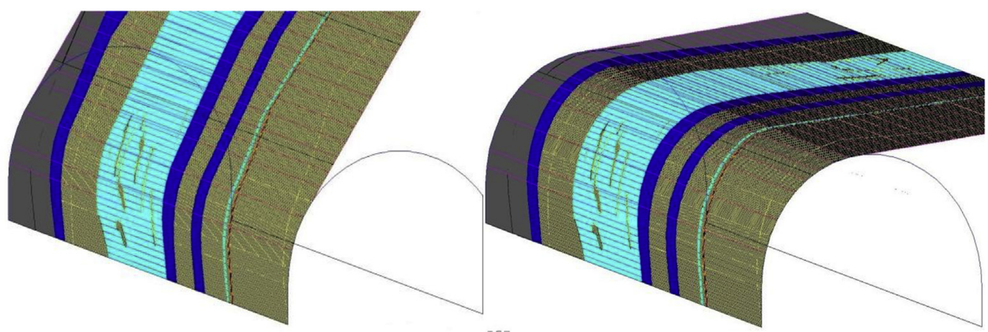

Fig. 5. Fitting a 2D sketch to the shape of ŁP roof support (geological units see Fig. 4).

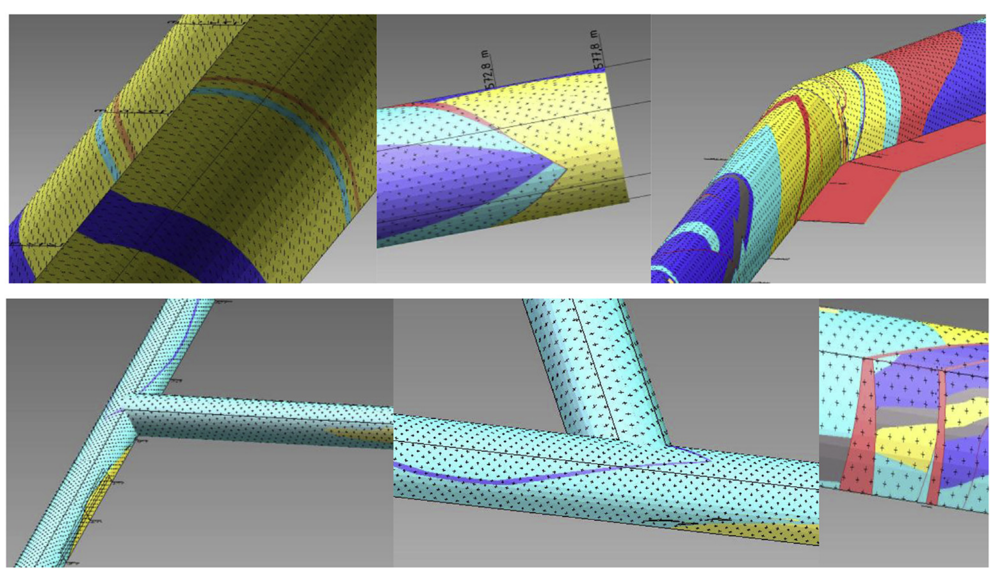

Fig. 6. Visualisations of geological units in modelled inclines (geological units see Fig. 4).

2013; Winkler, 2002; Winkler et al., 2007). Digital 3D visualisations of mine workings, including geological units and AutoCAD options concerning 3D visualization, greatly support and facilitate the interpretation of the geological structure of a deposit, including the aforementioned determination of the actual parameters of a deposit structure, the course of geological disturbances, reconstruction of fold structures and determination of fault displacements, as was also noticed by other researchers (Kecojevic et al., 2005). They also substitute, and even eliminate, traditional methods (visualisations, projections, trigonometry, co-dependences, theorems, lists), which are implemented in AutoCAD and both CAD and GIS.

5. Conclusion

The article presents a fraction of the possibilities of 3D visualization geological units in access mine workings in a hard coal deposit with a CAD environment and AutoCAD program options.

The search for the most effective tools to optimize ‘works in a deposit’ at each stage of its management continues. It seems that the presented 3D approach to geological and mining conditions shows potential to forecast geological and mining hazards while designing safe and effective mining operations and rational deposit management.

The described method of visualization can be applied for mine workings being, as well as pre-existing ones, which have rich geological documentation, which in turn is associated with a possibility (sometimes necessity) to reinterpret the information as the deposit is better and better assessed, and geological sciences together with IT continuously develop.

Use of the presented techniques significantly broadens (even provides new) possibilities for geologists to interpret and analyse many variants of solutions in a relatively short period of time, considering all the available data about a deposit, assuming that interpreting geological data is one of a geologist's (not only a mining geologist's) essential tasks, and the method of their interpretation is a combination of knowledge, experience and geological intuition.

The foundation for the interpretation is the obtained and collected data, and its result are different types of quantitative and qualitative models of a deposit in the form of maps, cross-sections, lists, graphs etc., and currently more and more often models in a 3D form, aimed at finding the optimal manner of conducting mining operations. Combining geological and mining data economic and financial information makes it possible to manage the production in a rational way from a technical and economic point of view.

Conflict of interest

None declared.

Ethical statement

Authors state that the research was conducted according to ethical standards.

Funding body

None.

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