PROCEEDINGS OF THE THIRD INTERNATIONAL SYMPOSIUM
ON MINE PLANNING AND EQUIPMENT SELECTION
ISTANBUL / TURKEY / 18 - 20 OCTOBER 1994

Mine Planning and Equipment Selection 1994

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OFFPRINT

A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1994

Mine Planning and Equipment Selection, Paşamehmetoğlu et al. (eds) © 1994 Balkema, Rotterdam, ISBN 90 5410 327 2

Mining of a thick inclined bauxite deposit by a modified sublevel caving method under marginal conditions of the surrounding rocks' characteristics

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ABSTRACT: A modified and innovative sublevel caving method for the exploitation of relatively low value deposits under marginal conditions of the surrounding rocks' characteristics is described. Several special alternative design scenarios are examined, including certain changes in production drilling, ore drawing, rib pillars' design, mechanization aspects and surrounding rocks' monitoring. The method has been proved to be efficient, cost competitive and safe. The production cost achieved by the application of the aforementioned modified sublevel caving method is much lower than the corresponding one resulted by the room and pillar mining, mainly due to the higher productivity rates, the lower explosives' and drilling materials' consumption, the less labour required and the lower rock reinforcement and support costs.

1 INTRODUCTION

Bauxite deposits are abundant in the Greek mainland. Mining activities expand within the geosyncline of Parnassos - Giona - Helicon - Oiti mountains, the main axis of which has a northwest-southeast orientation. Three main bauxite stratigraphic formations may be distinguished in the region, the deepest called the first, the intermediate the second and the top the third. The two upper horizons are nowadays intensively mined. The limestone rock formations that consist the stratigraphic footwall of the bauxite deposits are always establishing characteristic angular unconformity with the hangingwall limestones.

The bauxite deposits of the second horizon are of boehmitic type. The hangingwall of these deposits consists of white-coloured, thin-bedded Tithonian limestones of the Lower Cretaceous. The bauxite deposits belonging to the second horizon are overlying thick-bedded Kimmeridian limestones.

The uniaxial compressive strength of the intact hangingwall limestone is approx. 110MPa, while the structural behaviour of the rock mass is mainly determined by the existence of major weakness planes, characterized by an average spacing between 4 and 6m, and a secondary discontinuity set (joint spacing 1m), thus prohibiting the excavation of large underground openings. The footwall limestone is more competent and is distinguished by a uniaxial compression strength of intact rock specimens of about 160MPa while the respective value of the bauxite is not exceeding 70MPa. A typical chemical composition of these bauxite deposits, which varies substantially with respect to the prevailing mineralogical conditions in each deposit, is the following: Al_2O_3 52-58%, CaO 0.8-1.5%, SiO_2 4.5-8%, TiO_2 1.5-2.5% and Fe_2O_3 23-25%.

According to the mining experience gained by the exploitation of deposits belonging to the two upper bauxite horizons in the region, the most remarkable differences being noticed are the following:

a) The second horizon's deposits are distinguished by much lower strength values, higher brittleness, worse stability conditions and essential ground control difficulties in comparison to those belonging to the third horizon.

b) The second horizon's deposits are characterized by higher SiO_2 and lower CaO average contents, when compared to the respective values of the third horizon's deposits, thus making easier the formation of an extracted mining product with wide commercial range, through proper mixing, without necessitating mineral processing plant and related facilities.

c) The bauxite coming from the second horizon's deposits is more finely grained than the one from the third horizon, mainly due to the considerably low values of its mechanical and physical properties.

d) The majority of the deposits belonging to the second horizon are distinguished by steeper dip and greater thickness.

e) The limestone hangingwall of the second bauxite horizon ordinarily consists of densely jointed, fair to poor rock mass with quite short stand-up time and insufficient ground stability, while the third horizon's hangingwall is more competent, distinguished by higher rock mechanical properties.

2 MINING METHODS

Mechanized room and pillar is the usually applied mining method of the third bauxite horizon, because the majority of the deposits under exploitation are characterized by relatively small thickness and moderate dip (usually between 5°- 25°). Besides the aforementioned common rule, there is actually a considerable potential of deposits, mainly belonging to the second bauxite horizon which are distinguished by greater thickness (usually more than 30m) and greater dip (more than 35°), not suitable for the typical application of conventional room and pillar mining, even if it is combined with cut and fill extraction procedures.

Ascending cut and fill mining of the thick inclined bauxite deposits is considered as quite labour-intensive method, necessitating the in situ quality of the orebody being high. On the other hand, the success of the method requires the achievement of close control of the behaviour of rock mass in the immediate contour of the work area.

The application of the sublevel caving mining method is justified, since it is suitable for steeply dipping, thick orebodies with sufficiently competent orebody rock, enclosed by rather incompetent hanging and footwall rocks. The method may cause significant disturbance of the ground surface imposing some possible limitations on its applicability, as it concerns local topography and hydrology.

The main scope of the mining activity is to induce free displacement of the surrounding rock, while the ore is fragmented by using blast holes drilled upwards in fan patterns from headings developed at relatively small vertical intervals. As broken ore is extracted, fragmented ore as well as caved waste displace in order to fill the temporary void. The success of the draw operations and of the method itself is determined by the relative mobilities of caved waste and fragmented ore. Close control and careful design is required in order to prevent low ore recovery and essential ore dilution.

Due to the physical weakness of numerous bauxite deposits and the eventual absense of competent surrounding rocks, it is reasonable to turn towards caving methods so that the tendency of the rock mass to cave could be utilized for ore extraction instead of insisting on mining methods and support techniques to keep it stable.

Sublevel caving does not require large stope openings but only extraction drifts of limited width, within the bauxite deposit and/or the surrounding limestone rocks. The size of these sublevel drifts may be determined as a compromise between the rock mass stability requirements and the functional constraints of the equipment used underground. Sublevel caving is quite well adopted to fully mechanized underground mining, employing highly productive Load-Haul-Dump Diesel powered units, limited in size only by the dimensions of the sublevel drifts. According to the prevailing mining conditions at the Company's mines, equipment similar to these widely used in modern room and pillar mining is allowed to be employed.

As described below, in the case of the modified sublevel caving (SLC) mining method a certain number of properly designed pillars is kept in order to minimize the dilution of the bauxite ore, whereas by applying the conventional method these pillars are not required.

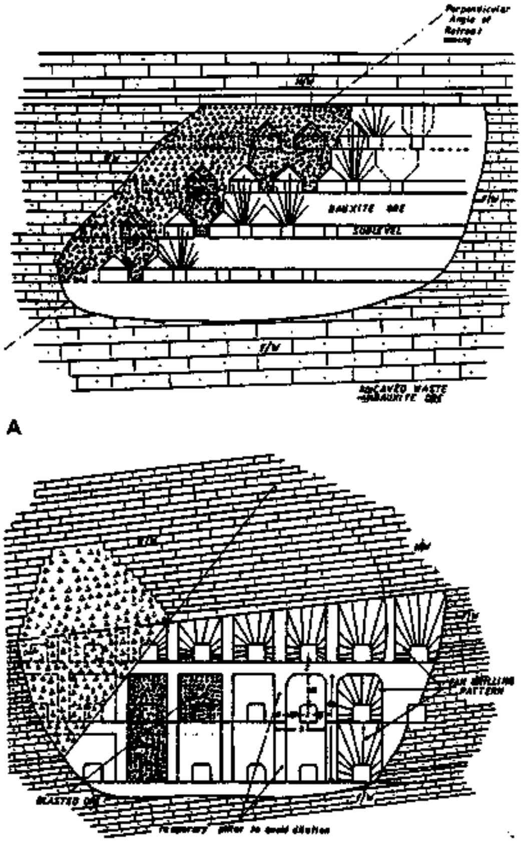
3 DEVELOPMENT OF THE MODIFIED SLC METHOD

The first full scale experiments at a pilot stage took place in 1983. The main targets that were set as a research objective from the mine management were the achievement of as high as possible safety standards and recovery grade as well as the minimization of ore dilution.

In the first step, the typical sublevel caving design which was followed resulted in low ore recovery and high dilution (Fig. 1a, 2a). In the second step, a combination between the sublevel caving and the room and pillar mining method was tested, but certain safety problems and productivity concerns were encountered. At the final step, several modifications of the initial design were decided. They mainly included the decrease of the crosscuts' horizontal and of the sublevels' vertical distance, the more effective support of the sublevel drifts, the forming of specially designed horizontal and vertical bauxite pillars, the use of remote controlled underground production equipment, the excavation of the sublevel crosscuts in non-staggered layout and the crosscuts' orientation at an angle to the sublevel drifts to facilitate equipment turnouts from the haulage to the production drifts (Fig. 1b, 2b).

As known one of the major disadvantages of the sublevel caving mining method are the high dilution percentages. However due to the special mine design and the considerable modifications of the typical method layout, there is actually no dilution at all in the mine product. By the application of the modified sublevel caving method the average recovery grade reaches the level of about 70% while its respective value for the bauxite deposits belonging to the third horizon exploited by the room and pillar mining is more than 80%.

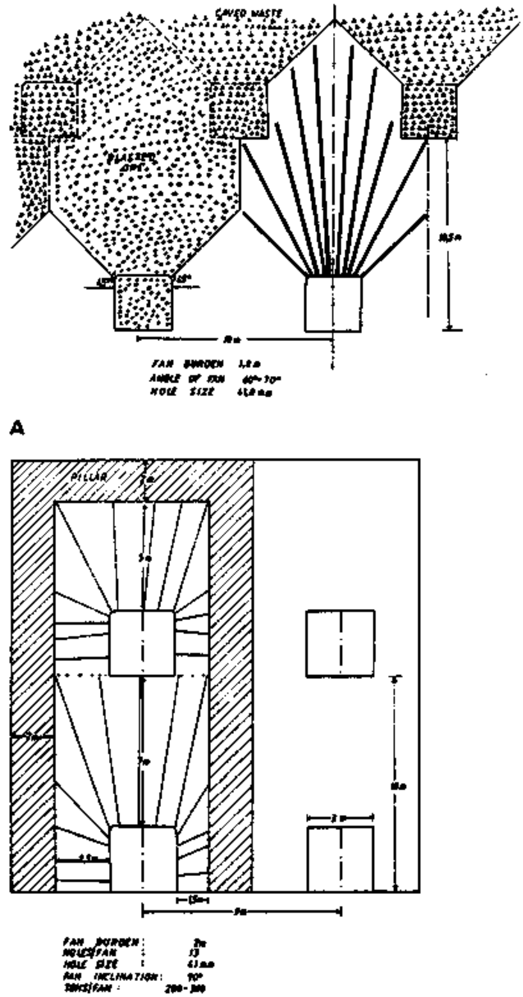
There are usually two main access drifts for each



A

B

Figure 1. Longitudinal sectional view of the typical (a) and the modified (b) sublevel caving mining method.



A

B

Figure 2. Fan drilling layout and crosscuts' spacing of the typical (a) and the modified (b) sublevel caving mining method.

bauxite deposit excavated, in its highest and lowest hangingwall elevation level, within the limestone rock mass, which are connected via a spiral ramp, excavated in the vicinity of the contact between the bauxite deposit and the hangingwall.

The bauxite deposit is divided into mining sublevels at vertical distances of 10m through the excavation of development drifts (width 3.5m, height 2.5-4m) in the contact of the hangingwall and the deposit, adjacent to its strike, interconnected with the spiral ramp. Numerous parallel crosscuts (height 3m) are excavated in 9m distances, from each development drift, within the bauxitic rock mass. These crosscuts are excavated until they reach the footwall contact while they form a 70° angle with the sublevel drifts, to provide the space required by the LHD units and the drilling jumbos. The sublevel drifts are supported by expansion shell point anchor rockbolts while the crosscut adits by densely joined timber and steel sets.

It should be noticed that due to the relatively low price of the bauxite in the international markets, the dilution of the extracted ore must be minimized (less than 1% CaO) so that its chemical composition will always be kept within strict limits.

A raise for ventilation purposes is driven from each sublevel drift thus connecting it with its overlying sublevel and establishing an adequate ventilation circuit.

The exploitation of the deposit proceeds from the upper sublevel to the lower ones, from the ends of the sublevel drifts to their starting points and from the footwall to the hangingwall of the bauxite deposit (Fig. 3).

Mining starts by excavating a slot raise adjacent to

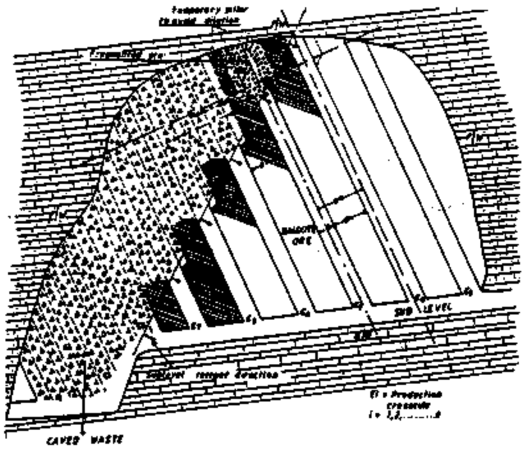


Figure 3. Sublevel plan of the modified sublevel caving mining method.

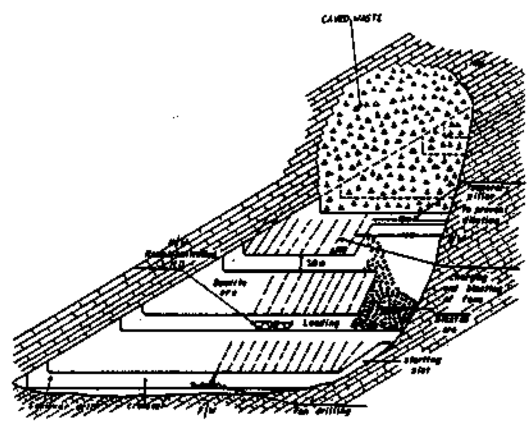


Figure 4. Cross sectional view of the modified sublevel mining system showing the principal operations.

the contact between the deposit and the footwall to separate the bauxite from the limestone thus making the extraction of the deposit easier by using longhole upward production drilling (Fig. 4).

Due to the vertical distance between the sublevels (10m) and the crosscuts' height (3m), horizontal bauxite pillars of 7m thickness are formed between the sublevels (Fig. 2b). These pillars are mined partially through a carefully designed drilling pattern so that their final thickness does not exceed 2m, thus causing their remaining part to behave as a supporting or, at least, protecting rock beam or "pillow" for the caved limestone of the hangingwall, thus prohibiting its mixing with the extracted ore. In order to limitate the ore loss during the application of the modified sublevel caving method, these horizontal bauxite pillars are finally abandoned in every two sublevel intervals thus prohibiting ore dilution problems.

During the depillaring stage, the part of the remaining pillar increases in length. When the length of the remaining pillar exceeds 12m, the pillar usually fails due to the increasing loads created by the overlying caved limestone weights.

In some cases, both the horizontal bauxite pillar as well as the hangingwall do not cave, thus necessitating the application of induced caving techniques for achieving the desired caving rates and the completion of each caving stage. Besides the abandoned horizontal pillars, a series of vertical pillars (2m in width) is also formed between the parallel crosscuts for achieving a much better quality of the mined product. The production drilling pattern is characterized by a non symmetrical fan shape due to the need for gradual reduction of the vertical pillars' dimensions created by both its neighbouring crosscuts, for keeping the pillar stable and protected in order to enable the complete mining procedure of the sublevel panel.

The production drillholes (length 5-8m, diameter 41mm) are drilled by special air powered jumbos, due to the need for keeping quite narrow crosscuts drifts since otherwise they cannot remain stable because of the low mechanical properties of the bauxite as well as of the hangingwall of the deposit. The drilling angle is approx. 70° while the fan burden is 2.0m. Charging the drillholes with ANFO is being carried out by using a series of jet charging equipment. Mucking of the extracted bauxite, which is being performed by remote controlled Load-Haul-Dump units (3.5cy), is followed by ore dumping into a series of almost vertical ore passes which end to the lower main access drift. The general mining sequence of the modified method is shown in Fig. 5.

The hangingwall rock mass caving is usually taking place gradually. The stratified limestone is broken into prismatic plates or irregular blocks having an ordinary size up to 100cm. The swelling factor is approx. 1.7 while the shrinkage rate of the broken limestone rock mass is very low. The overburden thickness exceeds 200m. There has never been reported any vertical or horizontal surface subsidence.

The main functional differences in comparison to the conventional sublevel caving mining method are the following :

a) Forming of abandoned horizontal and vertical pillars in every two sublevel intervals for keeping ore dilution as low as possible.

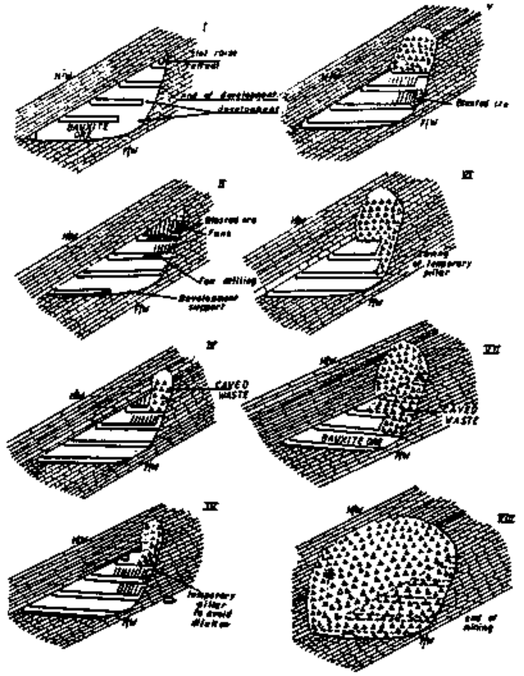


Figure 5. Schematic presentation of the modified sublevel caving mining sequence.

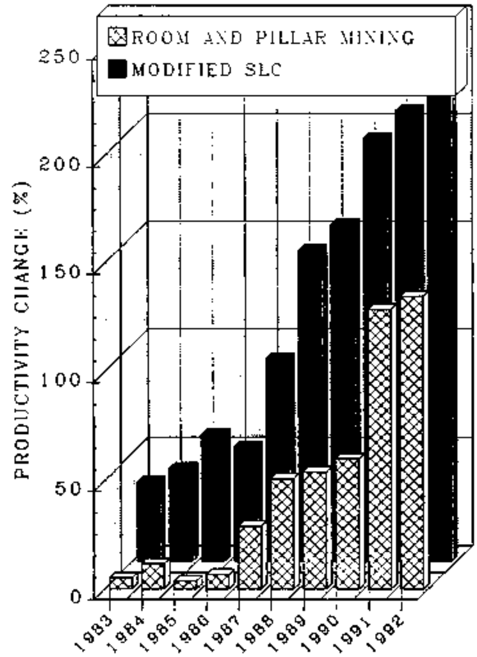


Figure 6. Productivity percentage changes for the modified sublevel caving and the room and pillar mining.

b) Each sublevel crosscut is located exactly below and above its respective of the directly upper and the lower sublevel, instead of following the staggered layout being usually applied.

c) The excavation of very narrow crosscuts and the application of especially modified non-symmetrical drilling patterns according to the prevailing conditions have been proved necessary, since the bauxite ore is characterized by low values of mechanical properties.

d) In the first mining stage a series of open stopes is formed inside the bauxite deposit, being protected by the bauxite pillar "curtains". At the depillaring retreat stage, the caving of the hangingwall does not imply ore dilution problems since it is very closely controlled by induced caving techniques and is monitored through several rock mass deformation devices.

The typical consumption of explosives per ton of extracted bauxite ore is approx. 170gr.

In certain cases of quite incompetent bauxite, heavy timber and steel sets combined by dense roof bolting have to be installed in the junctions between the sublevel drifts and the crosscuts, to prevent large scale roof failures mainly during the retreating stage.

Some years ago, a remote controlled LHD unit was completely covered by huge quantities of the fragmented hangingwall limestone which was suddenly caved inside the production crosscut drift without giving any warning signals. A lot of efforts took place in order to identify the exact position of the unit inside the caved waste and to regain the equipment. Several techniques were applied by using specially designed drilling patterns and careful mucking procedures from the underlying crosscut that achieved an initial vertical movement of the unit but at the final stage the LHD unit was interlocked and wedged with the caved waste and the overlying horizontal bauxite pillar. The systematic mucking from the underlying crosscut, which had been taking place for several days, did not finally unlock the unit.

In Fig. 6, the productivity percentage changes of the company's mines for the exploitation of bauxite deposits of the second (room and pillar mining) and the third (modified sublevel caving) horizon are shown. In bauxite underground mining, the productivity value is found by dividing the total respected tonnage of extracted bauxite and waste with the corresponding amount of the consumed man hours.

In Fig. 7, the production cost percentage changes of

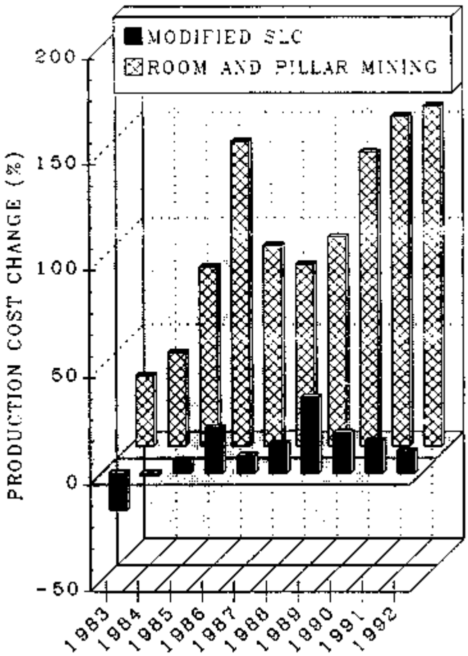


Figure 7. Production cost percentage changes for the modified sublevel caving and the room and pillar mining method.

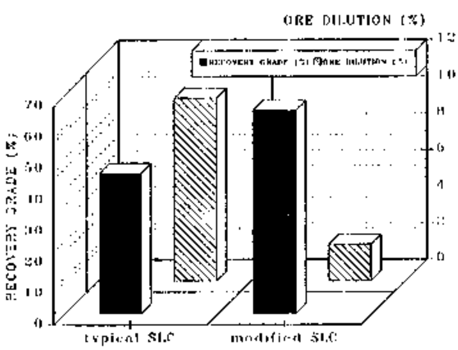


Figure 8. Recovery grade and ore dilution percentage values for the typical and the modified sublevel caving mining method.

the company's mines for the exploitation of bauxite deposits of the second and the third horizon are shown.

In Fig. 8, the values of the recovery grade and the ore dilution for the typical sublevel caving mining method, which was initially applied, and the modified one, are given.

4 CONCLUSIONS

The increased application of the sublevel caving methods of mining in recent years may be attributed to various new technological developments, to better understanding of the mechanics of this method and the determination of the role of the ore and surrounding rocks' characteristics.

A certain dilution of the ore is inevitable when using the method at its conventional form and careful draw control is necessary if a portion of the ore is not to be lost.

Ore recovery and dilution remain the main factors, which characterize the success of the method if its application is decided.

Nevertheless, the method is apt to modifications according to the prevailing general mining conditions, under the assumption that the final layout is planned as a comprise between a variety of factors.

In the case examined an optimum sublevel layout was designed following a thorough examination of the various interfering parameters, like the mechanical characteristics of the bauxite ore and the surrounding rocks, the size and shape of the draw zone, the mechanics of the draw, the fan burden, the draw control, the spacing of the sublevels and the production drifts etc.

The modified sublevel caving method, as described above, seems to lead to a safer and more economic extraction, a higher ore recovery and a lesser dilution in comparison with the previously applied conventional sublevel caving system.

However, a continuous experimentation is necessary, in order to improve the sublevel layout and achieve even better results.

ACKNOWLEDGEMENTS

The authors express their sincere thanks to Mrs Penelope Barlou, Managing Director of the "Greek Helicon Bauxites - G.L.Barlos" Ind. Min. Co S.A. for her kind permission to present this paper.