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AN ANALYSIS OF THE INTERACTION DURING SIMULTANEOUS USE OF COPPER ORE AND SALT DEPOSITS IN THE LGOM MINES WITH REGARD TO DISPLACEMENT AND DEFORMATION OF ROCK MASS

ANALIZA WZAJEMNEGO ODDZIAŁYWANIA RÓWNOCZESNEJ EKSPLOATACJI ZŁOŻA RUD MIEDZI I ZŁOŻA SOLI W KOPALNIACH LGOM W ZAKRESIE PRZEMIESZCZEŃ I DEFORMACJI GÓROTWORU

Excavation of the two bedded deposits of mineral resources in a small vertical distance may cause additional increased mining risks (rock mass deformation, rock bursts and mining tremors, threat to land surface). This paper considers the impact of excavation of the copper ore deposit on the bed of rock salt located above it and the opposite, in terms of displacements and deformations. We used the theoretical models of processes verified by previous *in situ* observations in the mines of the Legnica-Głogów Copper Mining District. We analysed the potential for reducing the risks, among others, through coordination of mining works.

Keywords: impact of mining, mining risks, displacements and deformation of rock mass, forecasts of mining impact

W przypadku występowania w górotworze dwóch różnych, pokładowych złóż surowców mineralnych, szczególnie przy niewielkiej ich odległości pionowej, powstaje konieczność analizy wzajemnego oddziaływania eksploatacji górniczej tych złóż. W pracy dokonano analizy przemieszczeń i deformacji w górotworze i na powierzchni terenu przy równoczesnym prowadzeniu tych eksploatacji. Wskazano działania minimalizujące wzajemne oddziaływania w odniesieniu do prowadzenia działalności górniczej w kopalniach Legnicko-Głogowskiego Okręgu Miedziowego.

Główne zagrożenia występujące w LGOM to:

- przemieszczenia i deformacje górotworu związane z tworzeniem pustek poeksploatacyjnych, wywołujące w efekcie ruchy górotworu powodujące zagrożenia dla wyrobisk górniczych oraz powierzchni terenu i obiektów, jako wynik tworzenia się poeksploatacyjnych niecek obniżeniowych,

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- wstrząsy górnicze i tąpania wynikające z koncentracji naprężeń w skałach otaczających wyrobiska górnicze i nagłego wyładowania uprzednio nagromadzonej energii sprężystej (wpływy dynamiczne).

W pracy rozważano pierwsze zagrożenie, drugie będzie przedmiotem oddzielnej publikacji autorów.

Po schematycznym przedstawieniu warunków geologiczno-górniczych (rozdz.2) rozważono oddziaływanie eksploatacji złoża rud miedzi na wyrobiska wykonane w złożu soli kamiennej. Rozważania te oparto o prognozy przemieszczeń i deformacji prowadzone na bazie dobrze zweryfikowanej w warunkach LGOM teorii B. Budryka - S. Knothego. Wykorzystano też własne wieloletnie doświadczenia z kształtowania się pól przemieszczeń i odkształceń na powierzchni terenu, w górotworze i szybach górniczych. Na rysunku 4.1 przedstawiono przewidywany rozkład odkształceń poziomych i pionowych na wybranym poziomie nad złożem rud miedzi.

Na poziomie złoża soli mogą wystąpić przemieszczenia i deformacje o wartościach:

obniżenia	$W_{\max}$	do 1,9 m
odkształcenia poziome	$\varepsilon_{\max}$	do 9,5 mm/m
odkształcenia pionowe	$\varepsilon_{z\ \max}$	do 5,5 mm/m
nachylenia	$T_{\max}$	do 10,0 mm/m
przemieszczenia poziome	$U_{\max}$	do 0,65 m.

Są to znaczne wartości wskaźników deformacji, nie powinny one jednak w istotny sposób wpłynąć na stateczność wyrobisk solnych. Może natomiast nastąpić wzrost konwergencji wyrobisk czy też wzmożone odspajanie warstw solnych.

W kolejnym etapie rozważano wpływ wyrobisk w złożu soli kamiennej na wyrobiska eksploatacyjne w złożu rudy. Po szczegółowych analizach stwierdzono, że istnieje pewne zagrożenie zmian warunków stropowych w złożu rudy miedzi, jeżeli odległość pionowa pomiędzy stropem wyrobisk w tym złożu a spągiem najniższego poziomu wyrobisk solnych będzie mniejsza od 70 m. Istotniejsze zagrożenie wystąpi jeżeli odległość pionowa wyrobisk będzie mniejsza od 50 m (rys. 3). Aktualne projekty eksploatacji złoża rudy miedzi i złoża soli w polu Bądzów wskazują, że do 2016 roku, a praktycznie nawet do 2021 roku, eksploatacja złoża soli nie powinna stanowić istotniejszego zagrożenia dla wyrobisk rudnych.

W prognozach dla powierzchni terenu wykorzystano system prognozowania MODEZ autorstwa R. Hejmanowskiego. Z prognozy wynika, że wpływy eksploatacji złoża rud miedzi wywołają na powierzchni terenu, w rejonie nad przygotowywanym do wybierania złożem soli „Bądzów", obniżenia o wartości do 1,9 m a kategoria terenu górniczego nie powinna być wyższa od II-giej. Jeżeli uwzględnić równoczesną eksploatacje złoża soli w maksymalnie możliwym zakresie, to obniżenia terenu mogą wzrosnąć do ponad 4 m. Nastąpi to jednak nie prędzej niż po 100 latach a proces obniżeń i deformacji będzie łagodny i tylko w znikomym stopniu zagrażający obiektom na powierzchni terenu.

Z rozważań wynikają następujące zalecenia dla ograniczenia szkodliwego wzajemnego oddziaływania eksploatacji rud miedzi i złoża soli kamiennej:

- nie prowadzić jednoczesnej eksploatacji w zasięgu występowania wzajemnych wpływów,
- określić wielkości optymalnego wydobycia rudy miedzi w rejonie oddziaływania i wpływów tej eksploatacji na stan wytężenia zalegającego powyżej złoża soli kamiennej,
- uwzględniać prognozy aktywności sejsmicznej wzbudzonej eksploatacją rud miedzi a w szczególności jej wpływu na wyrobiska solne.

Na zakończenie Autorzy zalecają kontynuowanie monitoringu wzajemnych oddziaływań eksploatacji złoża rudy miedzi i złoża soli kamiennej, co pozwoli na dalszą weryfikację rozważań teoretycznych. Szczególnie zaleca się rozszerzenie zakresu obserwacji o pomiary przemieszczeń bezwzględnych w wyrobiskach solnych a także ich konwergencji w czasie.

Słowa kluczowe: wpływy eksploatacji górniczej, zagrożenia górnicze, przemieszczenia i deformacje górotworu, prognozy wpływów górniczych

1. Introduction

In the case of two or more mineral resources in a rock mass, there may be a situation where mining operations have impact on one another. This creates an additional threat to the stability of mine workings, the land surface and above all for the safety of people. It is important in such case to predict interactions, identify hazard zones and above all, appropriately coordinate mining of different deposits.

The solution to the problem, under specific conditions of the mining region, required the development of methods for prediction of displacements and deformations resulting from the deposits and their use in the analysis of interactions.

The study was based on good knowledge of displacements and deformations of rock mass and stress distribution in the Legnica-Głogów Copper Mining District (LGOM), where there are both copper ore, exploited on a large scale, and a bed of rock salt above it, which is exploited under experimental conditions and prepared for normal mining operations.

The authors used theoretical models, verified in the LGOM conditions, for distribution of displacements and deformations of the rock mass around the mine workings and on the surface, caused by the formation of excavation voids in the rock mass. They also used many years of experience from research on development of displacements, deformations and stresses on the surface, in rock mass and in mine shafts.

2. Outline of Geological Structure and Situation of the Deposit in the LGOM Conditions

The geological conditions of the LGOM region are well known and widely described in many publications, including in the LGOM Monograph (2007). The authors therefore focused primarily on information which is relevant to the topic of this paper. More information is provided only for the rock mass surrounding the bed of rock salt and the copper ore deposit.

2.1. Stratigraphy and Layers

There are three rock formations in the LGOM area, which are distinguished by period of creation and geomechanical properties:

- complex of crystalline Proterozoic rocks and old Paleozoic rocks (monocline base)
- complex of sedimentary Perm-Mesozoic rocks (rocks forming the monocline)
- complex of Tertiary and Cenozoic sediments forming the monocline cover.

Figure 1 shows the typical geological cross-section through the region of mining activity in the bed of salt.

The substrate of the copper ore deposit is lower Permian sediments in the form of the Rotliegend sandstone complex, which is over 400 meters thick. Sandstones in the top part (under the copper ore deposit) are fine-grained quartz white rim sandstone bonded with carbonate and copper sulphides.

The principal copper ore deposit is in the lowest level of the Zechstein rock, built of limestone and dolomite with a thickness of 5 m to 70 m, over which there are formations of primary anhydrite 10 to 30 m thick. Above, in carbonate rocks, there are layers of rock salt, composed of the oldest salt, the old salt and the youngest salt. Spread and thickness of the salt layers are variable, but generally the thickness of the salt layers increases in the north with the decline of Zechstein strata.

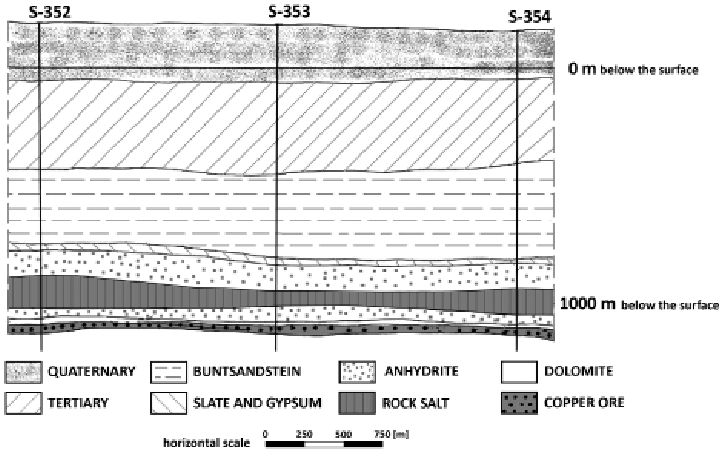

Fig. 1. Characteristic geological cross-section through the bed of rock salt and copper ore deposit in the LGOM

Above the bed of salt there are Triassic, Tertiary and Quaternary formations. The Triassic strata includes Buntsandstein formations composed of anhydrite claystone, carbonate rocks in the form of main dolomite and primary anhydrite, all of variable thickness. There are interbeddings of mudstones and shales. Buntsandstein thickness is variable and ranges from 44 m to 479 m, with an average of about 270 m.

Tertiary, with a thickness of 250 to 450 m, is represented by glauconitic and quartz sands, silts, siltstones, shales, marl, dolomite and gypsum. Locally there are layers of brown coals. Quaternary with thickness of about 50 m is represented by moraine and fluvial sediments. These are silts, sands, gravels and Holocene peats, which have developed podzolic soils and alluvial soils or peats in the valley of the Oder river.

2.2. Rock Salt Deposit

The salt deposit in the LGOM extends in the NW-SE direction and is located at a depth of about 765 m to about 1220 m below the surface. The base has a rather distinct morphological variation with differences in level of approximately 50 m, sometimes up to 150 m. The top part of the salt deposit is much less varied. It is located at a depth of about 745 m to about 1040 m and differences in level are within 20 m and only occasionally reach 50 m.

The average thickness of the salt deposits in the area of OG "Sieroszowice I" is about 70 m and the maximum is about 186 m. The deposit declines in the NE direction at an angle of 3 to 6 degrees, this is accompanied by an increase in the thickness of the salt.

2.3. Copper Ore Deposit

The copper ore deposit in the LGOM is a single layer deposit located at 30 m to 120 m below the bed of salt. It is a deposit of industrial value within the whole area under the envisaged salt pits. The copper ore deposit has been mined for many years.

3. Mining Hazards

When conducting mining activities under mining and geological conditions similar to those in the Legnica-Głogów Copper Mining District, it is to be expected that there will be multiple mining hazards, of which the most important are (Popiołek, Kłeczek et al., 2011, 2012):

- displacements and deformations of rock mass associated with the formation of excavation voids (rock mass deformation),
- threats to land surface and structures, as a result of the formation of post-mining subsidence basins,
- Mining and collapse shocks arising from the concentration of stresses in the rock surrounding mine workings and sudden discharge of the accumulated elastic energy (dynamic influences).

This paper, due to the breadth of mining hazards, will widely present the first two of these risks. Third threat will be presented in the next paper.

3.1. Rock Mass Deformations

Excavation voids in the rock mass initiate movement of the rock mass in the direction of the area, the size of which depends on the thickness of the deposit, the manner of removing voids and the excavation system used. Displacements and deformations under the deposit are generally small and usually do not extend further than a dozen or at most a few dozen meters. Above the bed, by the caving systems, a caving and crack zone is created, generally no thicker than 10-12 times the thickness of the exploited layer. Above this zone, the phenomenon is usually manifested as a regular subsidence basin moving in the direction of the surface and expanding its horizontal reach. All excavations, shaft chambers and sections within the subsidence basin will be displaced and deformed, which may cause hazards in their functioning.

3.2. Threats to the Land Surface and Structures Caused by Continuous Deformation of the Rock Mass

The subsidence basin emerging above the deposit mining area is associated with surface displacements and deformations that may cause damage to surface structures and so called natural damage on the ground. The obligation to protect structures against the anticipated mining effects significantly reduces these mining risks. There is no significant damage in thr LGOM in this respect, especially that exploitation is done at a very large depth and backfill is widely used to fill the voids after mining.

3.3. Dynamic impacts

A rapid discharge of elastic energy previously accumulated in the rock mass can cause rock bursts in mine workings and paraseismic phenomena (rock mass tremors) in the form of weak earthquakes. These are the most serious threats for the LGOM, which is mainly due to the large depth of mining exploitation (often more than 1000 m) and the presence of rigid and very durable layers of dolomite and anhydrite in the top part of the copper ore deposit. In the case of conducting mining activity in two deposits (rock salt and copper ore) located within short vertical distance, the risk of dynamic influences increases, which requires special attention. This problem, as mentioned above, will be the subject of the next paper.

4. Threats to Excavations in the Bed of Salt Posed by Exploitation of the Copper Ore Deposit

Mining one bed which is located just a little above another bed, almost at the same time, was done for the first time in Poland, and is unique in the global mining industry. This required developing a new methodology for the analysis and prediction of mining hazards which would be adequate for the LGOM conditions (Hejmanowski, 2001; Popiołek et al., 2011).

In this chapter, we first consider the influence of mining the copper ore deposit located below on the salt workings of the rock salt deposit located above. The analyses began by identifying the range of harmful deformation effects caused by mining the ore deposit. We extensively discuss the forecast of deformation effects at the level of the salt bed in terms of the occurrence of mining hazards.

4.1. Harmful Effects of Deformations Caused by the Mining of Copper Ore Deposits on the Workings in the Bed of Salt

As shown by experience from other mining regions, the description of deformations in the rock mass and on the surface in the LGOM area, in respect of mining and geological situation of the ore and rock salt deposits, can apply the theory by S. Knothe. It should be emphasized that the process of rock mass displacements and deformations occurs under conditions of high complexity of the rock mass. This complicates the problem of forecasting impacts on the rock mass located above the copper ore deposit. It also results from the fact that it is difficult to measure the phenomena occurring in the rock mass. In practice, measurements within the rock mass are carried out in the workings located above, mainly in the shafts, and principally in the range that does not allow for full verification of the mathematical model.

The previous operations, conducted outside the protective pillars, posed little threat especially to the bottom of the shafts, at the height of the vertical distance of salt pits in relation to the copper ore deposit (50 m to 100 m). There were no systematic measurements taken for the absolute movement of points in salt pits under which mining of copper ore deposit was carried out. Typically, the measurements dealt with convergence and relative movements of the ceiling, the floor and side walls of excavations.

Previous measurements registered vertical deformation of the pipe shaft resulting mainly from tightening of dehydrated layers of rock mass. The exception is finished mining in the area of Western Shafts of O/ZG “Lubin” (Niedojadło et al., 2010). Therefore, the theory parameters for the rock mass have not yet been verified sufficiently enough for the operating conditions of the copper ore deposit and its impact on the salt workings. In this connection, it should be noted that in the present circumstances, we can only talk about the estimated forecast and assessment of deformations in the salt workings resulting from mining activity in the copper ore deposit.

4.2. Forecast for Rock Mass Deformation Rate

As a result of mining the deposit, the rock mass deforms both vertically and horizontally. Displacement and deformation of the rock mass in vertical and horizontal planes are measured with the following deformation rates characterizing the state of emergency for excavation located above:

– subsidence of the rock mass points for different horizons $w(x,z)$ [m],
– distribution of vertical deformations ε_z [mm/m] – convergence of excavations,
– horizontal displacements u_z [m],
– inclination of the subsidence basin T_z [mm/m] – inclination of the pit floor,
– horizontal deformation $\varepsilon_{x,z}$, $\varepsilon_{y,z}$ [mm/m] – deformation of gallery support.

According to the integral theory by S. Knothe, the distribution of subsidence points on any rock mass horizon, in a cross section perpendicular to the rectilinear edge of the half-plane mining front is described in the paper (Hejmanowski, 2001) with the formula (1).

$$w_k(x,z) = -\frac{a(z)\cdot g}{r(z)}\cdot\int_x^{\infty}\exp\left[-\pi\frac{\lambda^2}{r^2(z)}\right]d\lambda \tag{1}$$

where:

$a(z)$ — excavation rate,
$r(z)$ — S.Knothe impact diffusion parameter on the horizon z [m],
z — vertical distance of the rock horizon from the excavated layer [m],
g — thickness of the excavated layer [mm],
x — horizontal distance of the point from the front edge of excavation [m],
$w_k(x,z)$ — final subsidence of the point on the horizon z [mm].

Underground mining causes displacement in the whole area of the rock mass deformation. The fulfilment of the postulate of transitivity allows for specifying deformation rates inside the rock mass (for various horizons). Vertical deflection is defined as follows:

$$\varepsilon_z(x,y,z) \overset{def}{=} \frac{\partial w(x,y,z)}{\partial z} \tag{2}$$

The decisive factor for determining the rock mass deformation at various levels is the distribution of parameter $r = r(z)$, i.e. the radius of impact diffusion in the rock mass.

Distribution of vertical deformation for the so-called infinite half-plane is described by the following relation (Fifth, 2009):

$$\varepsilon_z(x,z) = -\frac{n}{z}a\cdot g\frac{x}{r(z)}\exp\left[-\pi\frac{x^2}{r^2(z)}\right] \tag{3}$$

Using this formula (3) we can perform a calculation of the vertical deformation pattern along any horizontal and vertical line in the rock mass.

Formulas for other rates relevant to the assessment of the risks in salt pits and the surface are included in the paper (Popiołek, Kłeczek et al., 2011). Figure 2 shows diagrams of vertical deformation in the rectilinear area of excavation in the copper ore deposit.

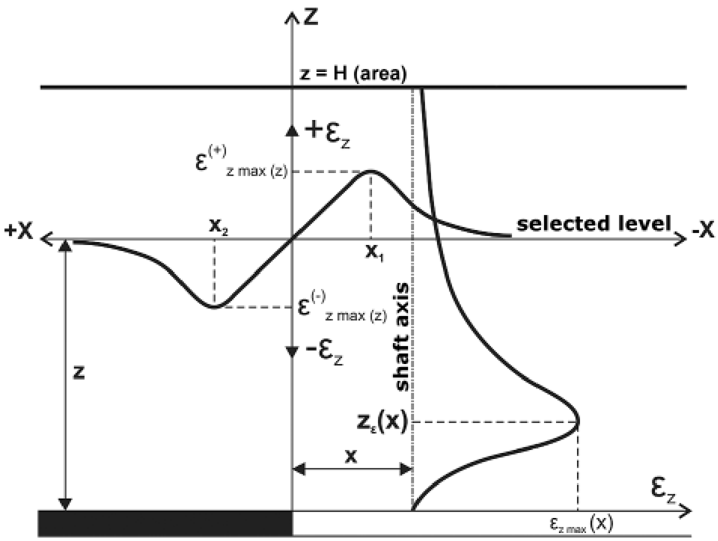

Fig. 2. Characteristics of vertical deformation distribution along vertical and horizontal lines (Sroka, 1976)

The locus of the maximum vertical deformation ε_z is visible quite high above the copper ore deposit and there is also a small horizontal range (from the edge of the area) of these deformations.

A good understanding of the parameters of S. Knothe theory in LGOM allows for a reliable estimate of all deformation rates for the land surface for any period of the proposed operations. For horizontal workings located in the bed of salt over the ore deposit it is not possible to quantitatively verify deformation rates by comparing them with geodetic measurements in excavations located above, they have been limited so far, as described above, in principle, to measurements of convergence. In connection with the above, the authors emphasize that the projections shown below for deformation rates (Table 1) are estimates.

The maximum predicted values of deformation within the concession boundaries for identification of rock salt and in the area of salt galleries are shown in Table 1. They refer to the currently-specified operational goals for 2016.

TABLE 1

Predicted maximum values of deformation in salt pits (2016) (Popiołek, Kłeczek et al., 2011)

Deformation rate	***a* = 0.75**	
	present excavations	**Excavations in the upcoming concession**
w [m]	1,8	1,9
ε_{max} [mm/m]	7,0	9,5
ε_z [mm/m]	3,5	5,5
T_{max} [mm/m]	9,5	10,0
U_{max} [m]	0,55	0,65

The use of ore deposit could have caused a subsidence in salt galleries of 0.8 m to 1.2 m, and the maximum values occur in the peripheral (north) parts of salt pits. In addition to existing excavations, subsidence in the concession area may reach a value of $W = 1.4$ m.

Further exploitation of copper deposits will increase the value of subsidence $w = 1.9$ m (proposed exploitation in 2013-16 of the deposit with thickness $g = 2.6$ m).

In 2010, the slope in the area over the edge of the exploitation region for the copper deposit was at $T_{max} = 7.5$ ¸ 9.5 mm/m. Further exploitation of the deposit will not result in a significant increase in these values ($T_{max} = 10.0$ mm/m), only a change in their location within the salt pits.

Horizontal displacements in salt deposits should not be greater than $U_{max} = 0.5$ m in the coming years and will increase as a result of continued exploitation of the ore body to $U_{max} = 0.65$ m.

The maximum values of horizontal deformations occur in the mining area 1 and are equal to $\varepsilon_{max} = 9.0$ mm/m. These values are so large due to the shape of the mining area with a width similar to a dangerous belt which is $d = 130 \div 150$ m. Plans for subsequent excavations under the salt pits should avoid support pillars and excavation areas of the above width. Currently, the value of horizontal deformation in the area of salt galleries should not exceed $\varepsilon_{max} = 6.0$ mm/m. Further excavations in the copper ore deposit will result in horizontal deformations with similar values.

Vertical deformation which are of some significance for the scope and rate of convergence of salt pits should not exceed $\varepsilon_{z\_max} = 5.0$ mm/m and will increase with further exploitation to $\varepsilon_{z\_max} = \pm 5.5$ mm/m. Maximum values can be expected in the region over the narrow exploitation areas or in the corner of the area, or the space with non extracted copper ore. For existing salt pits, these values should not exceed $\varepsilon_{z\_max} = \pm 3.5$ mm/m.

The above values of deformation rates are determined by the parameter $a = 0.75$ and they are predicted limits. They should not significantly affect the stability of the salt pits. However, they may have an impact on the pits through a small additional increase in the convergence of excavations or increased loosening of layers of rock. In the case of machinery and production lines in specific salt pits, we should consider whether the above values will be important for their proper functioning.

Currently, KGHM Polska Miedź S.A. has a license to exploit copper ore deposits until 2063. Mining projects provide for excavation of the deposit in the area under the bed of salt in the "Bądzów" region in the period until 2040, with a constant thickness of the mined deposit (Development plan for "Bądzów" deposit, 2012). It can therefore be assumed that there will be deformations and displacements in the bed of salt with the maximum rates similar to those in Table 1.

5. Impact of Exploitation of the Bed of Salt on the Excavations in the Copper Ore Deposit

This problem was widely discussed in the paper (Popiołek Kłeczek, 2011). The basis for the considerations was the vertical and horizontal range of the secondary effects of stress in salt pits based on analytical solutions verified by numerical methods (Jing, 2003). We adopted the plan for an elementary area of exploitation of the salt deposit using a pillar-chamber system (PZZ for the salt deposit) and the corresponding geomechanical properties of rocks.-

As a result of analyses, it was determined that increased vertical stresses, which may affect the excavations in the bed of copper ore, reach up to 70 m below the bottom of salt chambers. However, in relation to horizontal stresses, the range is lower and is approximately 50 m from the sidewall of the mining area.

The risk analysis made use of contour maps of the top part of the copper ore body and the bottom layers of rock salt. On this basis, we developed a baseline map of the vertical distance between the top part of the copper ore deposit and the bottom lowermost salt pits (Fig. 3).

The analysis of the baseline map shows that the potential threat of increased deformation occurs only in the northern and southern parts of Bądzów salt deposit, which may require appropriate coordination of both excavations and is easy to eliminate by first mining the copper ore deposit at a vertical distance of less than 70 m.

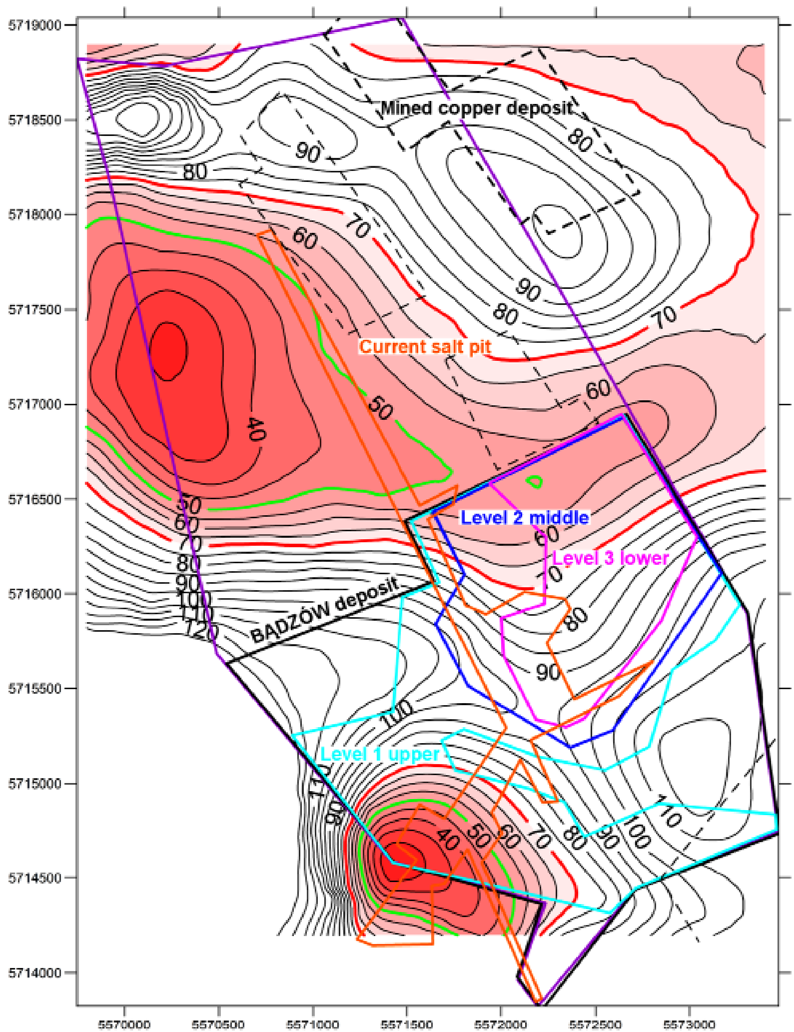

Fig. 3. Baseline map of distance between the top part of excavations in the copper ore deposit and the bottom part of excavations in the bed of salt (Popiołek, Kłeczek et al., 2012)

6. Threats to the Surface of the Land and Structures Due to Exploitation of Copper Ore and Rock Salt Deposits

Chapters 4 and 5 show mutual threats of salt and ore workings. This chapter presents the threats of simultaneous exploitation of both deposits. At present, the time periods for conducting mining operations have not yet been finally determined. In this situation, in the first place (as most likely), we will present the threat to the land surface due to mining of the copper ore deposit. This was drawn up with the participation of the authors for the current concession for the exploitation of copper ore by KGHM Polska Miedź S.A. for 2013-2063 (Popiołek et al., 2011).

Figure 4 shows the results of land subsidence prediction and categories of mining areas, which illustrate the threats to surface structures throughout the period of the current concession. In the area of the proposed "Bądzów" salt deposit, we expect land subsidence of up to 2 meters. The mining area categories should not be higher than II. This does pose a more substantial threat to most existing surface structures.

The prediction of displacements and deformations for the salt deposit were made in 2012 for three variants, assuming different degrees of backfilling excavation voids (Hejmanowski et al., 2012). As a result of detailed analyses, we adopted the option of backfilling all the salt excavations to about 80%. The prediction was carried out under the assumption of an identical disper-

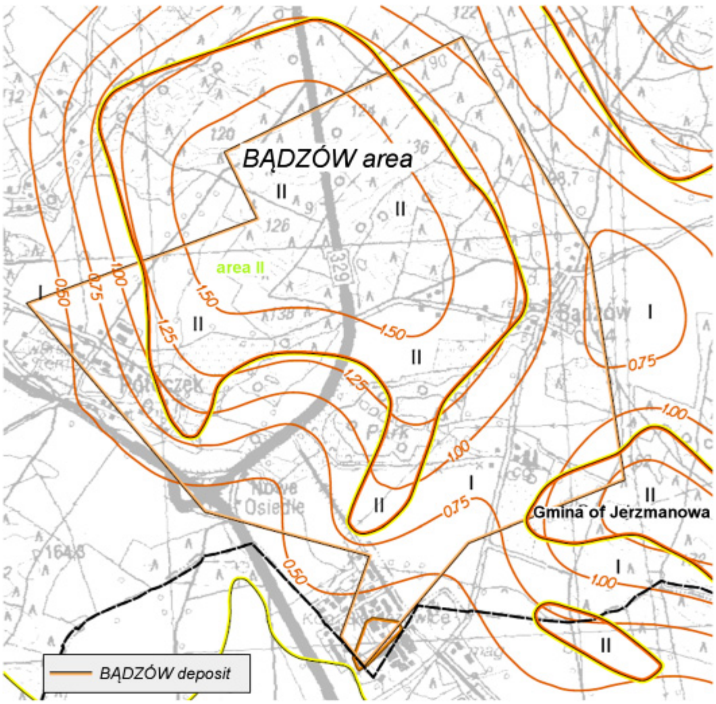

Fig. 4. Prediction of land subsidence and mining area categories due to exploitation of the copper ore deposit in the area of „Bądzów" salt deposit, according to the current concession for 2013-2063 (Popiołek, Kłeczek et al., 2012)

sion of impacts as for the impacts of mining the copper ore deposit (tgβ = 1.5). Target vertical displacements due to mining of the salt deposit are projected to range up to 3.25 m (Fig. 5). It should be noted that the period of disclosure of the impacts, until the above maximum value is achieved, assuming typical rheological properties of rock salt, can be up to several hundred years. Over the next 50 years, the impacts of mining the salt deposit should not exceed the maximum subsidence in the range of up to 2.0 m.

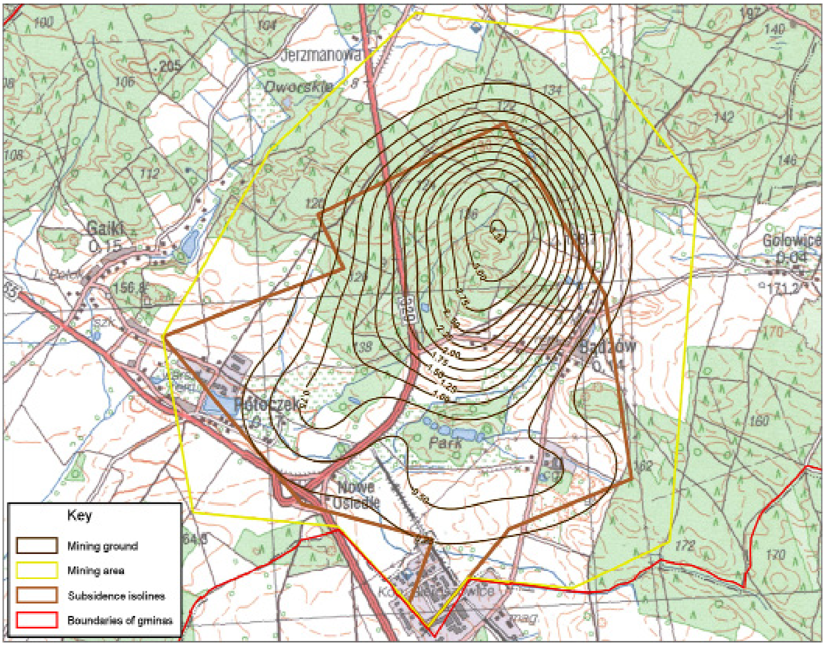

Fig. 5. Maximum target subsidence projected due to exploitation of the salt deposit (Hejmanowski et al., 2012)

To complete the picture of threats to land surface, we made a forecast for simultaneous mining of the two minerals. We took into account the temporal coordination of extracting both the copper ore and the salt deposit (Hejmanowski et al., 2012). As a result, we expect maximum subsidence in the range of up to 4.40 m (Fig. 6). It should be added that such impacts will be established on the surface no earlier than in 200 years. According to the schedule of mining operations, the first to reveal itself will be the impacts of mining the copper ore deposit; the mining of salt deposit and the subsidence will occur much later.

The resulting combined subsidence basin will be a local displacement field, generating surface deformations. Analysis of the land category allowed for the determination of threats to the surface. It was found that during mining of both deposits the threat to the surface will not exceed the upper limit of the III category of the mining area. The maximum values of horizontal deformations (extreme in time) should not exceed 4.1 mm/m, and inclinations should not exceed 6.5 mm/m (Hejmanowski et al., 2012). For developed and protected areas we do not expect Total impacts exceeding category II of the mining area. The largest deformations are expected only in forest

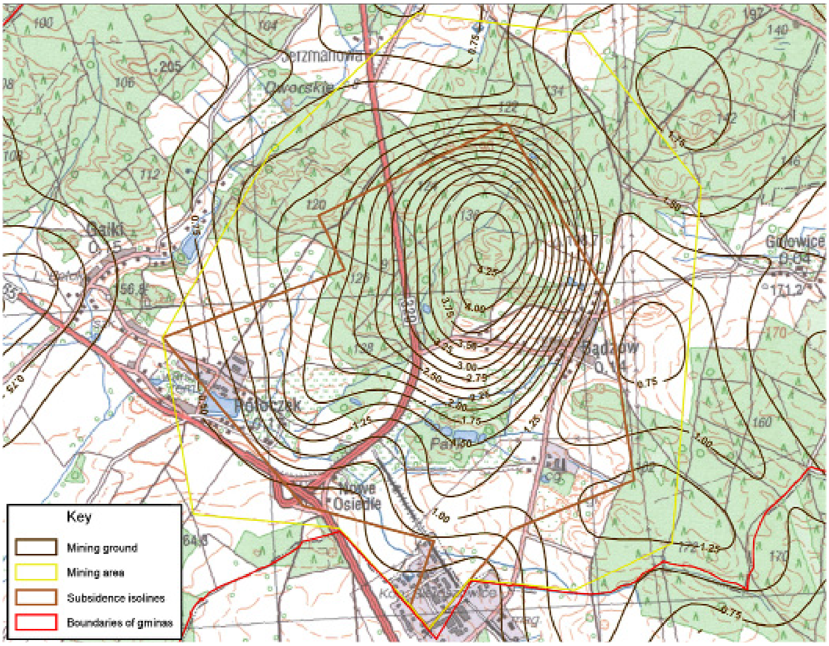

Fig. 6. Total impacts of mining copper ore and rock salt on the surface of OG „Sieroszowice“ (Hejmanowski et al., 2012)

areas (undeveloped). Given the rheological properties of rock salt, disclosure of impacts over the long term and stress relaxation in individual elements of buildings and technical infrastructure, it should be considered that harmful effects will not exceed impacts of the II category of the land.

7. Summary

The simultaneous mining of copper ore and rock salt in LGOM, and particularly in the "Sieroszowice" mining area, gave rise to a detailed diagnosis of mutual impacts of the operation in terms of mining safety and protection of the surface.

The considerations and analyses were based on predictions of mining the copper ore deposit on salt pits and vice versa. Analyses were carried out in relation to the plans for further extraction of copper ore under the new concession for KGHM Polska Miedź S.A. for 2013-2063 and the projects for exploitation of „Bądzów“ salt deposit in the upcoming application for a concession.

With regard to reducing the harmful effects of the continuous deformation of rock mass on salt pits and ore workings, we found that exploitation of the ore body should not be carried out at a distance from active excavation chambers of lower salt less than the vertical distance between the bed of salt and the copper deposit. This will allow for elimination of the impact of significant deformations caused by the exploitation of copper on the chambers in the bed of salt. The current plan for mining of the „Bądzów“ salt deposit on the third level leads to the conclusion that until 2021 the safe distance will be maintained. In subsequent years, maintaining the distance will be more difficult, but feasible.

The most important results of the foregoing considerations can be summarized in the following conclusions:

1) the direct impact of mining the copper ore deposit on excavations in the bed of salt (chambers) is considerable. Estimated rates of displacement and deformation suggest that copper ore and salt should not be mined simultaneously within the range of their direct impact. Until 2021, according to the schedule proposed in the Deposit Management Plan, this condition can be considered fulfilled. In the following years, this condition should be taken into account when planning exploitation of the salt deposit.
2) salt exploitation may adversely affect mining of ore deposits. The range of this impact for the "Bądzów" deposit is set at 70 m for the vertical component and 50 m for the horizontal component. The current operating plans for the ore and salt deposits satisfy the condition of safe vertical distance.

In summary, due to the considerations and analyses, we think it is advisable to continue monitoring the interaction of copper ore and rock salt mining, as well as their combined effect of the surface.

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