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Izlaganje sa znanstvenog skupa

THE IMPROVEMENT OF THE EXCAVATION METHODS IN BAUXITE DEPOSITS

Borislav PERIĆ, Slavko VUJEC, Robert ZVEŽINA

Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Pierottijeva 6, YU 41000 ZAGREB

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The underground bauxite excavation in Yugoslavia is getting more important recently due to gradual exploitation of shallow deposits. The main excavation method is sublevel caving method. That technology of exploitation is characterized by high excavation loosses reaching even to 50% due to mixing of bauxite with waste. By beds with competent limestone roof which are not liable to direct caving are formed unplanned open spaces so the work safety is often dangered by sudden caving. That was the reason for carrying out the observations in situ and investigations on mathematical models to define boundary of excavated space stability. This investigation were the basis for the new conception of further excavation of the »Jukići–Didare« mine with the application of even three exploitation methods maximally adapted to the characteristics of the remaining part of deposit.

Ključne riječi: Boksit, Podzemna eksploatacija boksita, Podetažna otkopna metoda

Zbog postupnog iscrpljivanja plićih ležišta, jamska proizvodnja u SFR Jugoslaviji dobiva sve više na važnosti. Podetažna otkopna metoda predstavlja osnovnu metodu. Karakteriziraju je visoki otkopni gubici i do 50% zbog miješanja boksita s jalovinom, dok se kod ležišta s čvrstom neposrednom krovinom stvaraju veliki otvoreni otkopani prostori koji zbog opasnosti od iznenadnog zarušavanja ugrožavaju sigurnost rada. Da bi se definirala granica stabilnosti takvih prostora obavljena su opažanja in situ i istraživanja na matematičkim modelima aplikacijom metode konačnih elemenata, na osnovi kojih je postavljena nova koncepcija daljnjeg otkopavanja jame Jukići–Didare, Dalmatinskih rudnika boksita – Obrovac, uz primjenu čak tri otkopne metode maksimalno prilagođene karakteristikama preostalog dijela ležišta.

Introduction

Bauxite exploitation in this country has a very long tradition. Still in the last century bauxite was mined in Istria, where it was used as a raw material for alum production (D'Ambrosi, 1955).

The initial production in aluminium industry started also in Istria 1914 and developed later in the areas of Drniš.

At the beginning being only of small–scale and local significance, not until after the World War II the production was intensified parallelly to the rapid development of aluminium industry in our country. Nowdays, our country with its annual production of cca 3,1 million tons is on the second place in Europe and on the seventh in the whole world.

Open pit exploitation is still dominant in the production structure, but utilizing succesively more shallow deposits lately, underground production on is coming into its own, so that its share of 20% today is planned to grow to 50% in 1995. Capacity and structure of bauxite production in our mines are presented in Table 1 (Vujec, Perić, Zeljković (1989).

In other European bauxite–producing countries (USSR, France, Hungary and Greece) underground exploitation is mostly applied, while the biggest world producers (Australia, Guinea, Jamaica, Brazil a.o.) use exclusively open pits.

Rapid growth of bauxite underground exploitation in this country unavoidably requires more intensive investigation in order to optimize the technological process and to improve the level of technological, safety and economic parameteres of the production. A special significance in this sense have investigations for the improvement of excavation method, which has not given satisfying results in practice so far, but it has a deciding impact on the succes of underground minig, since 70–90% total mine production is obtained by excavation.

Table 1. *(Tablica 1)*

BAUXITE MINES *(RUDNICI BOKSITA)*	Total production in 1988. *Ukupna proizvodnja u 1988.* t	Underground production in 1988 *Jamska proizvodnja u 1988.* t	Share of underground production in 1988 *Učešće jamske proizvodnje u 1988.* %	Planned share of underground production in 1995 *Planirano učešće jamske proizvodnje u 1995.* %
Vlasenica	1 099 105			
Mostar	457 710	89 033	19.45	50
Jajce	230 801	179 000	77.56	80
Nikšić	870 000	283 500	32.59	50
Obrovac	181 025	73 600	40.65	63
Bosanska Krupa	28 696	12 046	41.98	50
Pomgrad – Split	46 499			
Rovinj	101 010			
Kosovo	91 000			
Total *(Ukupno)*	3 105 846	637 179	20.51	50

Tasks of the investigation

In our bauxite mines with underground exploitation, sublevel caving method is the basic method, applied in several similar variants depending on the natural characteristics of individual deposits and on the mechanization of a technological process. It is designed only for excavation technology with caving of roof sediments, because the modification of this method with open stope in forms developed by other metal deposits does not corespond to the characteristics of bauxite and accompanied sediments. This means, that these sediments according to their physical–mechanical properties are not suitable to form larger open spaces, safety pillars and a system of ore chutes; it is neither possible to build safe mine workings in Yugoslav bauxite without supporting.

Excavation technology with roof caving requires strict and immediate caving successively after excavation, whereby the pressure stresses are decreased and conditions for safe work are created (Figure 1.).

Such a procedure can be performed only by the deposit where marly or other less firm sediments are located in immediate roof, which does not occur in most our deposits, especially in the areas of Bosnia, Herzegovina and Dalmatia, where immediate roof is composed of competent limestone sediments. By excavating of these deposits direct caving of the roof is not attained, and open spaces covering even several thousand m^2 with the span to 60 m are uncontrolled formed. This condition does not corespond to technological condition of sublevel caving method application, because by such undefined criteria of stability it necessarily comes to sudden and uncontrolled large–scale caving which threatens the work safety. Therefore, bauxite excavation by sublevel caving method with open spaces is applied in many of our bauxite deposits is not the result of a planned application with estimated and developed technological parameters, but it can rather be defined as an unavoidable consequence of irregular caving of roof sediments.

From technical, economic and safety point of view the application of underground method has not given any satisfying results up to now. Excavation in the conditions of direct roof caving is characterized by rather low recovery coefficient and high losses even 50%. By the excavation in conditions of open spaces formed due to irregular roof caving, very good technologic and economic parameters are obtained, but work safety is not a satisfying level (P e r i ć, 1988).

In foreign bauxite mines with underground exploitation, except the Hungarian mines problems of bauxite excavations are successively solved by the

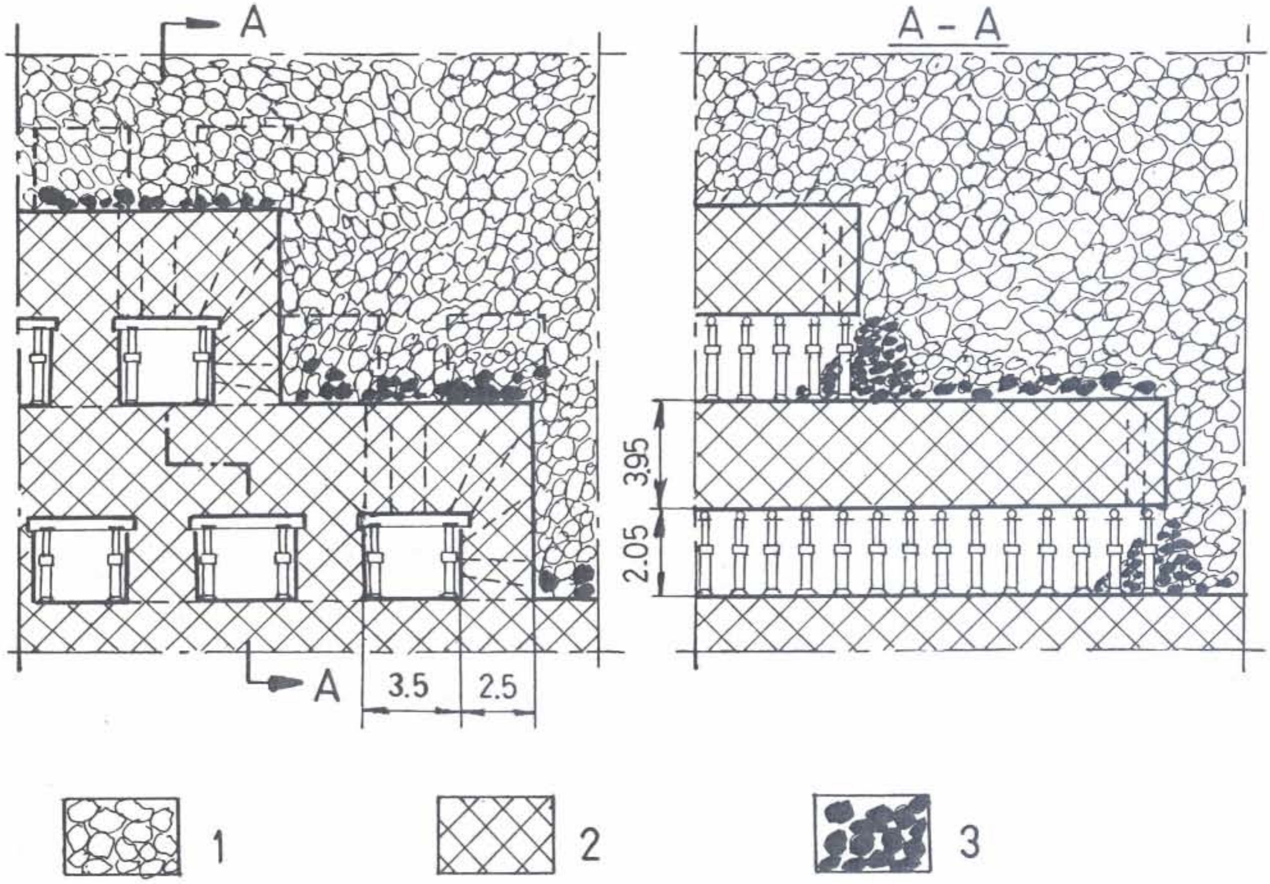

Fig. 1. Sublevel caving method, mine »Trobukva«, bauxite mines Posušje

Sl. 1. Podetažna otkopna metoda sa zarušavanjem krovine u jami »Trobukva« – Rudnici boksita Posušje

L e g e n d:
1 – caved roof
2 – bauxite
3 – blasted bauxite

L e g e n d a:
1 – zarušena krovina
2 – boksit
3 – odminirani boksit

application of several variants of room–and–pillar method, whose application is enabled by favourable natural characteristics of bauxite (sligth thickness, firm roof sediments and bauxite a.o.). Sublevel caving method has remained only in a few deposits with unfavourable characteristics for the application of room–and–pillar method.In Hungarian bauxite mines where roof sediments due to slight strenght are inclined to be directly caved, there are indentical problems to those ones in our deposits with similar characteristics. In that country intensive investigations are carried out in order to improve the underground method or to replace it with some more rational method.

The achievements of foreign mines in a bauxite excavation cannot be more frequently used in our deposits because of great differences–considering natural characteristics. That is the reason why the investigation for the improvement of the existing sublevel caving method in our deposits needs a special approach, which has to be based on a detailed study of natural characteristics and on the adaptation of excavation method to the deposit conditions.

Geological and geotechnical characteristics of the bauxite deposits

Bauxite deposits in our country occur in the Dinarides in seven basic stratigraphic horizons ranging from the upper Triassic to the Neogene (Sakač, 1988). Each of these horizons contains bauxites with certain characteristics, varying according to the type of occurrence, forms and dimensions of a deposit, depth of bedding, mineral–chemical composition of bauxites, petrographic composition of the roof, and the tectonics and hydrology of orebearing area, all of which indicate the economic value of bauxite and the conditions of exploitation. According to such a large number of stratigraphic horizons and varyity of bauxite deposits, the Dinaric area is unique in the world.

Bauxite deposits have a particularly irregular form rezulting from the complex genesis, irregular karst forms of paleorelief in the period of sedimentation and posture tectonic displacements. Most frequent forms are irregular lenses and pockets, and somewhere the deposits have forms of a bed with scattered thickenings and grooves.

Contact of the bauxite with the floor is irregular with frequent presence of footwall pyramids with changeable hardness and penetration depth in bauxite. The roof sediments lay discordantly on the footwall sediments and the contact plane is rather regular.

The bauxite footwall is principally composed of firm compact carbonate sediments suitable for the location of underground working rooms. Petrographic composition of roof sediments is mostly very complex and characterized by frequent lateral and vertical exchanges of different sediments composed of marls, limestone breccias, conglomerates, limestones, clays a.o. (figure 2.).

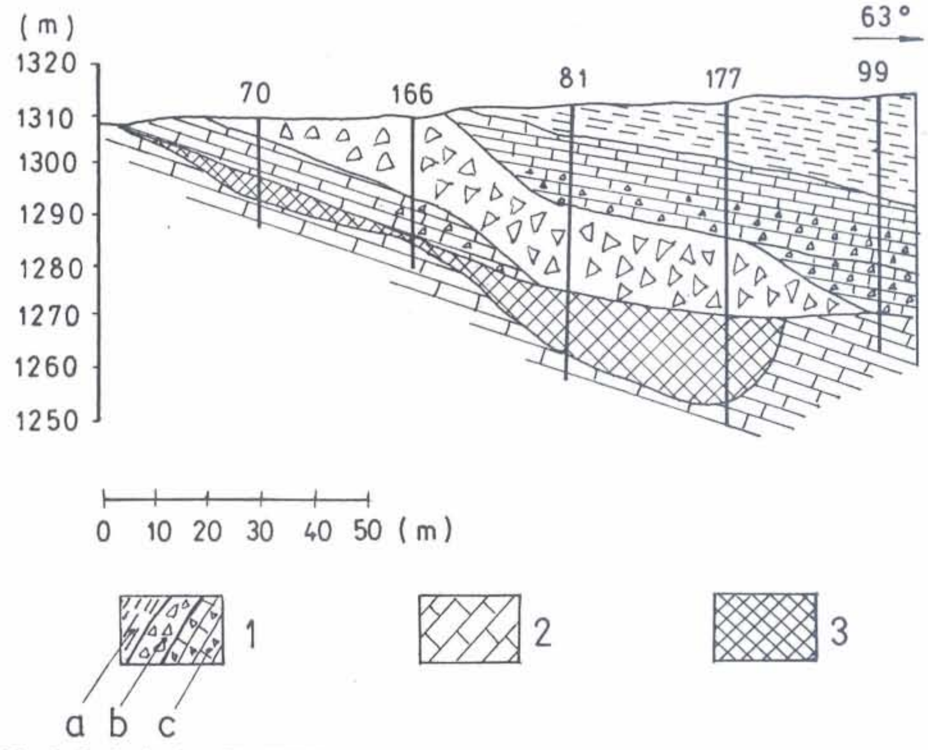

Fig. 2. Geological profile III-III' through the deposit L-6, bauxite mine »Crvene stijene«, Bauxite mines Jajce (After Sakač, 1987)

Sl. 2. Geološki profil III-III' kroz ležište L-6, jama »Crvene stijene« – Rudnici boksita Jajce (prema Sakač, 1987)

Legend:
1 – flysch (a-marl, b-breccia, c-calcarenite)
2 – limestones
3 – bauxite

Legenda:
1 – fliš (a-lapor, b-breča, c-kalkarenit)
2 – vapnenci
3 – boksit

Table 2. *(Tablica 2.)*

MATERIAL (MATERIJAL)	*ROCK TYPE (VRSTA STIJENE)*	*Bulk* Density *(Volumna masa)* $\varrho(kg/m^3)$	*Young's* moduls *(Modul elastičnosti)* E(MPa)	*Poisson's* ratio *(Poissonov koeficijent)* ν	*Compressive* strength *(Tlačna čvrstoća)* δc (MPa)	*Cohesion (Kohezija)* c (MPa)	*Angle of* friction *(Kut unutrašnjeg trenja)* φ (°)
M1	footwal foraminifers limestone *(podinski foraminiferski vapnenac)*	2683	5856	0,25	112,5	11	55
M2	BAUXITE *(BOKSIT)*	2700	3526	0,25	35,9	2	52
M3	clayey limestones *(glinoviti vapnenci)*	2291	1531	0,35	45,9	4–8	55
M4	conglomerates and limestones in exchange *(konglomerati i vapnenci u izmjeni)*	2614	5334	0,32	71,9	9-10	52
M5	limestones *(vapnenci)*	2565	8918	0,40	73,3	10	53
M6	conglomerates *(konglomerati)*	2629	3543	0,25	67,9	9	51

Geomechanical properties of roof sediments range widely depending on the properties of individual petrographic members (Table 2). Considering these properties of roof sediments one should particularly have in mind the arrangement, thickness and the way of exchange of these members. Bauxite is characterized by a relative high density (higher than that of accompanied rocks) and the angle of friction, and rather low value of compressive strength and cohesion. In all bauxite deposits there are several families of discontinuities, and among structure elements of accompanied sediments cleavage planes, fractures and faults are specially significant.

Improvement of excavation methods

The investigations and experiences concerning bauxite underground exploitation up to now, obviously indicate that the excavation is really not performative with only one excavation method, because there is no such a universal and flexible method which would be successfully adapted to so different and variable natural characteristics being present in our deposits. That is the reason why the sublevel caving method is not everywhere successfully applied, although in expert literature it is treated as very adaptable to various irregular forms of metalliferous and nonmetalliferous deposits.

Improvement of the existing sublevel caving method, as well as the choice of other more suitable methods in bauxite deposits should be necessarily based on the previous definition of technological approach with open spaces, which should provide the roof control i.e. safe working conditions.

One of the most complex problems in mining science and practice is the definition of roof control procedure, respectively the optimal solution of the open spaces, treatment as a principle factor for a safe work and correspondingly the choice of excavation method and its parameters. All of them depend on many, often not enough known values connected with natural properties of a deposit and the possibility of their coordination with technological requirements of the excavation method. For successful application the excavation method must, in addition to safe working conditions, also provide favourable technologic and economics parameters. Such an approach to the investigation for the improvement of sublevel caving method needs multiple study of the deposit, using scientific methods and technical accomplishment from different areas e.g. geological explorations, rock mechanics, underground exploitation of various mineral raw materials, optimalization of mining mechanization and equipment a.o. Beside research work it is necessary to use the existing experiences and experimental examinations in the laboratory and directly in deposits.

The disadvantages of sublevel caving method in bauxite deposits have led to the investigations into two directions:

- the increase of deposit output and the improvement of technological and economic parameters in excavation in conditions of regular and immediate roof caving,
- the improvement of work safety by adequate technological solutions of the excavation method in deposits with firmer roof sediments.

Investigations in the conditions of excavation with regular and immediate roof caving

The recovery coefficient in underground exploitation in our bauxite deposits is considerably lower compared to other metalliferous deposits and ranges mostly from 0,50–0,70. Such a condition results from many unfavourable factors related to complex natural characteristics of the deposit and from technological processing requirements, which have a specially big infulence on the loss creation in excavation process. Namely, due to damaging impact of calcium in bauxite processing, pollution of bauxite with waste (max 1,5% CaO) is not allowed. As bauxite is not subjected to subsequent separation, loading has to be stopped during excavation if it comes to the least interference of waste. Therefore in deposits where the roof is caved immediately after the excavation, there are losses to 50%. To achieve necessary economic effects, the modern underground bauxite exploitation is oriented to mass production using complete mechanization of the whole technological process, wherewith the selective loading is almost completely excluded at stopes. Losses decrease the reserves and the deposit exploitation duration and essentially influence the productivity decrease of a stope and the productivity of labour, which increases the costs of investments and preliminary works as well as material costs per product unit.

The decrease of excavation losses must be accomplished primarily by the improvement of excavation method, but with obvious tendecies of underground production increase, and a better bauxite valorization. The introduction of bauxite separation procedure is becoming a reality both in research and in practice.

The improvements of sublevel caving method in order to decrease the excavation losses are investigated today in foreign and to a certain degree also in our mines by the following treatments:

- finding the optimal parameters of excavation method depending on natural characteristics of deposits, with wider application of roof bolting,
- introduction of the Swedish variant in the deposits with greater thickness, based on the coordination of parameters of excavation with the postulates of the theory of gravity flow of blasted ore on the stope,
- application of so called »temporary small chambers« in bauxite, which prevents interference of bauxite with waste in the first phase of loading at the stope,
- separation of waste and ore by nets, plates a.o.

Investigations in the deposits with competent roof sediments

Investigations for the improvement of excavation technology and work safety in the bauxite deposits with competent roof sediments are based on a detailed study of natural characteristics of the deposits and of the adaptation of excavation methods to deposit conditions, tending to leave open spaces to established stability limits.

The definition of stability limits is based on the estimations and distributions of stresses and displacements round the open excavated space for different deposit conditions and different situations occurring at the excavation, performed on mathematical models formed according to characterized geological profiles through bauxite beds. Such investigations were carried out at the Faculty of Mining, Geology and Petroleum Engineering on several bauxite deposits in the areas of Jajce and Obrovac, where the problem of irregular roof caving was most apparantly expressed. Stability conditions were considered by the function of structure and physical–mechanical rock properties and the dimensions and space location of open excavated spaces, and the estimates were made by the application of finite element method.

Since it is not realistic to inculde into mathematical models all the irregularities resulting from complex and variable natural characteristics of bauxite deposits as discontinuities, unhomogenity of materials a.o., the results from estimations were analised and corrected with additional knowledge about the properties of a concrete deposit as well as the experiences from the deposit excavation with similar characteristics.

Results from the investigation of the deposit »Jukići–Đidare« – Bauxite mine Obrovac

Based on the investigations carried out in »Jukići–Đidare« deposit a new conception of further excavation was established (S. Vujec et al. (1985), applying even three excavation methods maximally adapted to characteristics of the remained part of bauxite deposit and to technological requirements for excavation. Such an approach gives real assumptions that the continued excavation would, beside the work safety solution, realize also the satisfying appropriate technological parameters of production, and therewith appropriate economic effects.

The »Jukići–Đidare« deposit occupies the area of cca 29000 m^2, its shape is irregular having a lenticular anticlinal shape (Figure 3.)

Sides of the anticline are inclined towards southwest under the angle of 45° and towards northeast under the angle of 65°. The deposit length in the direction southeast–northwest amounts cca 300 m and maximal width cca 200 m. The deposit is situated between the elevations 270 m, and 140 m and in depth below the surface from 30 m to 140 m. Due to its irregular shape bauxite thickness varies considerably from 1.8 to 60 m, with an average of 10.2 m and bauxite concretation of 26.4 t/m^2. According to totally established A+B categories balance reserves of cca 528 000 t bauxite, it belongs to bigger deposits in the area of Drniš. The deposit has been excavated for several years, and the remained exploitation reserves amount cca 138 000 t.

The bauxite footwall is composed of competent foraminiferal limestones and the roof contains carbonate and clastic Promina sediments of the Upper Eocene. In the immediate roof there are marls, marly limestones and conglomerates, and breccias' conglomerates. Geomechanical properties of bauxite and accompanied sediments obtained on the basis of numerous laboratory examinations vary considerably, though the roof sediments are generally characterized by a rather considerable strength (Table 2).

During the excavation in the period between 1981 and 1988 three levels were excavated at the elevations +220, +210 and +200 with sublevel caving method, where the predicted roof caving did not occur, so that open spaces of cca 4080 m^2 entire area was formed. By the narrowing of deposit in the central part, the anticline sides were almost completely devided by nearly equal dimensions of open spaces having 105x35 m and the length of 30 m.

Deposit situation after the excavated three levels is identical to the situation observed at the mathematical model (Figure 4.), obtained by computer estimation, where the condition of stress and displacement in the deposit is presented.

Compression stresses in the upper support (element 360) amount 4.40 MPa and in the lower support (element 251) 4.54 MPa. The zone of combined stresses, where one principal stress is compression and the other tension, covers the entire central part of the roof above the open space, with dimensions 30x36 m. In roof sediments there are no zones of

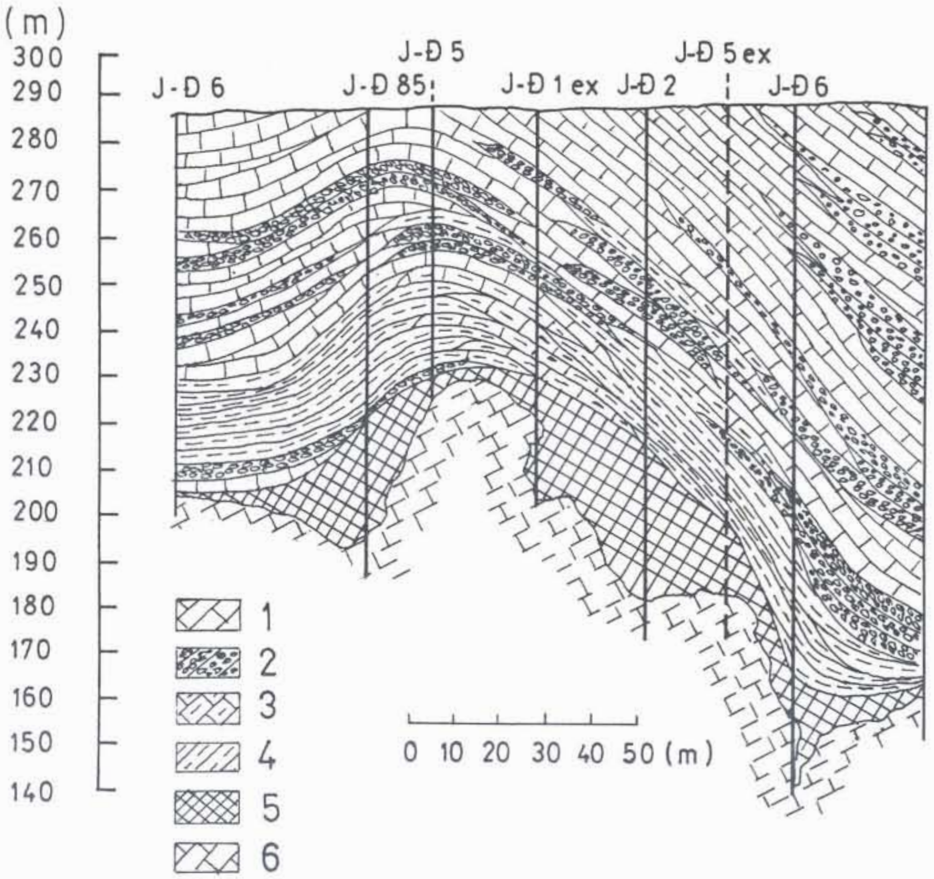

Fig. 3. Geological profile 11 through the deposit »Jukići-Đidare« – Bauxite mines Obrovac (After Eleršek, 1985)

Sl. 3. Geološki profil 11 kroz ležište »Jukići-Đidare« – Dalmatinski rudnici boksita – Obrovac (prema Eleršek, 1985)

Legend:
1 – limestones
2 – conglomerates
3 – clayey limestones
4 – marls
5 – bauxite
6 – Upper Cretaceous limestones

Legenda:
1 – vapnenci
2 – konglomerati
3 – laporoviti vapnenci
4 – lapori
5 – boksit
6 – vapnenci gornje krede

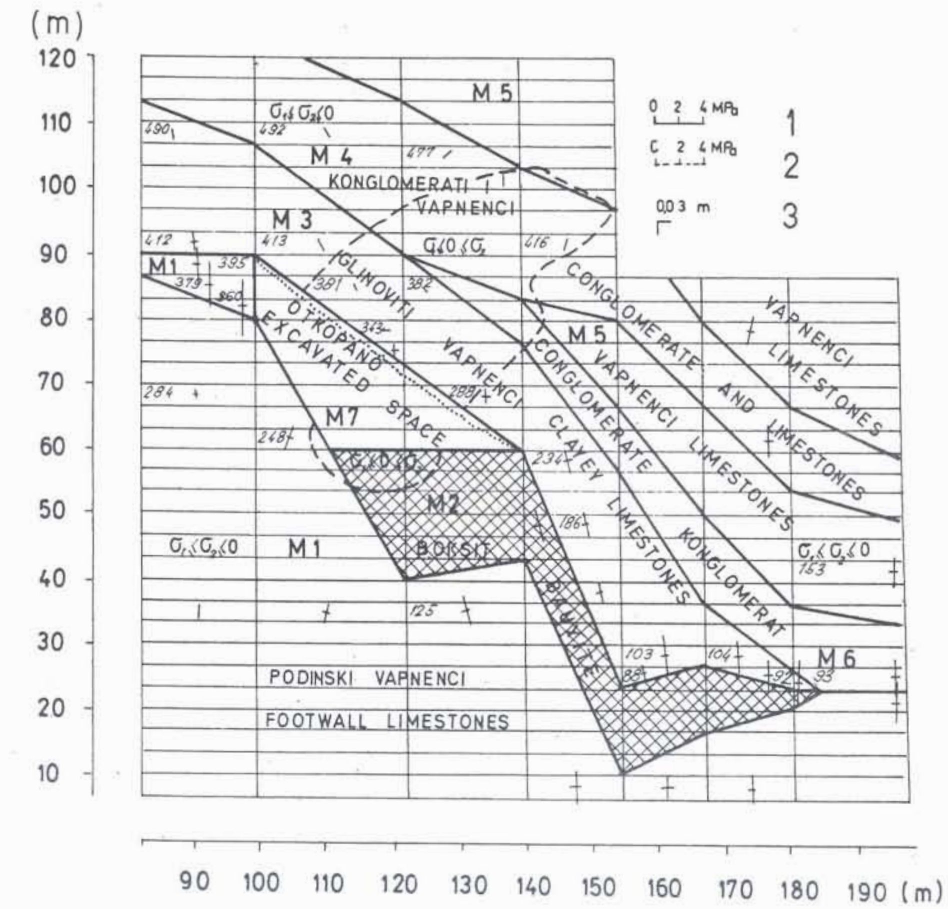

Fig. 4. Disposition of principle stresses and displacements on mathematical model II for the span of excavated space of 50 m (excavated 3rd level), mine »Jukići-Đidare«, Bauxite mines Obrovac

Sl. 4. Raspored glavnih naprezanja i pomaka na matematičkom modelu II za otvor raspona 50 m (otkopana treća etaža), jama »Jukići-Đidare« – DRB Obrovac

Legend:
1 – principle stresses-compression
2 – principle stresses – tension
3 – displacements

Legenda:
1 – glavna naprezanja – tlak
2 – glavna naprezanja – vlak
3 – pomaci

tension stresses in the both principal axes. The differences in roof displacements between the initial state and after the excavation of the 3rd level as observed in nodal points, amount 7–21 mm.

The condition of stresses and deformations in the observed situation of mathematical model, beside the additional knowledge about discontinuity presence, obviously indicates an insufficient stability of roof sediments, as well as real possibilities for their caving. This means, that continued excavation of lower levels with the existing method, beside the increased open spaces, would be risky, because in such conditions a sudden caving would threaten the work safety at stope faces. Therefore, to continue the exploitation of this deposit under the elevation +200, a new excavation technology has been planned on the basis of the following conceptions:

- isolation of working face at the stope from demaging caving effects in the parts of deposit immediately under the existing open space,
- establishing of the principle of obligatory roof control in all excavation phases, in the deposit parts outside the existing open space.

In accordance with such conceptions for the excavation of the remained part under elevation +200, the following methods are accepted:

- sublevel caving method with the protective bauxite layer above stope faces in the southwest side of anticline and in the central part of north east side of anticline, where the ore body settles (is bedded) into depth 40–50 m immediately under the existing open space (Figures 5 and 6),
- sublevel stoping method by restriction of the stope span to the limits of established stability i.e. 25 m in the peripheral steep part of northeast anticline side of the ore body with the thickness over 4 m (Figures 5 and 7),
- room–and–pillar method with subsequent pillar excavation of the northeast anticline side with the thickness to 4 m (Figures 5 and 8).

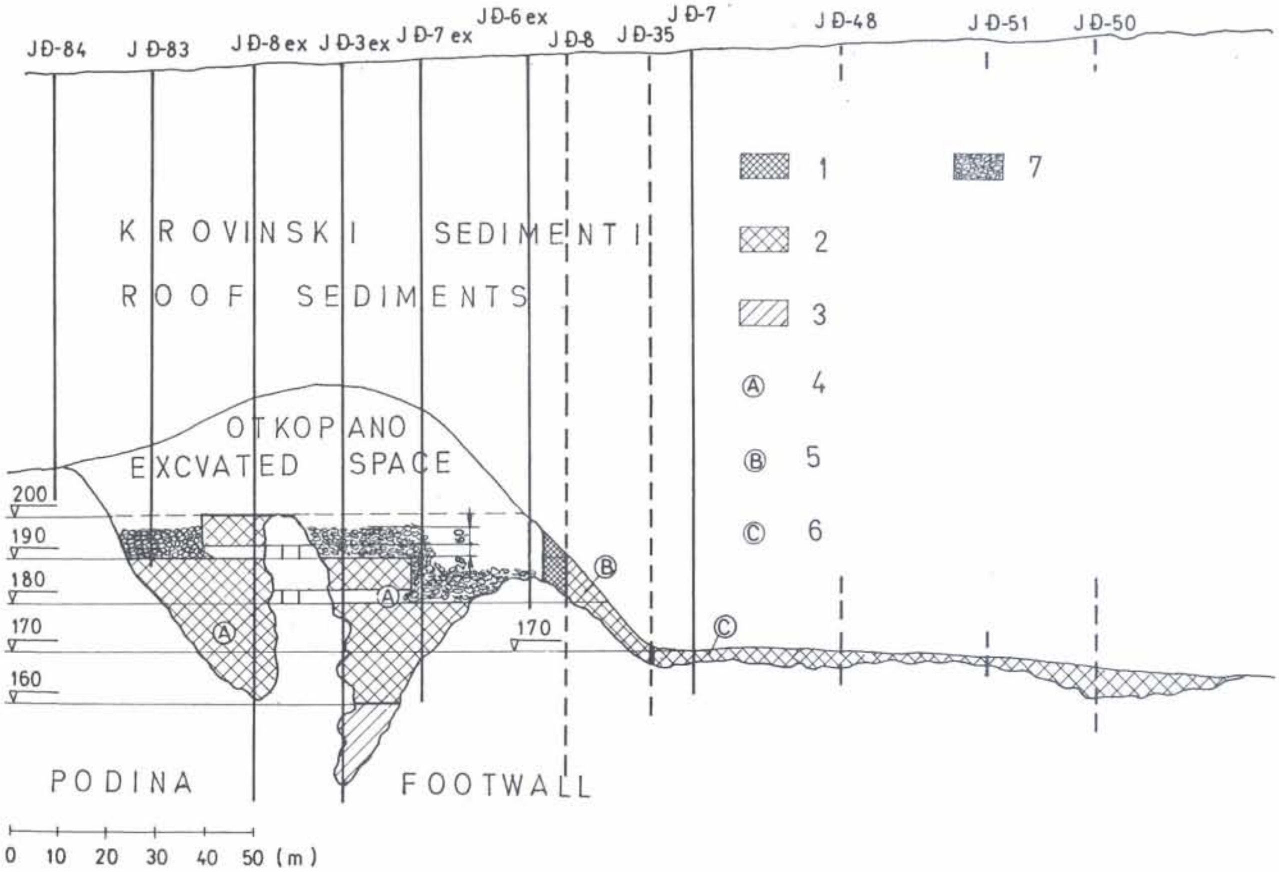

Fig. 5. Excavation methods in remained part of the deposit »Jukići-Đidare« – Bauxite mines Obrovac

Sl. 5. Metode otkopavanja preostalog dijela ležišta »Jukići-Đidare« – Dalmatinski rudnici boksita – Obrovac

Legend:
1 – safety pillar in bauxite
2 – bauxite which is draw up plans for excavation
3 – bauxite which is not draw up plans for excavation
4 – sublevel caving with protective bauxite layer
5 – sublevel stoping method
6 – room and pillar method
7 – protective bauxite layer

Legenda:
1 – sigurnosni stup u boksitu
2 – boksit koji je projektom predviđen za eksploataciju
3 – boksit koji nije projektom predviđen za eksploataciju
4 – podetažna metoda sa zaštitnim slojem boksita
5 – podetažna metoda s otvorenim otkopanim prostorima
6 – komorno-stupna metoda
7 – zaštitni sloj boksita

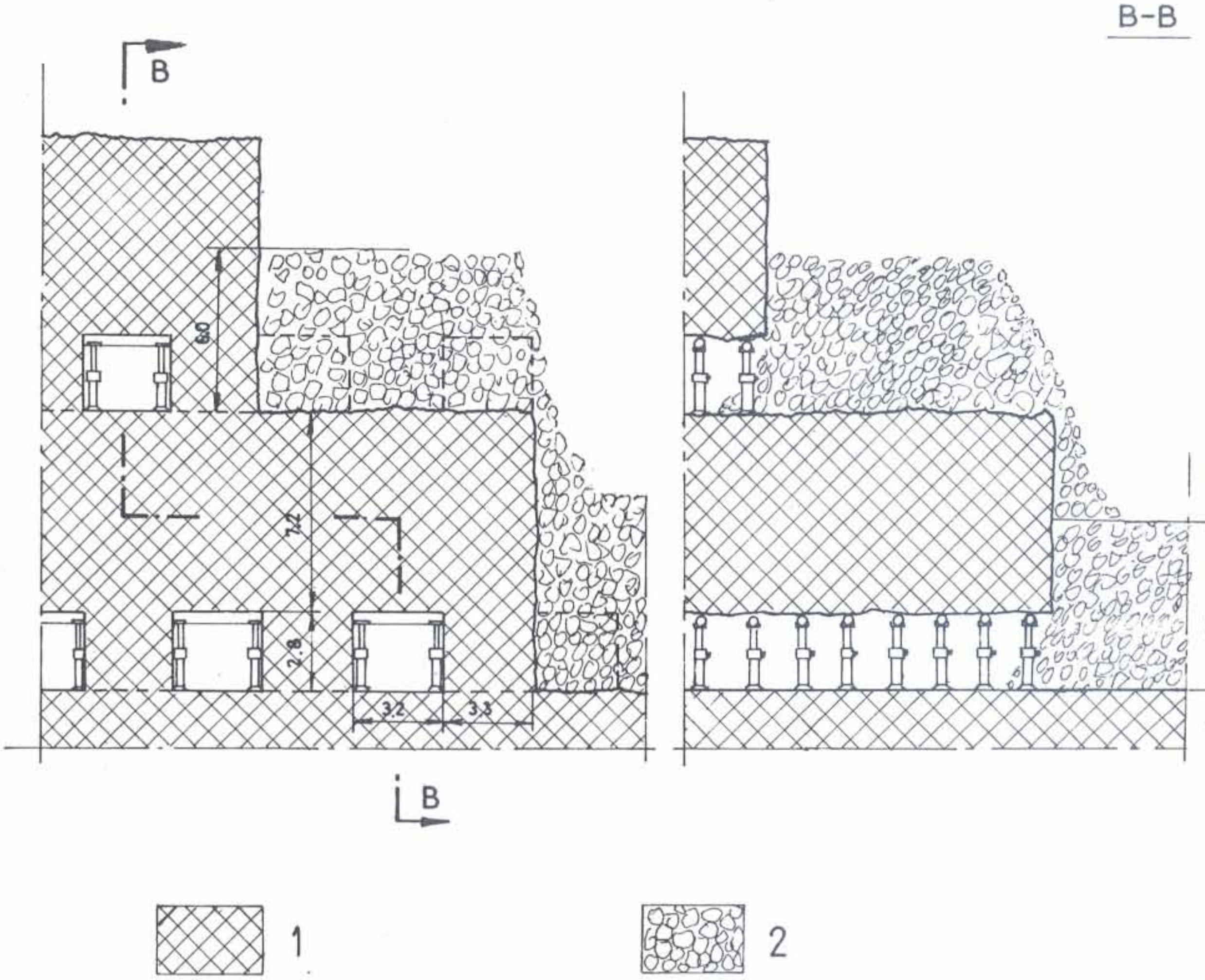

Fig. 6. Parameters of sublevel caving method with protective bauxite layer

Sl. 6. Parametri podetažne otkopne metode sa zaštitinim slojem boksita

Legend:
1 – bauxite
2 – protective bauxite layer

Legenda:
1 – boksit
2 – zaštitni sloj u boksitu

The basic excavation principle, applying the sublevel caving with protective bauxite layer means the formation of protective layer from the blasted ore over the stope faces, which protects the working face from uncontrolled roof caving.

The application of this method is based on the investigation on mathematical models, proved in practice. Namely, on the supporting elements round the open excavated space, only compression stresses are present, increasing proportionally with the increase of span, but even at the largest observed span of 160 m at depth of 150 m they do not exceed the compressive rock strength, which means that no breaking of accompanied sediments or bauxite occur on the supports. Consequently, working face at the stope should be protected only from dropping out of individual blocks and caving of roof masses, which is in the existing situation possible to accomplish only by entire isolation of working surroundings from open space, forming a protective bauxite layer of appropriate thickness. By such a solution, eventual roof caving would not have any direct influence on the working face of the stope, because it will be protected by the protective layer, i.e. isolated from all damaging influences.

In the application of the considered excavation method, a strict technological discipline is necessary at bauxite loading, not to allow the thickness of protective layer to decrease under minimum. The application of sublevel stoping method to the established stability limit is also based on the results from estimations on mathematical models and on experiences from exploitation of the »Jukići–Điđare« deposit as well as of many similar bauxite deposits in our country with firmer roof sediments. It is important, that by stope span which is in this deposit established to the limit of 25 m, the roof stress is characterized by compression stresses of such an intensity which provides stable position related to caving.

This method has signifficant advantages from the technical and economical point of view in relation to the method with immediate roof caving because the stope productivity, labour productivity and mechanization utilization are considerably increased, and the stope losses are decreased, because there

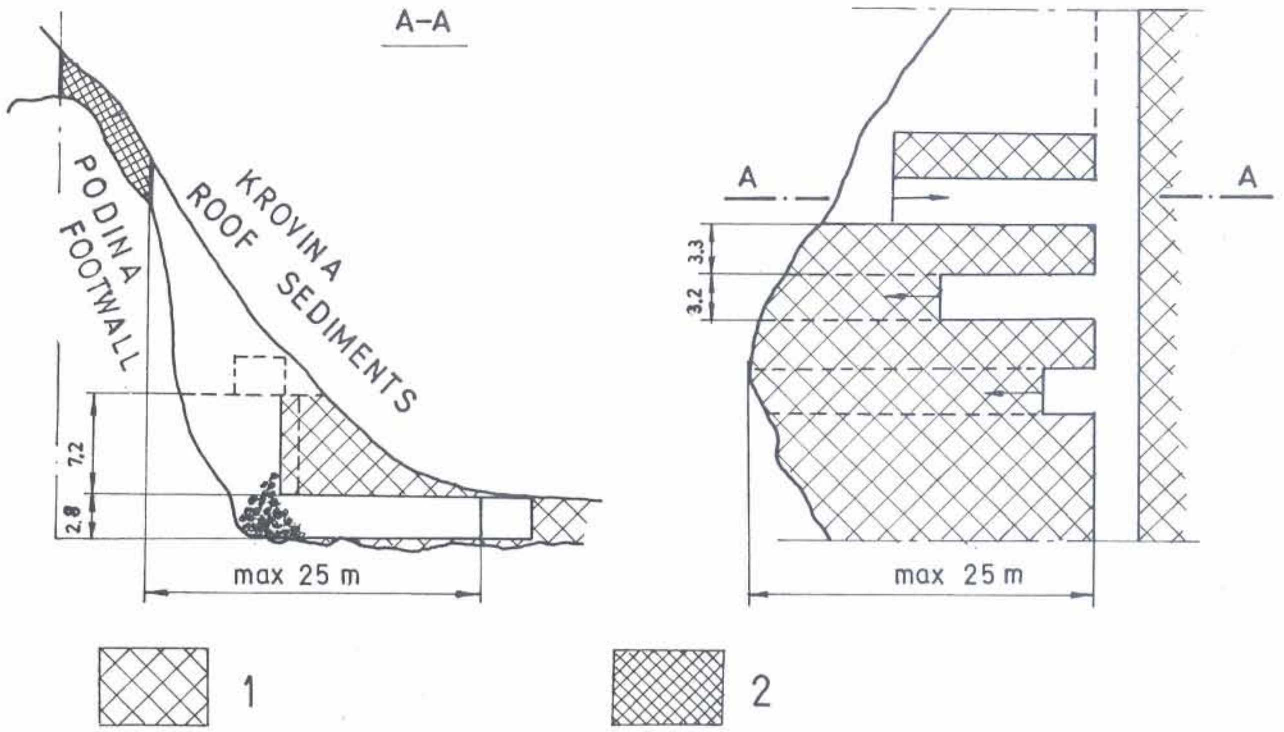

Fig. 7. Sublevel caving method

Sl. 7. Podetažna otkopna metoda s otvorenim otkopanim prostorima

Legend:
1 – bauxite
2 – safety pillar in bauxite

Legenda:
1 – boksit
2 – sigurnosni stup u boksitu

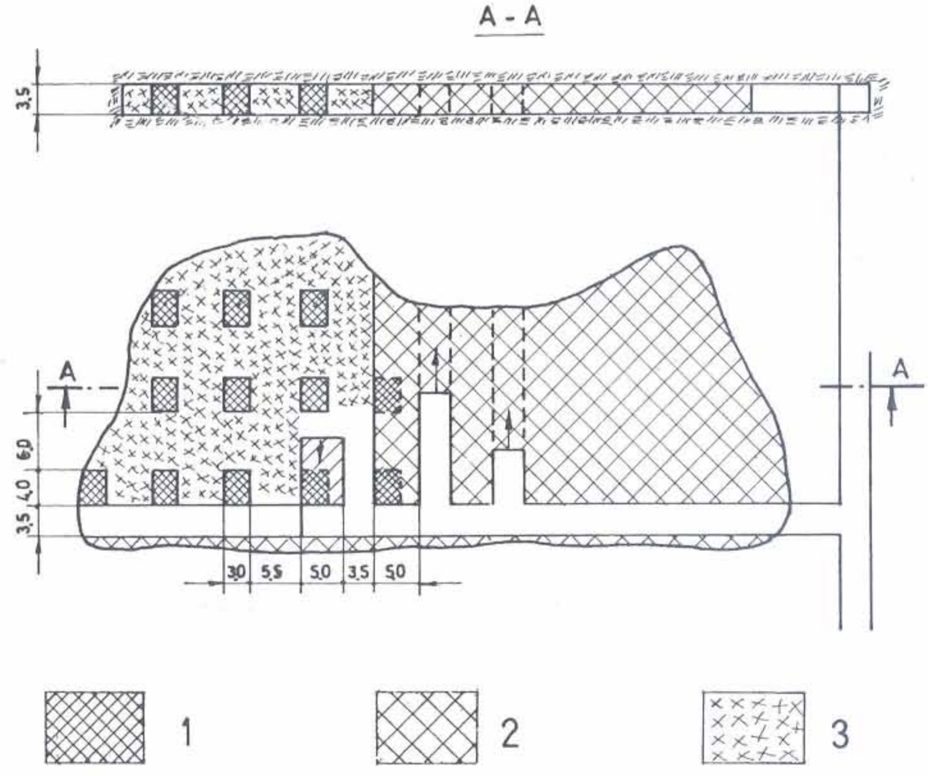

Fig. 8. Room and pillar method

Sl. 8. Komorno-stupna otkopna metoda

Legend:
1 – safety pillars
2 – bauxite
3 – caved roof

Legenda:
1 – sigurnosni stupovi
2 – boksit
3 – zarušena krovina

is no dilution with waste from the roof. For this application an increased technological discipline is also required, considering maximal stope span. Besides, it is necessary to provide additional protective measures at working face to prevent eventual dropping out from the roof of remained bauxite sticked particles or loosened waste particles. Additional protective measures are accomplished by using more frequent control of stope condition, by the application of remote controls for loading and drilling machines, by prevention of entering the excavated space and performing the activities in limit area of the stope drift and excavated space.

The sublevel stoping method in the »Jukići–Đidare« deposit represents in fact a transition form between the sublevel caving with protective bauxite layer above stope and the room–and–pillar method. In favourable parts of the deposit where the stope span does not exceed 25 m, the sublevel caving with protective bauxite layer transforms quickly into sublevel stoping, by loading of the whole bauxite at the stope. The reverse transformation by renewed formation of protective bauxite layer is also simple.

The transformation of sublevel stoping method into the room–and–pillar method is also very simple. If there are slightly inclined deposit parts with the thickness less than 4 m, one would plan the formation of rooms and pillars with the designed dimensions.

The application of room–and–pillar method with subsequent pillar excavation is planned in northeast parts of the deposit with bauxite thickness to 4 m. In this area the deposit is by its larger part spread horizontally or under a slight angle, maximally to 10°. In similar foreign deposits, this variant of the room–and–pillar method is very successfully applied and its introduction in this mine should not cause any considerble difficulties.

The basic principle of the room–and–pillar method application is the performance of drifts (horizontal or inclined) and crosscut, so rooms and safety pillars are formed as protection from uncontrolled caving. Drifts are driven along the entire thickness of an ore body with maximal height to 4 m, width of cca 10 m and roof sediments are strengthened by support. Safety pillars are kept as permanent or temporary with subsequent excavation, and they are dimensioned with the planned purpose on the bases of detailed estimations.

The planned excavation methods are already in the phase of their introduction into the »Jukići–Đidare« mine and as they will be applied for the first time in one mine in Obrovac, i.e. in our country, during the trial period it is necessary to provide a thorough control and additional investigations in all phases of excavation in order to check the established solutions and to acquire new experiences, as well as to make necessary corrections for the improvement of their efficiency.

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Poboljšanje metode otkopavanja u ležištima boksita

B. Perić, S. Vujec i R. Zvežina

Postupnim iscrpljivanjem plićih ležišta, jamska proizvodnja boksita u Jugoslaviji dobiva sve više na važnosti, pa se njezin udio sa sadašnjih 20% planira povećati do 1995. godine na 50%. Takav brzi rast podzemne eksploatacije zahtijeva intenzivnija istraživanja u optimalizaciji tehnološkog procesa, a poseban značaj imaju istraživanja na poboljšanju metode otkopavanja koja u dosadašnjoj praksi nije dala zadovoljavajuće rezultate.

U našim boksitnim jamama osnovnu metodu predstavlja podetažna otkopna metoda koja se primjenjuje u raznim varijantama. Ona je koncipirana isključivo za tehnologiju otkopavanja sa zarušavanjem krovine. Ovakav postupak uspješno se provodi samo u ležištima gdje su u neposrednoj krovini laporovite ili druge naslage manje čvrstoće. Otkopavanje u takvim uvjetima karakterizira zadovoljavjuća sigurnost ali i visoki otkopni gubici koji dostižu i do 50%. Naime, radi štetnog djelovanja kalcija u preradi boksita, maksimalno dozvoljeno onečišćenje boksita kalcijevim oksidom je 1,5%. Budući da se boksit ne podvrgava naknadnoj separaciji, utovar se obustavlja pri najmanjem miješanju s jalovinom. Smanjenje otkopnih gubitaka mora se provoditi prvenstveno kroz poboljšanje metode otkopavanja, ali s izraženim tendencijama porasta jamske proizvodnje, boljom valorizacijom boksita u istraživanju i primjeni postupaka separacije boksita.

Poboljšanje podetažne metode u cilju smanjenja otkopnih gubitaka, danas se u svijetu, a i u našim rudnicima istražuje kroz slijedeće tehnološke zahvate: iznalaženje optimalnih parametara ovisno o prirodnim karakteristikama ležišta uz širu primjenu sidrenja, uvođenja švedske varijante u ležištima veće moćnosti, primjena tzv. »Privremenih malih komora« u boksitu čime se spriječava miješanje boksita s jalovinom u prvoj fazi utovara na otkopu, te odvajanje jalovine i rude mrežama, pločama i sličnim postupcima.

Kod velikog broja naših ležišta, naročito u područjima Bosne, Hercegovine i Dalmacije, neposrednu krovinu čine čvrste vapnenjačke naslage, gdje se ne postiže neposredno zarušavanje krovine, pa se stoga nekontrolirano formiraju otvoreni otkopani prostori površine i po nekoliko tisuća m^2 s rasponom i do 60 m, što neminovno uzrokuje zarušavanje većih razmjera, čime je sigurnost rada na otkopima ugrožena. U svrhu definiranja granice stabilnosti otkopanih prostora, pristupilo se je ispitivanjima na više ležišta u području Jajca i Obrovca, gdje su najviše izraženi problemi neregularnog zarušavanja. Ova ispitivanja obavljena su na Rudarsko–geološko–naftnom fakultetu u Zagrebu, a temeljila su se na proračunima stanja i rasporeda naprezanja i deformacija oko otkopanog prostora za razne uvjete ležišta i razne situacije koje nastaju pri otkopavanju a izvedena su na matematičkim modelima formiranima prema karakterističnim geološkim profilima kroz ležišta boksita. Kako u matematičke modele nije moguće uključiti sve neregularnosti koje proizlaze iz prirodnih karakteristika ležišta, rezultati proračuna analizirani su i korigirani opažanjima in situ.

Na temelju istraživanja provedenih u jami »Jukići–Đidare« Dalmatinskih rudnika boksita – Obrovac, postavljena je nova koncepcija daljnjeg otkopavanja ležišta uz primjenu čak tri otkopne metode koje su maksimalno prilagođene karakteristikama preostalog dijela ležišta i tehnološkim zahtjevima otkopavanja (sl. 5). Dosadašnjom eksploatacijom prve tri etaže formirao se je otkopani prostor površine 4 080 m^2, dimenzija 105x35 m i visine 30 m. Daljnja eksploatacija podetažnom otkopnom metodom bila bi vrlo rizična zbog iznenadnog zarušavanja krovine. Radi toga za nastavak eksploatacije projektirana je nova tehnologija otkopavanja zasnovana na slijedećim koncepcijama:

- izoliranje radnog prostora od štetnog djelovanja zarušavanja,
- uspostavljanje principa obaveznog upravljanja krovinom u svim fazama otkopavanja, što je vezano i za dijelove ležišta izvan područja postojećeg otkopanog prostora.

Prema ovome usvojene su slijedeće metode:

- podetažna metoda sa zaštitnim slojem boksita neposredno ispod postojećeg otkopanog prostora (sl. 6),
- podetažna metoda s ostavljanjem otvorenog otkopanog prostora uz ograničenja raspona do granica utvrđene stabilnosti, tj do 25 m (sl. 7),
- komorno–stupna metoda s naknadnim otkopavanjem stupova u dijelu ležišta moćnosti do 4 m (sl. 8).

Sve ove tri metode vrlo se lako mogu transformirati jedna u drugu, a već su u fazi uvođenja u jamu »Jukići–Đidare«. Budući da će se po prvi puta primijeniti u našoj zemlji, neophodno je tijekom pokusnog perioda obavljati temeljita praćenja i dodatna ispitivanja.