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PIOTR URBAŃSKI
ARTUR GAWLIK

Rock salt production in O/ZG "Polkowice-Sieroszowice" – a case study

The first works related to the exploration of the salt deposit in O/ZG "Polkowice--Sieroszowice" took place in 1991. At that time, a number of opening-out headings to the salt deposit from the level of the copper ore level were begun. Currently, the total length of the excavations in the salt deposit is approximately 40 km. It should be noted that, depending on the function, the volume of drifts is different, which results from the dimensions of individual excavations. The total volume of drifts in the salt deposit is estimated to be approximately 2.5 million m^3. In the Sieroszowice mining area, salt occurs at a depth of 950 m above sea level. In November 2013, the mine obtained a license to extract rock salt from the "Bądzów" deposit (50 years).
Part of the mining activities in the salt deposit are performed mechanically in a chamber system with the use of roadheaders. The applied technology for deposit extraction requires the methodology of headings mining. These headings (chambers) are made in layers, from top to bottom. The target transverse dimensions of the chambers are 15 m × 15 m (width × height) in a variety of lengths. Chambers are separated by inter--chamber pillars 20 m wide. which should ensure the stability of the chambers and the pillars themselves. The remaining works consist of drifts driving with dimensions 7 m × 5 m (width × height).
The mining works carried out so far take place more or less in the middle part of the deposit (understood in terms of thickness), and the excavations created as a result of these works are located in salts with various geomechanical parameters.

Key words: *KGHM Polska Miedź S.A., deposit, rock salt, roadheader, exploitation*

1. CURRENT STATUS OF SALT EXPLOITATION – BASIC INFORMATION

KGHM Polska Miedź S.A., O/ZG "Polkowice--Sieroszowice" is a mining facility where the main activity is copper ore extraction. Since 1991, under the terms of the deposit exploration concession, the mine has been carrying out mining works within the salt deposit, which is located several dozen meters above the ore deposit. In the Sieroszowice mining area, salt occurs at a depth of 950 m above sea level. In November 2013, the mine obtained a license to extract rock salt from the "Bądzów" deposit (50 years).

At present, the advancement of mining works is about 2.5 million m^3 of voids obtained as a result of about 40 km of access, development and exploitation excavations (Fig. 1).

Currently, single-level rock salt mining takes place in the lower level of the "Bądzów" mining area.

2. DEPOSIT GEOLOGY

The rock salt bed in the "Bądzów" Area is located above the Zechstein base from 20 to 100 m. Directly below it, there is the lower anhydrite with a thickness of 20 to 90 m, and above it, the upper anhydrite with a thickness of 40 to 100 m within the Werra cyclothem (PZ1). The rock salt bed is irregular, with a variable thickness from 21.6 m in the S part of the mining area to 180.1 m in the NE part of the mining area [1]. A characteristic phenomenon of the internal structure of the "Bądzów" rock salt deposit are discontinuous layers of intra salt anhydrite.

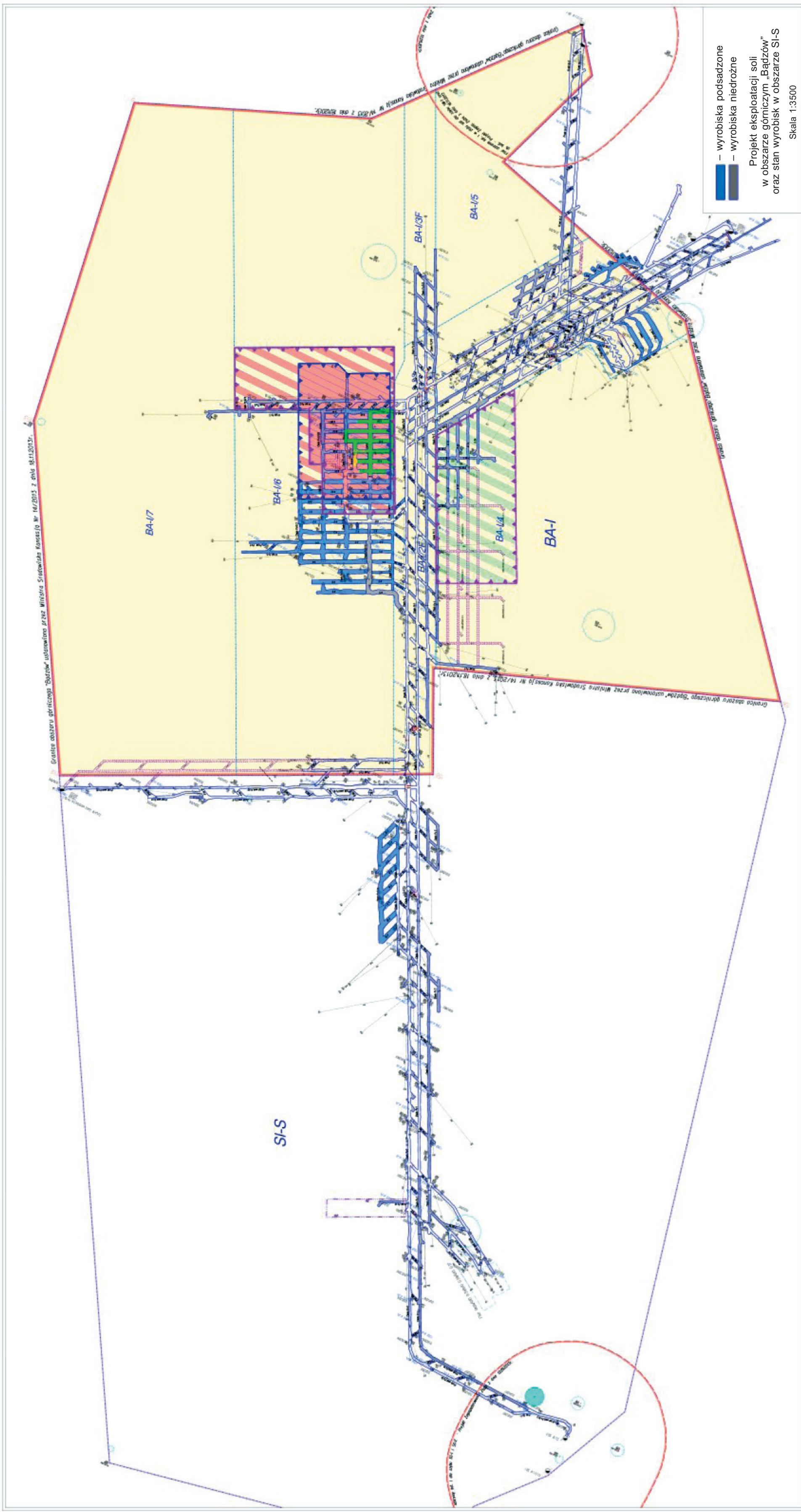


Fig. 1. The current state of salt excavations

In the vertical profile, the deposit consists of a series of petrologically diverse salt layers (Figs. 2 and 3). There are three separations of stratigraphic units in the profile of the oldest rock salt in the area of the "Bądzów" deposit. A characteristic feature of the internal structure of the "Bądzów" rock salt deposit is the variable quality of the mineral which is dependent on the mineral composition of the admixtures. There are various types of salt in the rock salt seam (8 petrological types) distinguished in terms of the presence and amount of contaminants in it (Tab. 1). The average NaCl content in the recoverable reserves is 96.26%, the maximum is about 99.5%, and the minimum is 31.10% in the undesirable excesses included in the balance intervals.

A characteristic feature of the oldest rock salt (Na1) bed is its lithological variability depending on the mineral composition of admixtures, the degree of granularity and texture. They are usually mixed, medium and coarse-crystalline salts (with a predominance of medium-crystalline ones), occurring in the form of alternating layers with a thickness of several to several dozen centimeters. The fine crystalline salt is subordinate and overgrowths of brittle – medium crystalline salts are common. Clear salt overgrowths occur sporadically. The different crystalline varieties are mostly light gray or off-white salts with admixtures of anhydrite-clay substance or fine anhydrite crumbs, locally with predominance or admixtures of medium or coarse-crystalline salt. Coarse-crystalline varieties are generally pure whitish or transparent salts, in which there is lamination (light and darker salt layers) and admixtures of pollutants (anhydrite crumbs and clay substance) and medium and fine crystalline salt.

Generally, the oldest rock salt forms a seam with an extension close to the latitudinal direction (WNW-ESE), with a gentle collapse of the layers at an angle of 3–8 degrees. The seam thickness is highly diversified – from 10.0 m (in the area of its wedging in the south – area S-345a) to about 190.0 m (in the area of the BG-39 well).

Due to the amount and size of the contamination, there are eight petrological types of rock salt.

Additionally, it is necessary to mention the values of the average strength parameters of Zechstein salts occurring in the "Polkowice-Sieroszowice" mine. Namely, the average density is 2.10 Mg/m^3, compressive strength: 36 MPa, tensile strength: 1.7 MPa, bending strength: 2.2 MPa. The above data was determined on the basis of archival data from one of the exploratory wells.

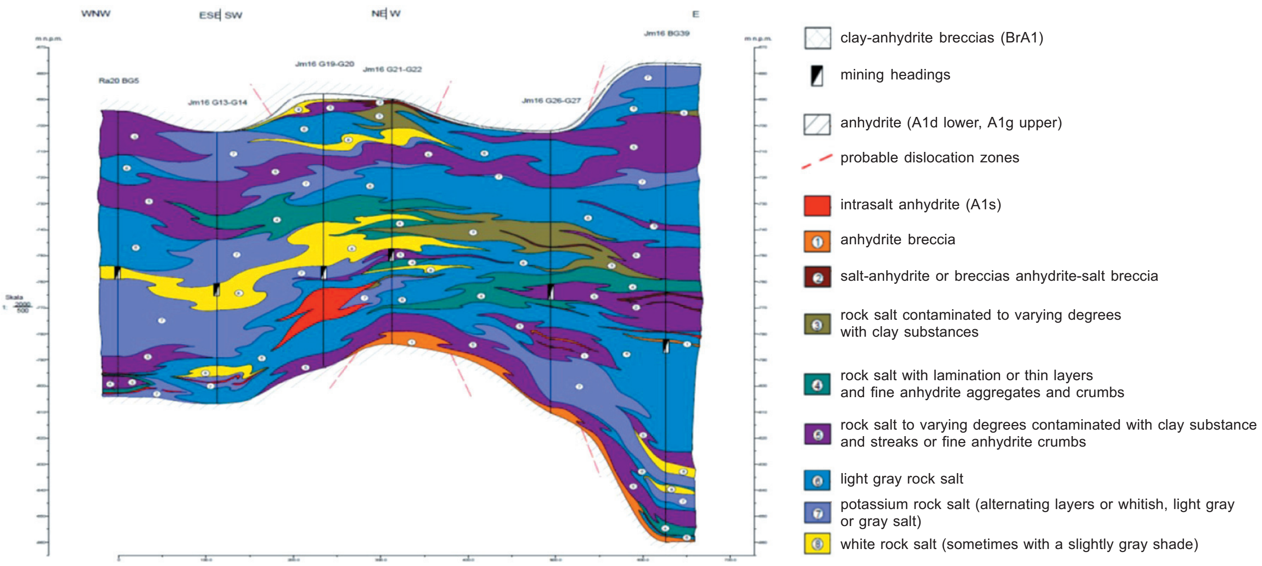


Fig. 2. Geological cross-section according to A. Szybist

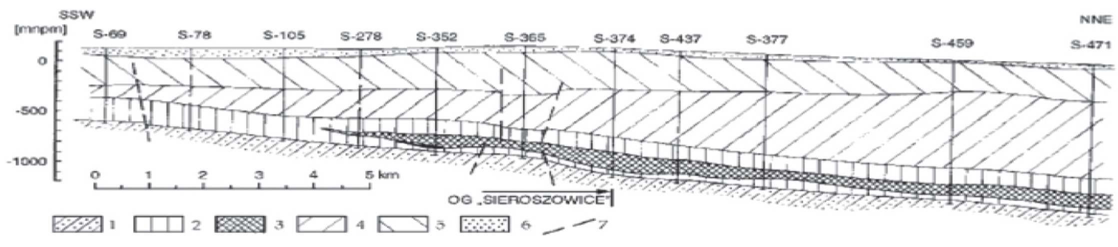
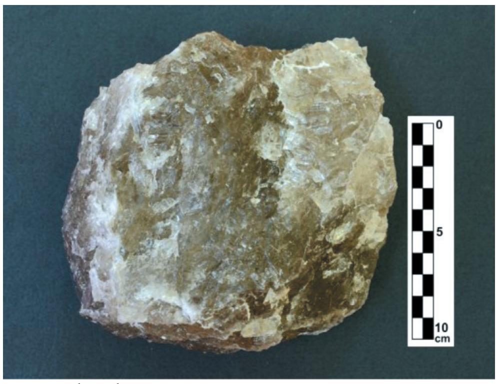


Fig. 3. Geological transverse section: 1 – Rotliegend; 2 – Zechstein formation; 3 – oldest rock salt (Na1); 4 – Triassic; 5 – Tertiary; 6 – Quaternary; 7 – presumed fault dislocations

Table 1

Rock salt petrological types

No	Salt type	Characteristic
1	 Pure rock salt	Pure rock salt (transparent), has a medium-crystalline structure, coarse and large-crystalline, crystals (idiomorphic) are properly formed, have an isometric habit. Disordered texture – disorderly, dense. Occasionally, medium-grained dispersed anhydrite sand occurs between the crystals
2	 Striped rock salt	Striped rock salt is made of gray, light gray, white and pure (transparent) salts, individual salts lie parallel, one above the other. The structure of the striped salt changes continuously from medium-crystalline to coarse-crystalline. Crystals (idiomorphic) are formed correctly, have an isometric habit. The texture is dense, disorderly (non-directional)
3	 Light gray rock salt	Pure rock salt (transparent) has a medium-crystalline structure, coarse and large-crystalline, crystals (idiomorphic) are properly formed, have an isometric habit. Disordered texture – disorderly, dense. Occasionally, medium-grained dispersed anhydrite sand occurs between the crystals
4	 Dark gray rock salt	Dark gray, gray rock salt, has a medium-crystalline, coarse-crystalline structure, crystals (idiomorphic) are properly formed, have an isometric habit. Disordered texture – disorderly, dense. Occasionally, medium--grained dispersed anhydrite sand occurs between the crystals

5	 Rock salt contaminated with clay substance and sporadically with aggregates or streaks of anhydrite	Rock salt contaminated with clay substances and occasionally clusters or streaks of anhydrite, light gray and gray in color, cloudy in places, with a medium--crystalline structure. Crystals (idiomorphic) are formed correctly, have an isometric habit. Disordered texture – disorderly, dense. Contamination occurs in the form of single anhydrite crumbs up to 3 cm in size and scattered medium-grained sand and clay substance in the form of streaks, flakes and dispersed. Sand and clay substance are inside the crystals and in the spaces between them
6	 Rock salt with lamination or fine aggregates and anhydrite crumbs	Rock salt with lamination or fine anhydrite aggregates and crumbs consists of pure, white and gray salt, which are characterized by a medium-crystalline structure, correctly formed (idiomorphic) crystals of isometric habit, and a disordered texture – chaotic, compact. The salt layers are up to 80 mm thick. Between them there are anhydrites and clay substance in the form of: laminates with a thickness of 1 mm to 5 mm, creating textures: straight, wavy laminated; anhydrite and clay bands (laminates from 10 mm to 30 mm) creating a ribbon texture. Single lamines are made of anhydrite itself with a small proportion of clay and anhydrite-salt matter
7	 Rock salt contaminated with clay substance with layers or numerous anhydrite chips	Rock salt contaminated with clay substances with layers or numerous anhydrite crumbs is formed by light gray, gray, transparent salts, which are characterized by medium, coarse and large crystalline structure, correctly formed (idiomorphic) crystals of isometric habit, disordered – random, compact texture. The salts contain anhydrites in the form of laminae (2–3 mm), bent skins, sharp-edged crumbs (up to 10 mm), medium and coarse sand, clay substance in the form of islets, flakes and dispersed substance (sand and clay is present in the spaces between the crystals). Often the lamines combine into groups and then their thickness can be up to 60 mm. The salt thicknesses between the anhydrite lamellae are usually from 50 mm to 150 mm. At the boundaries of the laminae, the salt loosens. The anhydrite crumbs are usually arranged in a messy arrangement, but sometimes in a directional arrangement
8	 Rock salt with thick anhydrite growths	Rock salt with coarse anhydrite agglomerates, gray and dark gray are characterized by a medium--crystalline structure, correctly formed (idiomorphic) crystals of isometric habit, and a disordered texture – disorderly, dense. The salts contain anhydrites in the form of crumbs (from 30 mm to 200 mm), bent "skins" (up to 40 mm), scattered fine sand and sporadically dispersed clay substance (sand and clay substance appear in the spaces between the crystals). Anhydrite crumbs appear in the form of round, ellipsoidal, and sometimes also sharp-edged fragments. Some of the anhydrite fragments are cracked, the gaps are filled with salt. The arrangement of anhydrite chips is usually chaotic, but directional arrangement does occur

3. SALT EXTRACTION METHOD

The "Bądzów" deposit is exploited by underground methods, consisting dry, mechanical and selective mining of salt rock mass. All headings are driven into the rock salt seam.

The model of salt deposit mining assumes:

- minimum thickness of roof safety shelf – 15 m,
- minimum thickness of floor safety shelf – 10 m,
- minimum thickness of inter-chamber pillar – 20 m,
- minimum thickness of inter-level shelf – 15 m.

The basic method for the deposit exploitation is a chamber system with chambers transverse dimensions up to 15 m × 15 m, while the headings which are cutting the production block are adapted to the technological needs and are taking into account the technical capabilities of used roadheaders.

The exploitation of the salt deposit is planned to be driven at three levels of chambers, and the size of levels is directly related to the thickness of the deposit and the quality of the salt (Fig. 4).

Sequencing of individual levels within a production block is not imposed.

During development and exploitation in salt deposit, environmental risks may occur, such as: water, heat, gas as well as rock bursts.

Two Zechstein aquifers are located in the vicinity of the rock salt deposit. Above the salt roof there is the water-bearing level of the main dolomite Ca2, below its bottom – the level of limestones and Ca1 dolomites. Both levels are separated from the salt by, respectively, thick and continuous insulating layers – a series of A1g and A1d anhydrites. These levels do not directly threaten mining excavations in salt.

The criterion for assessing heat risk is the presence of a temperature at the workplace, measured with a dry thermometer, not exceeding 43°C and a temperature measured with a wet thermometer, not exceeding 27°C.

Due to the elastic properties of salt, there is no immediate risk of a roof collapse.

Workings unnecessary for the proper functioning of the department should be excluded, fenced off and marked.

The area of the mining activity is not prone to featuring methane, however, in order to detect possible flammable and explosive gases in the salt deposit and to ensure the safety of the staff, preventive measures should be carried out in accordance with the O/ZG "Polkowice-Sieroszowice" Directors directive on: working in conditions of possible occurrence of geodynamic gas phenomena or exceedances of acceptable gas concentrations in headings. Due to possibility of increased concentrations of hydrogen sulfide in the excavations, employees of the salt department are obliged to absolutely have personal protective equipment, i.e. gas masks and half-masks and protective glasses.

The main point of the mining method at a given level consists in the fact that from drifts made in the roof layer of a given level (under the safety shelf – roof or inter-level) chamber with separate ventilation to breaking with main heading and previously made chamber or ventilation drift providing circulating ventilation is made.

Subsequently, the chamber pavement along with the main heading is widened to the dimensions of the chamber width, ie approx. 15 m.

In the second phase, the second and third layers are made (Fig. 4). The target maximum dimension of the excavation is 15 m high and 15 m wide. The length of the chamber depends on the work progress in a given area, mining and geological conditions. Work performance, according to such technology, allows for the full utilization of resources from the chamber and ensures appropriate safe dips on communication routes and proper ventilation.

Salt dust generated during the mechanical processing of muck in the underground processing plant is stocked in previously excavated chambers. Quality salt – anhydrite layers and impurities found in the salt bed, as well as waste from developments, is stored in the chambers or drifts intended for liquidation (Fig. 5). It is assumed that practical tests will continue, filling the operating chambers to the temporary level of 35% of the volume. As further tests are carried out, it is assumed that these chambers will then be filled to the target level.

4. CURRENT MINE OPERATIONS

Today, the exploitation of the rock salt deposit takes place in the central part of the "Bądzów" mining area, while the mining of the copper ore deposit below is currently carried out in the immediate vicinity of the G-53 and G-54 mining fields (Fig. 6). Due to the operation of the above-mentioned divisions under the mining chambers in the salt deposit and the lack of experience in the interaction of these two operations, the extraction of rock salt from the chambers should be limited for technical and organizational reasons.

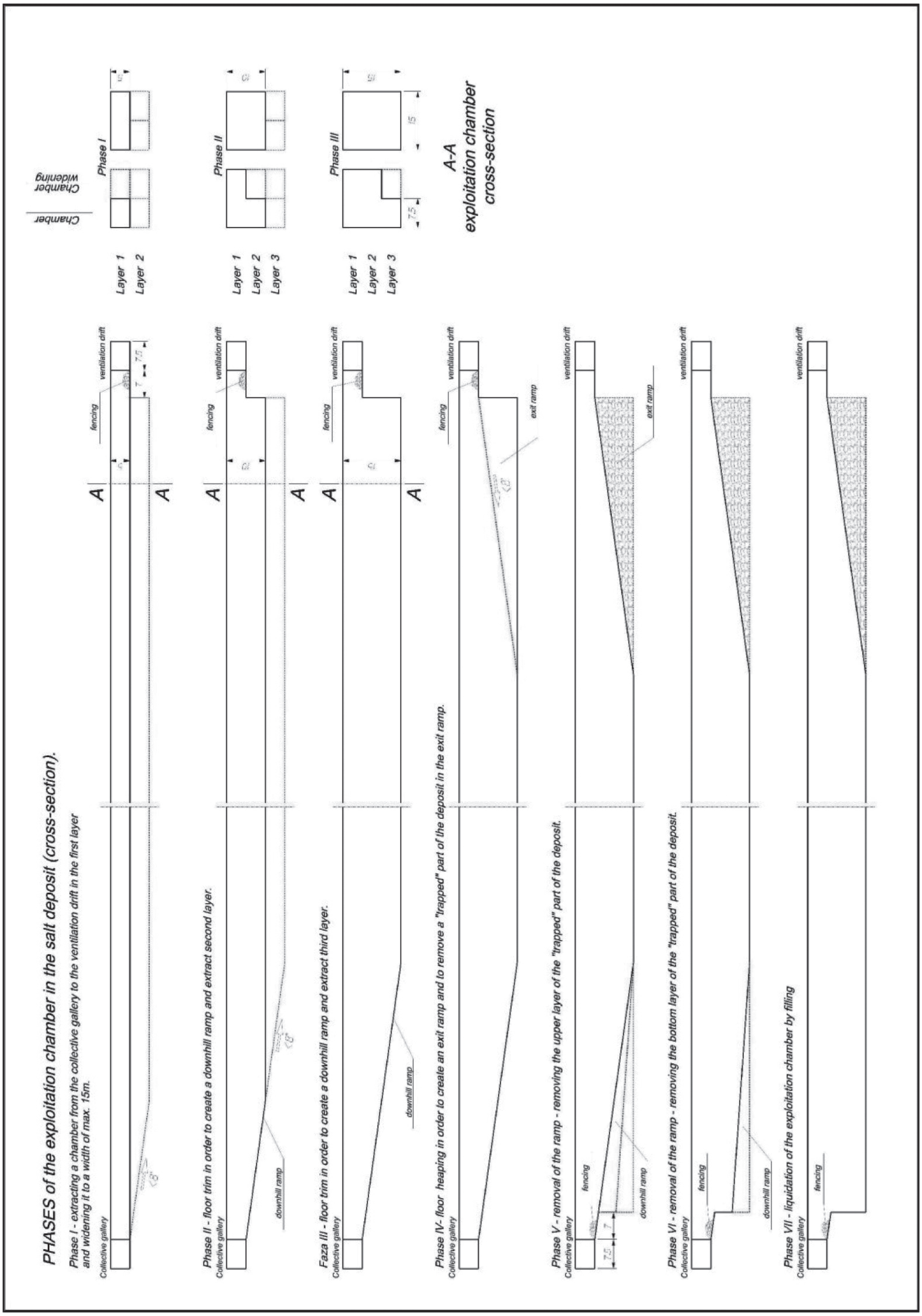


Fig. 4. Scheme of the exploitation chamber excavation technology

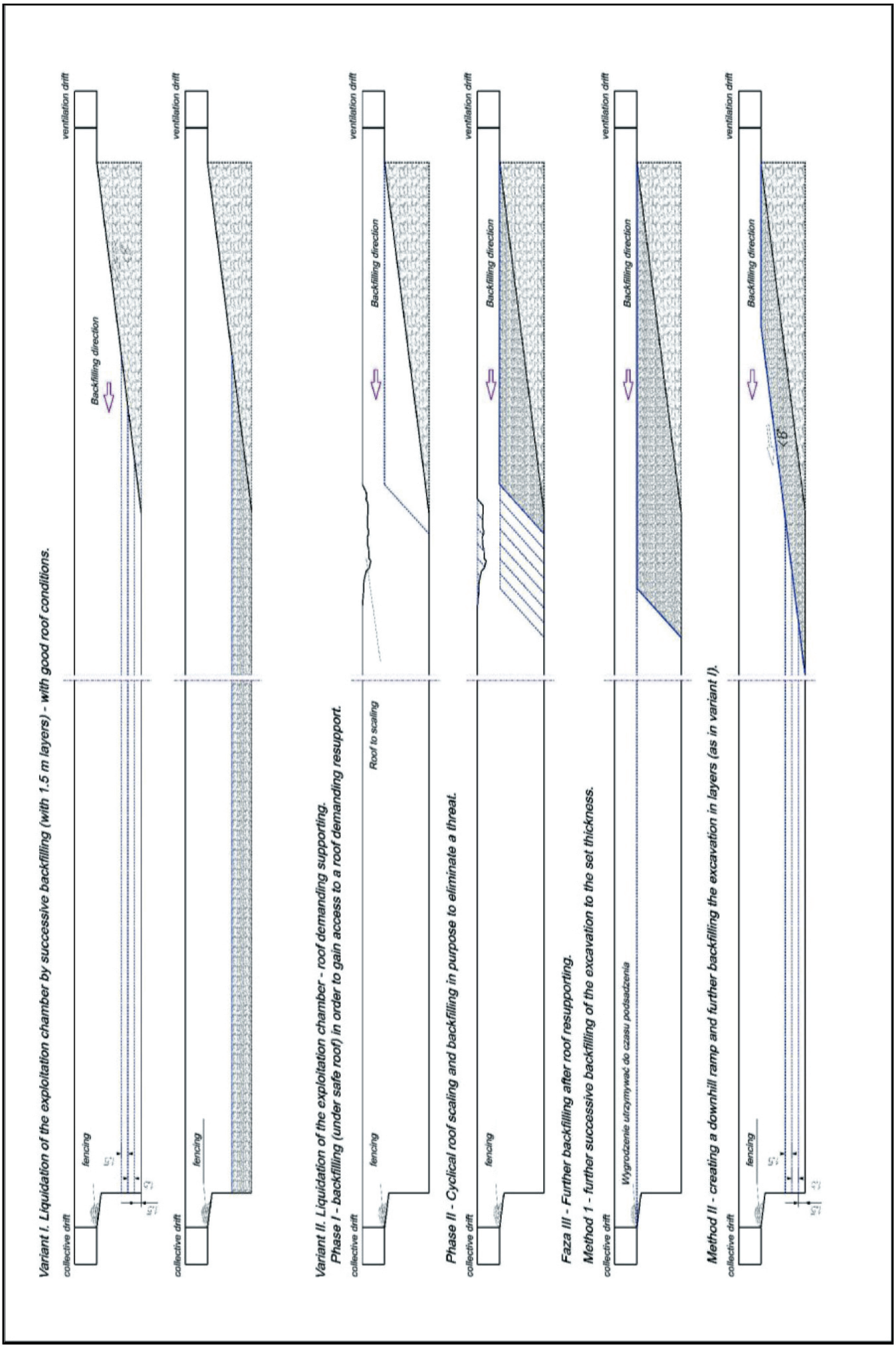


Fig. 5. Scheme of exploited chamber filling technology

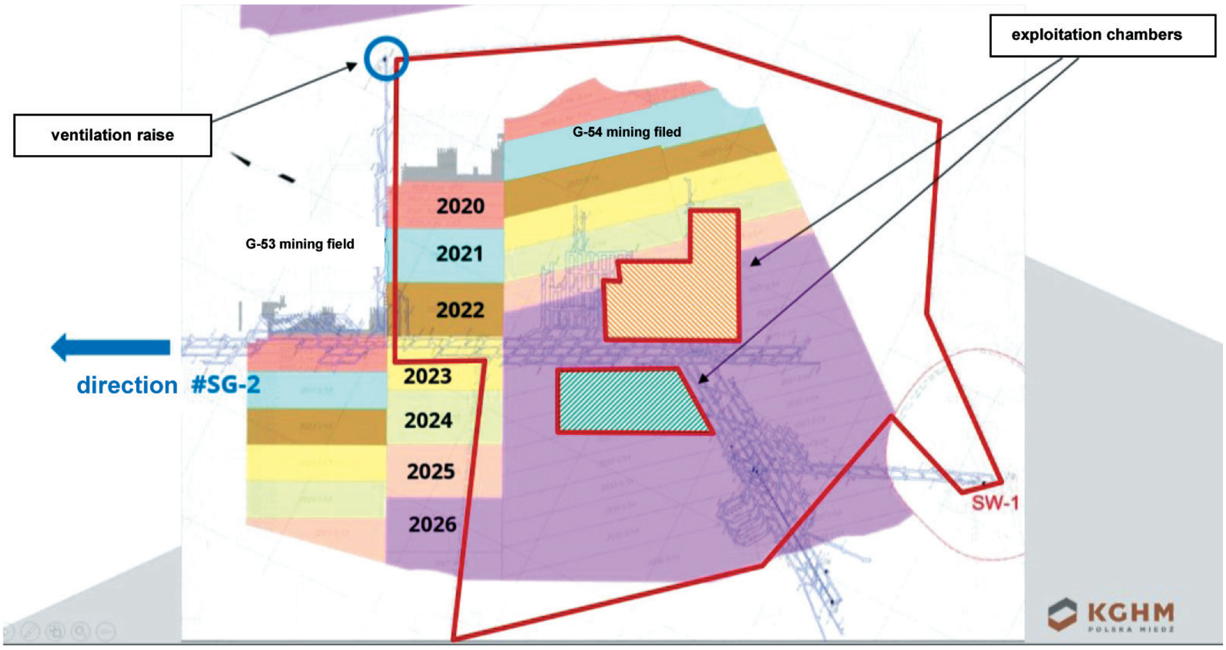


Fig. 6. Salt mining in the background of extracting copper ore divisions

5. USAGE OF SALT GALLERIES FOR AIR DISCHARGE FROM THE COPPER LEVEL DIVISION

The conducted mining works led to the connection of the SW-1 shaft area with the SG-2 shaft area by means of a double-threaded drifts (Ps-0 and Ps-1 galleries). Drifts connection (2017) was an element of the project of discharging used and hot air through the salt deposit to the SG-2 shaft. The workings Ps-1 and Ps-0 from Przecinka 42 to Przecinka 56 were excavated in rock salt.

The last stage of mining works was the execution of the Ps-1a ventilation drift from Nn-1 to the SG-2 shaft in anhydrite. The length was 79 m. The ventilation drifts were made with the use of the ATM-105 road header. Previously, a raise was made connecting the copper ore deposit with the salt seam above it – Ps-10 and Ps-11 ventilation drifts (Fig. 7). Through the galleries of the T-359 and W-359, intake air is transported from the SW-4 shaft, which, after passing through the mining field of the G-51 division, and then through the salt workings, goes to the SG-2 exhaust shaft.

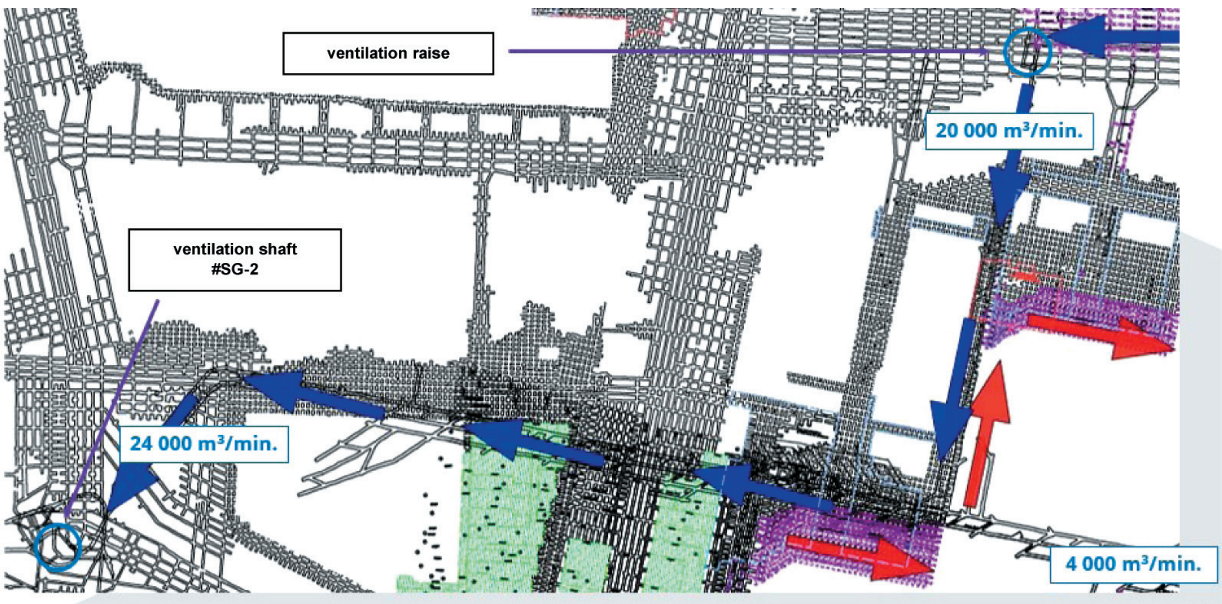


Fig. 7. Scheme of the exhaust air flow

Another element of the ventilation network was the construction of a corrugated sheet culvert within the intersecting workings (Fig. 8). The task of the culvert was to separate the used air current from the copper deposit from the air stream used in the workings in the rock salt deposit. The arch span of the culvert is 9.31 m, and its structure is made of corrugated sheet with a 200 mm × 55 mm corrugation. This type of structure is well known in surface construction, mainly in road and hydraulic engineering, but such structures have never been used in mining construction solutions.

The arch profile was designed according to the Swedish design method (Tab. 2). The structure was heaped with crushed rock salt and this material has a specific weight of 2.1 kN/m^3 and an internal friction angle of 39 degrees to 45 degrees.

The steel sheet used for the production of the structure complies with the PN-EN 10025-2:2019-11 and PN-EN 10149-2:2014-02 EN 10025-2: 2007 and EN 10149-2: 2000 standards [3, 4]. The anti-corrosion protection complies with the PN-EN ISO 1461:2011 standard [5]. The salt environment in the chamber does not cause corrosion because the atmosphere is relatively dry (humidity approx. 20%).

Based on the static analyzes, the necessary verification of all strength calculations was made. The following checks were made:
- compressive strength,
- buckling,
- bending resistance,
- load capacity of bolted connections.

One of the basic problems of the design process that had to be taken into account was the process of clamping the workings in the rock salt bed and the impact of the interaction of copper ore mining with the rock salt deposit.

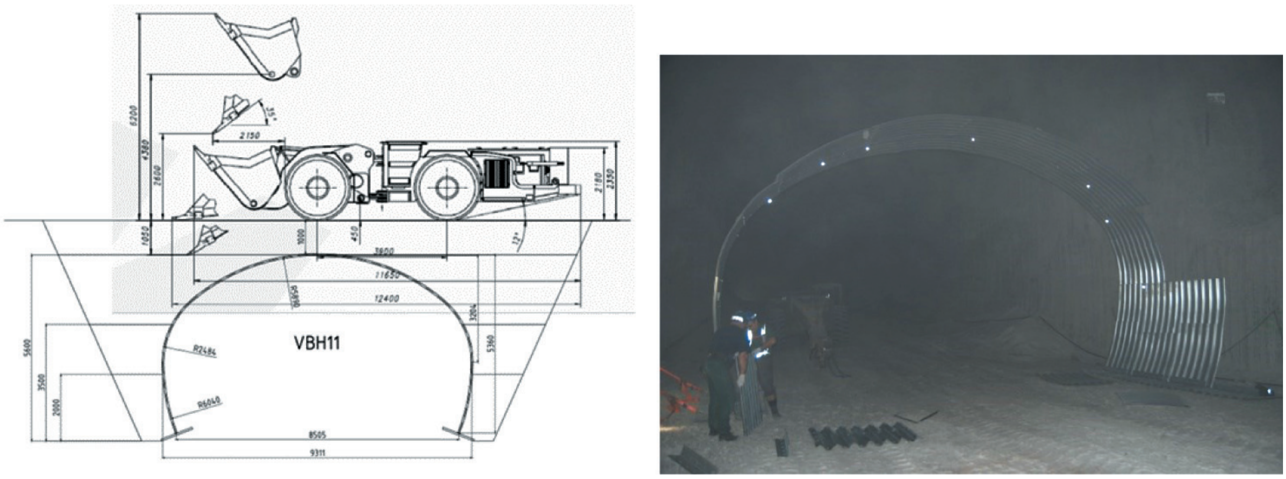


Fig. 8. Corrugated sheet culvert

Table 2
Basic geometrical parameters of the structure

Structural solution	structure: ground-steel sheet arched structure made of corrugated steel sheets
Final processing	vertical front walls made of EPS blocks (expanded polystyrene)
Fundament	foundation made of flexible, shallow corrugated sheets
Foundations [m]	9,31
Internal height [m]	5,36
Total length [m]	20
Corrugated profile [mm]	200 × 55

6. SALT PRODUCTION 1991–2021

At present, the extraction of rock salt amounts to slightly more than 200,000 Mg/year (Fig. 9). In previous years, even more than 500,000 Mg/year were produced (2012/2013). The mining activity in the salt deposit, carried out for over 20 years, resulted in a measurable effect in the form of extraction in the years 1991–2021 at the level of over 6 million Mg. The weather conditions undoubtedly have an impact on the production volume (warm winters).

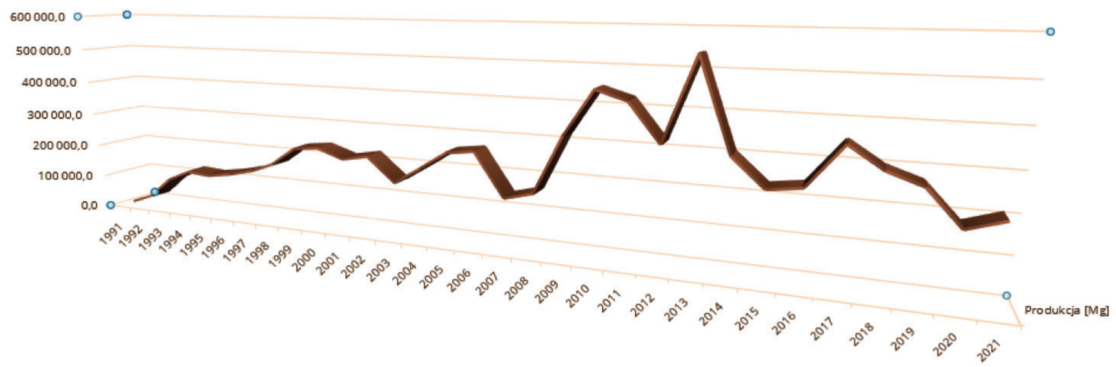


Fig. 9. Salt production 1991–2021

7. ROCK SALT PRODUCTION SCHEME

The workings are bored with the use of a mechanical method, through milling, with the use of roadhead--type shearers MB 770 (Fig. 11), ATM 105 (Fig. 12), AM 85 (Fig. 13) by Sandvik. The roadheaders used in salt mining differ in terms of technical parameters. Basic data on this equipment are presented in Table 3. In salt headings which require maintenance due to difficult geological and mining conditions and the reduced cross-section of the workings, a machine with a cutting- milling head (Fig. 14) is used for roof scaling. The excavated material is loaded on Dosan moxy MT-41 and Bell B40D articulated haul trucks (Fig. 15), then transported to a dump box of a retention tank with a capacity of 100 Mg, and from there to an underground processing plant (Fig. 16). In the processing plant, commercial fractions with a grain size above 0.16 mm are separated from the dust fraction and are transported to the surface via a shaft (Fig. 10), in trolleys with a capacity of 9 Mg (Fig. 18). On the other hand, the fraction with particle size below 0.16 mm is a waste in the form of salt dust located in the spaces to be liquidated. On the surface, salt is transported to a storage facility by means of conveyors (Fig. 18) which have a capacity of 70,000 Mg (Fig. 11). KGHM METRACO S.A. is responsible for the sale of salt.

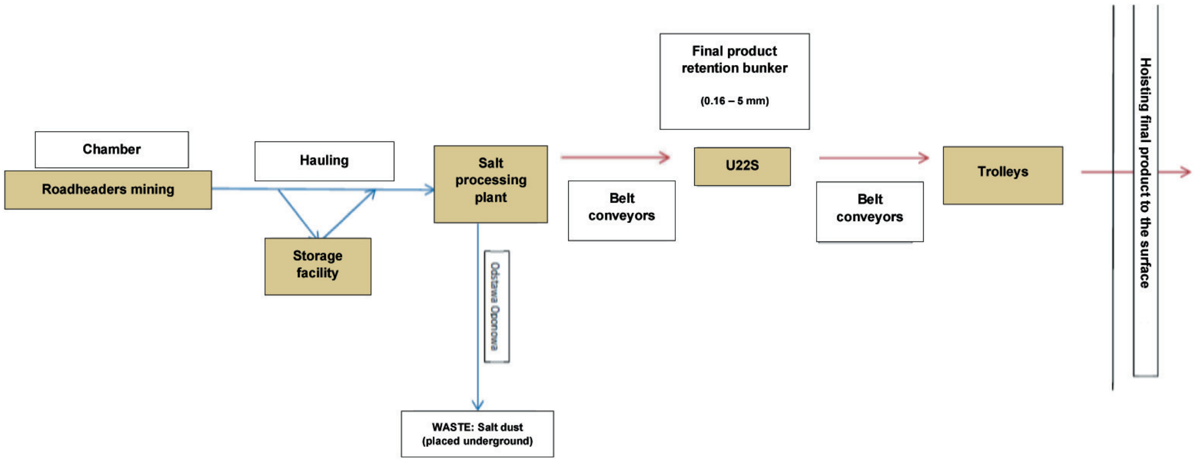


Fig. 10. Salt production scheme (underground)

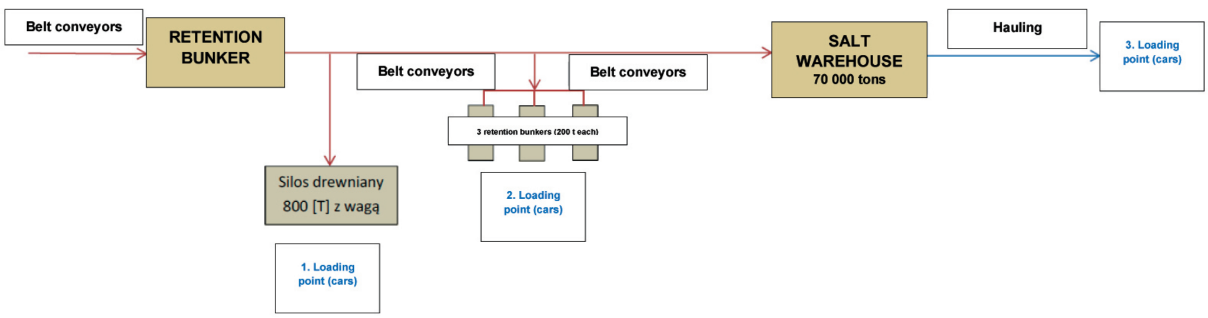


Fig. 11. Salt production scheme (surface)

Fig. 12. Continuous miner MB 770

Fig. 13. Roadheader ATM 105 IC

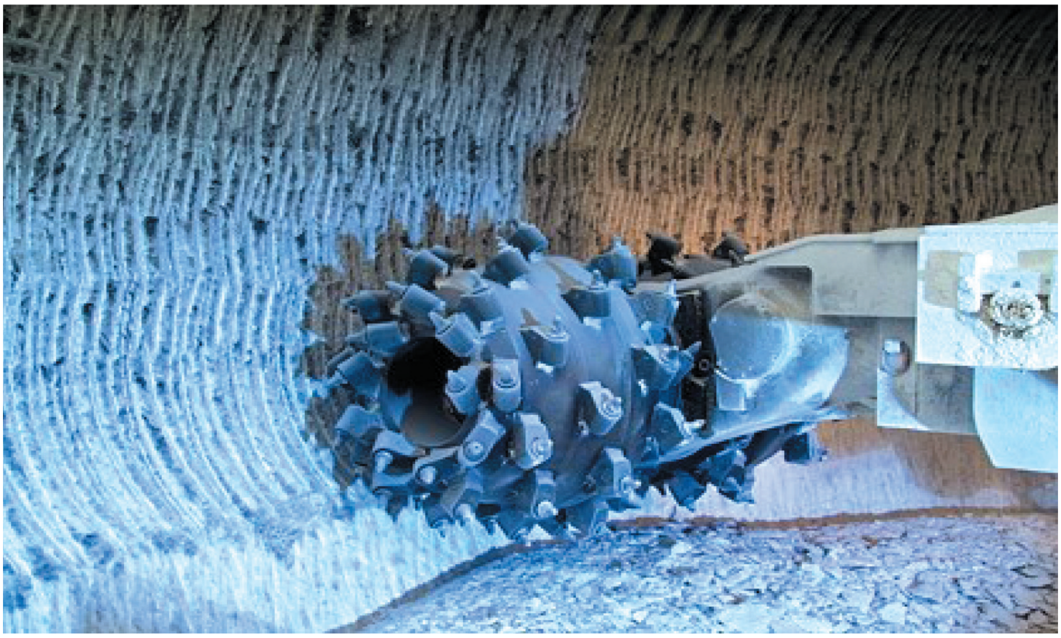


Fig. 14. Roadheader AM85

Fig. 15. SWBF-3230-AD scaling truck

Fig. 16. Haul truck

Fig. 17. Salt processing plant

Fig. 18. Salt extraction trolleys

Fig. 19. Rock salt and copper ore conveyor belt

8. MACHINE PARK

The opening, development and exploitation operations in the salt deposit are carried out on the basis of a modern and efficient machine system, which consists of: roadheaders, LHDs, haul trucks.

Roadheaders are used for driving drift and chamber workings, as well as for their reconstruction (restoration of the original state) [2]. The list and number of machines currently used for salt mining at the O/ZG "Polkowice-Sieroszowice" is presented in Table 3.

Table 3

List of machines used for salt mining in O/ZG "Polkowice-Sieroszowice"

Machine type	Machine model	Quantity
Roadheader	AM 85P	1
Roadheader	ATM 105IC-P	1
Continuous miner	MB 770	1
Articulated haul truck	DOOSAN DA-30 WIG	1
Articulated haul truck	BELL B40D	3
Articulated haul truck	BELL B40E	1
LHD	LKP-0805C	1
LHD	LKP-0403C	1
LHD	LKP-1601B	1
Fuel and Lubrication Truck	SWPS-4A	1
Scaler	SWBF-3230-AD	1
Crew truck	SWT-Team 14/1,9	1
Crew truck	SWT-Team 10/1,9	1
Crew truck	SWT-Team 20/1,9	1
Utility truck	SWT-Team 20/1.9/PTMK-18	1

Table 4

Basic technical data of roadheaders

Parameter	Unit	Roadheader model		
		AM 85	ATM 105	MB 770
Length in transport position	[mm]	14050	20115	13800
Height	[mm]	3940	4800	4530
Width	[mm]	5510	6500	7200
Weight	[t]	90	145	130
Max. cutting width	[mm]	8000	9100	7200
Max. cutting height	[mm]	5000	6600	5300
Average cutting cross-section	[m^2]	40	48	38
Electric voltage	[W/Hz]	1000/50	1000/50	6000/50
Power	[kW]	474	542	702
Cutting picks	[piece]	108	2·72/2·57	2·70
Transportation system efficiency	[Mg/min]	12	15	36
travel speed	[m/min]	13,0	15,0	0,15
Cutting profile	[–]	arched	arched	rectangular
Excavations basic parameters				
Min. height	[mm]	4140	5000	4900
Min. width	[mm]	6510	7500	7200
Max. longitudinal slope	[°]	18	18	15
Max. transverse slope	[°]	8	5	–

9. SUMMARY

The current level of rock salt production is a result of the implementation of the deposit exploration project and the capacity/efficiency of the technological line: mining – haulage – processing – shaft output, which do not allow the growing market needs to be fully met. The increasing demand for road salt, better sales logistics, large rock salt resources and the potential use of already existing mining infrastructure facilities justified the need to increase the mining capacity. In the current situation, the salt production plan for 2021–2025 results from the technical and organizational capabilities of the salt division is at the level of 200,000 Mg/year with about 95% NaCl content.

The rock salt resources in the area of the "Polkowice--Sieroszowice" mine are estimated at 2 billion tons, which, given the current level of domestic demand, is sufficient for approximately one thousand years.

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PIOTR URBAŃSKI, M.Sc., Eng.
ARTUR GAWLIK, M.Sc., Eng.
KGHM Polska Miedź S.A.
Oddział Zakłady Górnicze "Polkowice-Sieroszowice"
Kaźmierzów 100, 59-101 Polkowice, Poland
piotr.urbanski@kghm.com