UNDERGROUND BAUXITE EXPLOITATION IN THE WESTERN DINARIDS
ESSENTIAL FACTS AND COMMENTS

Slavko VUJEC1, Rikard MARUŠIČ2 and Krešimir SAKAČ2

1Faculty of Mining, Geology, and Petroleum Engineering, Pierottijeva 6, 41000 Zagreb, Croatia
2Croatian Natural History Museum, Demetrova 1, 41000 Zagreb, Croatia

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Introduction

1. About the bauxites on the territory of former Yugoslavia rather a lot is written. In the so far most complete bibliography, prepared by two of the present authors (Sakač & Marušić, 1974) there are quoted, ending with the year 1991, 810 bibliographic units: up to this day (end of 1993) some 40-odd headings may be added, what means that about these bauxites, directly or in relevant publications, roughly 850 articles are published. However, in this imposing reference list comparatively few articles about underground exploitation can be found, although such a working mode often was remarkable for this bauxite mining area, especially in some mining provinces.

There are several reasons for such a relatively small share of underground literature. First, in the period before the 1st world war all working bauxite mines were, with the exception of just one deposit near Mostar, in the hands of foreign mining companies which very unwillingly delivered whatsoever data about their activities. Second, to publish a technical article some relevant graphical and numerical elements are needed, e.g. in the form of at least a rudimentary sketch. As a rule, nothing in that sense was performed. "Projecting« was made "in walking«, during the everyday attendance at the working face, by directly watching the development of the workings. Thirdly, the total share of underground work was however small enough and the underground workings for a long time had small dimensions, too, so their presentation in professional publications would not arouse a big interest. Fourthly, not until after the war verified projects also for bauxite mines became truly obligatory, especially as the mines were nationalized and in some particular regions merged to united companies; and interesting projects for bigger ventures — that was already worth publishing. True, often just the fact that a project was in question could be a hindrance to make it public, in early times because of "secret keeping« and later on also because of "authors' rights«.

In this paper essential facts about the underground bauxite mining in Istria, Dalmatia, Bosnia & Herzegovina are presented, i.e. in the regions within administrative sites in Rovinj, Obrovac, Drniš, Sinj, Jajce, and Mostar (Fig. 1); Montenegro (Nikšić) is not dealt with for the authors have no reliable data.

2. As a comparatively cheap raw material bauxite was, and is, won by underground workings only from necessity: maybe big surface deposits
Dalmatia (on Dalmatian isles and near Drniš). Surface deposits were worked, and that remained the characteristic feature of bauxite mining in the Dinarids until the period after world war II. That means, the exploitation was initiated on the outcrop and then the ore was followed till the point was reached where from the economic and security standards could not be warranted any more. These proceedings have been impressively presented by the late engineer Franotović, the unsurpassed designer and unforgotten master of graphical representation of bauxite features and mining objects (Fig. 2).

Some circumstances here must be borne in mind. First, the mineral wealth; for example, in the Istrian mineralized zone there on an areal of one square kilometer on average 40...45 deposits have been identified, with roughly 150 000 t of ore all in all, and on the »most dense« kilometer, the Balčiko Polje, Fig. 3, 110 deposits have been found, with 460 000 t of ore altogether; similar, although distributed in a different way (along a »contact« line), the situation was in Herzegovina, and also in Bosnia around Bosanska Krupa. Second, the quality of the ore: in view of the deposit abundance, the quality could be selected, what of course was done, for in the selling contracts substantial premiums for exceeding aluminium values and especially for low silica values were conceded; yes, it could be mixed, but that was easy, however, only with large deposits, with small ones only if they were very close to each other, otherwise the manipulation becomes too expensive. Thirdly, and this is deducible already from the foregoing two facts, the affairs came about in conditions of the capitalistic system; that means that the owner was anxious about a profit, and this in mining can be acquired by low costs; so, the cream had to be skimmed swiftly.

All that pointed to a selective exploitation of individual deposits and not to a systematically planned exploitation of whole regions or at least a group of deposits. The later was, however, sometimes done but preferentially by reasons of transport, i.e. when inexorable logic forced out a dispatch concentration from a common loading ramp.

Naturally, in such circumstances it was hard to decide in favour of underground exploitation. The main motive for such a decision were the ownership circumstances. So, e.g., in the Mostar region there were six main owners of mining claims, in the Drniš region also several, in Istria a dozen or so, etc, etc. Each owner was authorized to exploit only his deal (sometimes mining claims were not yet known, or they are to far away, traffic-cally unavailing, »politically« inaccessible, in one word, economically out of all reasonable categories. Therefore, like everywhere and always in the history of mining, also the raw material bauxite was exploited firstly by open pits — with one, phantastic, exception: in the valley of the river Mirna in Istria, beneath the Castle of Sovinjak near Buzet, pyritic bauxite has been exploited underground and, what is more to the point, yet 400 years ago! But about that exception here we cannot talk: the authors have already published several papers on this historical and technical phenomenon and so we can refer to it (Marušić et al. 1993 (2×), Sakač et al. 1993, Sakač 1993).

Like all ores, bauxite, too, was firstly won from outcrops. Excluding the mentioned Istrien case, the beginning can be set to the end of the 19th century, i.e. when the aluminium industry began to develop and for this bauxite was the only raw material, like it is yet today. The first mine opened 1873 in France, because there the new ore was »located«, an application was found, and a method for extraction of the metal from it has been developed, and so 1874 the first aluminium plant was erected (Neher 1942). However, up to the first world war all that have been activities of a modest volume. The use of aluminium was restricted to craftsmanships, and only the immense expansion of the aircraft industry (of course, partially also thanks to the physico-mechanical characteristics of aluminium) launched the new ore into the sphere of military metal wherewith it came to age.

After France, bauxite was found in Austria-Hungary (we do not write the history of bauxite and therefore we cannot mention relevant but modest informations from other countries, too, like Italy, Germany, Greece). In Austria the exploitation of bauxite began during the war-years 1914/15, in Istria (in the region of Labin) and in Fig. 2. Typical succession from surface to underground works. 1 Roof layers, 2 bauxite, 3 floor layers
ped, near Jajce a little stronger. For the undergro-
and sandstones. The relief under the ore in the
limestonic breccias and limestones which upwar-
were leased). So, when the outcrop extended into
underground, the bitter pill had to be swallowed,
especially when rich ores were in question.
World war II radically changed the circumstan-
ces in bauxite mining, like in all other things. The-
therefore, in the following the »prewar« or »prima-
period will be thus indicated.

The geological situation

Of eight essential bauxitebearing stratigraphic
horizons in the Dinarids, originated from Middle
Trias till Lower Miocene (Sakač & Škinkovec,
1991), only three are of importance for the bauxi-
ete underground exploitation in the western part of
the Dinarids. These are the Senonic bauxites of
Western Bosnia, the bauxites of the Older Pale-
gene (mainly, Paleocene) in Istria, Dalmatia, and
western Herzegovina, and the Younger Paleoge-
ne (i. e. mainly the younger part of Eocene) in
Dalmatia and Western Herzegovina. In the eas-
tern part of the Dinarids, which here is not con-
dered, in Montenegro bauxites of Upper Jura
(Malm) have been exploited, and of Lower Creta-
cean near Vlasenica in Eastern Bosnia.

Senonic bauxites, won by underground work-
ings, in Western Bosnia, occur in two regions. The
first is the region Bosanska Krupa between the
places Bihać and Klječ, predominantly in some
sectors of the Grmeć Mountain. The region covers
an area of some 500 km². The second comprises
the larger surroundings of Jajce, where the ore
occurs predominantly on the Ranča Mountain.

In the footwall of the Senonic bauxites occur
Alb-Cenoman limestones, and in the hanging wall
limestone breccias and limestones which upwar-
d pass into Younger Senonic Paleocenic marls
and sandstones. The relief under the ore in the
Grmeć Mountain is, on the whole, poorly devel-
oped, near Jajce a little stronger. For the undergro-
and exploitation there strange occurrences of pse-
udopaleorelief in the immediate footwall are rat-
er important: the Carbonaceous layers of Youn-
ger Senonic age have an inverted position, so far
a practically unknown phenomenon with bauxites
(Sakač, 1966); inconvenient are also »pyrami-
des« in the normal geologic hanging in deposits
of the Ranča Mountain. In both cases the bauxite
lays on an uneven immediate footwall and has an
uneven hanging surface, too.

The deposits of Senonic bauxites are very diffe-rent both in size and form. Partly, that are thin
orebodies, like sheets, only 1 to 1,5 meters thick
(Grmeć); for the most part they form small lenses
of various thickness (B. Krupa, Jajce); in the re-
gion Jajce there are bigger orebodies, too. All ore-
body are incorporated to tectonic structures.
Predominantly, that are synforms, in varying in-
tensity, disarranged by normal or thrust faults.
The orebearing surfaces of these structures may
be gentle inclined, like in the mine Crvene Stijene
on the Ranča Mountain near Jajce, stronger incli-
nde, like in the mine Poljane in the same region,
or perpendicular, e. g. in the mine Tihotina near
Bihac; and, finally, they also can be overthrown,
in an inverted position, like in Liskovica near Jaj-
ce. A great deal of the deposits in the central part
of Grmeć are placed in a complex lot of lammelar
structures which, with interruptions, stretch in a
length of almost 30 km.

The bauxites are of boehmitic-hematitic com-
position with various, mainly low contents of kao-
line and other mineral components. In Grmeć
there are also boehmitic-hematitic-diassporic bau-
xites; these are marked by a great hardness, so
that they have been used in the industry of abrasi-
ates (at Ruše in Slovenia). Their composition is
otherwise rather favourable: they contain
55 ... 60% Al₂O₃, up to 5% SiO₂, 4 ... 22% Fe₂O₃,
and the ignition loss is about 14% (Sakač, 1966).
In consequence of deferrification, the Fe₂O₃ con-
tent may be much lower than 10%, therefore these
»white« bauxites have been used in the chemical
industry and for other purposes. Such »allitized«
bauxites may contain up to 70% alumina, and are
in that view the Dinaric bauxites of the highest
quality. Yet, the quantities of these bauxites are
practically neglectable; nevertheless, a lot of such
deposits has been excavated, some even under-
ground, as in Pritoka near Bihac.

Bauxite of the Older Paleogene (Paleocene)
have been exploited by underground workings in
Istria, but there in the region of Sovinjak only
(Marušić et al., 1993), in a small volume on so-
me North Adriatic isles, e. g. near Stara Baška
on the island of Krk, and in Central Dalmatia on
the Promina Mountain near Driš. In West-
tern Herzegovina during the world war II the-
ere were underground workings in the region of Sí-
roki Brijeg: at Crne Loke, Trbošić and Sudrova
Glavica. The footwall of these bauxites is built of
Upper Cretaceous limestones and the hanging wall
of well-bedded partly clayey bituminous li-
imestone with clay lenses and coal occurrences
(Kozina layers), sedimented in a freshwater, par-
The Paleocene bauxite deposits are of various sizes. In Istria, the Adriatic isles, Dalmatia and a part of Herzegovina appear smaller orebodies, in the form of pockets, in fact various fillings of paleosinkholes. The surface of individual deposits does not exceed 100...300 m², the depth is between several and 30 m, the content between 50 and 25 000 t of ore. In Herzegovina there are also bigger deposits, so in the environs of Široki Brijeg, in the mining districts of Crne Lokve, Tribošić and Sudrova Glavica; there have been deposits from some ten thousands tons to several hundred thousands, and the biggest deposit, Orašnica at Crne Lokve, was closed after roughly one million tons has been excavated.

The bauxites of Older Paleogene show an oolitic texture and massive structure. The main minerals are boehmite, accessory gibbsite, and hematite resp. goethite. Some kaolinite is also found, and some parts of the deposits may contain pyritic bauxite, as the case is in the Mirna valley in Istria, but in other regions, too. The chemical composition of the bauxites is mainly equalized: in the average they contain 50...60% Al₂O₃, 1...6% SiO₂, 17...24% Fe₂O₃, and the ignition loss is 13...16%. Thanks to the good quality, also small deposits have been exploited for decades if only they were near enough to communications or the sea, like in Istria, Dalmatia and parts of Herzegovina.

Younger Paleogene Bauxites have from the mining point of view the greatest importance in the Western Dinarids because they have had the greatest share in the excavated volume of ore, and here is also the remainder of reserves. Numerous deposits of that age are exploited underground. These bauxites are appearing in a protracted and relatively narrow zone. It goes from Maslenica near Obrovac in the northwest over Enverik, Drniš, Sinj and Imotski in Dalmatia and then over Posušje, Citluk till Stolac in Herzegovina in the southeast. In that part of the Western Dinarids the following bauxite regions are situated: Obrovac, Drniš, Sinj, Imotski, Stolac (Dabrca), and a part of the region Mostar (Citluk, Posušje). Here were opened a great deal of bauxite mines which have been exploited for quite a long time, as in Kalun (Drniš); several big underground objects have been active even till the outbreak of the Serbian rebellion 1991, when all mining activities were stopped; that is true especially for the mine Grzićine—Cukovac near Obrovac, Jukići near Drniš, and Dabrca near Stolac (the open pits not to mention). In the footwall of the Younger Paleogene bauxites there are carboniferous Cretaceous rocks of various age as well as older Paleogenic rocks. Mainly, that are Upper-Cretaceous Rudist limestones and Lower and Middle Eocene Foraminifera limestones. This footwall is very uneven, with numerous deep bauxitic fillings in carbonate rocks and many »pyramids« as a regular feature, especially in horizontal and gentle inclined deposits, where hypergenetic transformations of the carbonate basis were stronger manifested. Such phenomena cause great difficulties during the exploitation, especially when introducing heavy mechanization. Contrary to the contact bauxite/footwall, the hanging rocks above the ore lie as a plane plate. The hanging wall is composed of lithologically heterogeneous Promina layers of Upper Lutetian (Middle Eocene) — Lower Oligocene age. These layers consist of various limestones, conglomerates, sandstones, marls, clay lenses and occurrences of brown coal.

The bauxite deposits differ as to the form and size. There may be small lenses, more rarely pseudobedded accumulations, but predominantly orebodies of irregular forms with sizes from several hundred to many thousand square meters; the average thickness varies from 3 to 40 m. The outcrops are set on the surface in a row along contact lines of foot and roof layers resp. along the brims of numerous tectonic structures. The greater part of orebodies below the surface is under a hanging cover of different thickness. The mineralization of the bauxitebearing paleosurface is uneven. It is high in the districts Maslenica—Janžec and Kruševo near Obrovac, in parts of the region Drniš, and around Posušje and Citluk (region Mostar). On the contrary, it is low in the regions of Ervenik, Sinj and Imotski in Dalmatia and in some parts of Herzegovina. For the greater part, the orebodies appear in groups but their position varies greatly, what depends on the mineralization intensity and on the type of tectonic structures in which they are bedded. For the most part, the area is a series of synclinales with variously inclined sides. Such structures are common at Kruševo (Obrovac), somewhat more are known from the Promina Mountain near Drniš, then Visoka near Sinj, Citluk in Herzegovina etc. Some structures have the form of anticlines, e. g. Kalun near Drniš and the main tectonic structure of the Mošeč Mountain in Dalmatia. There are complex structures, too, formed by reversible overtrust of the footwall over the bauxite and roof layers, the case, e. g., in Jasenice near Obrovac and a sector of Dabrca near Stolac in Herzegovina.

The Younger Paleogene bauxites are mostly of detrital texture and massive structure. The main minerals are gibbsite/boehmite and hematite/goethite while the kaolinite content is variable. The chemical composition is rather uneven from one
to the other group. The $\text{Al}_2\text{O}_3$ content is 45...52%, $\text{SiO}_2$ may amount to more than 10% but in the average holds 2 to 6%. The content of $\text{Fe}_2\text{O}_3$ equals 17...25% and the ignition loss is between 17 and 25. With regard to the suitable quality and the presence of many big deposits, these bauxites have the longest continuous working life in the realm of former Yugoslavia, beginning with world war I and with a substantially share of underground mines.

Exploration

On what exploration works Breithaupt 1847 resp. Fleckner—Lill 1866 have described the minerals chlachit resp. wochrome we don't know, but by these descriptions it's obvious that already then there have been prospecting works of some kind. It is sure enough that in the passing period from the 19. to the 20. century there already have been some substantial works e.g. in Dalmatia, because Schubert 1909 in his »Geology of Dalmatia« writes that »with regard to the practical use of the Dalmatian bauxites it must be noted that it is of great inconvenience that these deposits usually are too much unattainable for the traffic...« (p. 157); it must be deduced that these deposits by somebody have been visited. A confirmation can be found by Crema who states that in the year 1906, initiated by the engineer Deskovic, in Dalmatia bauxite investigations have begun; that year is mentioned also by Polley (1909) as the first exploration year in Istria. The first exploration works on bauxite in Herzegovina were carried out also during that period, 1909 (and 1912), as reported by Katzer, 1917, when he is writing about the deposit near Donja Nov climbing method came to use by compressed air. Normally, hydraulic drills were used, with a capacity to 400 m. The loose surface cover is pierced by a profile of 101 mm and then a protecting column of 98 mm is introduced; on it the exhaust pipe was mounted. Through the hanging rocks usually with full profile of 86 mm was bored, like the orebody too, only that from each boring meter an ore sample was taken. For that purpose, at the end of the exhaust pipe a box was placed in which the exhausted material was secured (this was of a nice red colour when the chisel travelled through bauxite and white when it traversed rocks). The advantages of the method are threefold: almost a complete recovery of the »core«, substantial savings in comparison with the classic core winning, and absence of care for the drilling water — a great relief in arid regions.

Machine boring in the right sense was generally introduced only after world war II, out of understandable reasons: after the surface and shallow deposits have been excavated, the turn has to be...
taken by underground deposits in greater depths, without outcrops, and secondly, the State — no more private firms — demanded a much bigger output than the prewar has been, for bauxite has became an important export commodity.

Drills of various types and capacities have been in use, but predominantly mobile types, e. g. on caterpillars (Fig. 4). In consequence of the inaccessibility of many areas, sometimes very sophisticated methods have been applied, e. g. transfer of drilling equipment by helicopters; such an action is shown in Fig. 5, when to the summit of Promina Mountain near Drniš (1148 m) a drill has been flown in (there an outcrop was known which the bauxite people long ago, from prewar times, has wished to drill but that always had to be postponed; as last, look! by end of the seventies the technical progress made it possible to fulfil our wish in an elegant mode [the effect was not worth the effort]).

Sampling was always a matter of greatest attention. The reconnaissance of new terrains, particularly in the beginnings, was not much more then sampling. In Fig. 6 the sample preparation on the outcrop of the big deposit Dračevac in the region Obrovac is shown; the deposit yielded later on around one million tons of ore.
Core drilling was after the war a standard proceeding for all deposits without outcrops which have been investigated by machine drilling.

At present, modern exploration, also in bauxite regions, begins with a search of the geologic structures by satellite images and sophisticated geophysics, is continued by drilling a dense net of machine boreholes, and ends by interpretation of the deposits size and form by geostatistical calculations with the help of mighty computer systems. The difference to prewar procedures is obvious, particularly considering the fact that then all tasks usually had to be performed by just one engineer, maybe with one older colleague in the «direction» in Triest, or Drniš, or Mostar — while nowadays all that is accomplished by whole teams of various experts.

Opening

In accession to underground workings, bauxite mining did not differ, nor differs now, from usual mining practice: dependent on the terrain, a bauxite underground mine is opened by shaft, adit, or incline. Since from a technical point of view, an adit is the most favourable access to an underground deposit, and moreover is conditioned by a mountainous configuration of the terrain, in which the investigated bauxites for the most part appear, this opening mode was applied wherever it was possible, beginning already in the 16. century with Castle Sovinjak in Istria.

In Fig. 7 classic modes of opening bauxite deposits by adit are shown. As can be seen, when it was possible and the circumstances demanded it, preference was given even to several adits if so a shaft sinking could be avoided.

During the first period, in former Yugoslavia and during the second world war, the cross sections of adits mostly did not exceed 4 m², what satisfied the needs of men riding and haulage. Haulage was most often executed by mine cars of 1 ton total mass pushed by haulers (»Laufer«, after the German term). The advance, in the conditions of bauxite mining in the Dinarids, i.e. in sedimentary limestone rocks, rarely exceeds 1 m/shift; at

Fig. 7. Mine opening by adits. A Small deposit D-14. 1 Roof layers, 2 bauxite (excavated), 3 collapse structure, 4 floor layers; B Small deposit Pale%; 1 roof limestones, 2 floor »pyramids«, 3 conglomerates, 4 cavity, 5 humus, 6 haulage adit, 7 bauxite; C Deposit group Visoka
present, by applying, for example, mobile hydraulic drills, mechanized loading and haulage, an advance up to 10 m/shift, and more, can be reached. Because of modern haulage — by locomotives, conveyor belts or trucks — the adit profiles are enlarged too, up to 10...14 m².

Deposits which couldn’t be opened by adits were opened by shafts or inclines.

In principle, shafts in mining generally are sunk in flat grounds and/or when there are big orebodies. A third reason is the presence of precious raw materials which can bear the costs of the expensive but otherwise manifold more advantageous shaft. Some Herzegovinian bauxite deposits answer to none of these three conditions and nevertheless have been opened by shafts, thus some deposits on the hilltop Sudrova Glavica near Široki Brijeg. The depth there did not exceed 30 m and the ground-plan came to 6 m². The shaft had two compartments, for the ore and for the miners. The ore was hauled in small cars on platforms by Diesel engines on the surface; in the other compartment wooden ladders with rest-platforms were mounted. The reason for the application of such a complicated and expensive system was the »Knešpolje« quality of the ore and the inconvenience of the terrain for development of inclines, adits especially.

The described case of opening by shafts of small bauxite deposits, with reserves of just a few thousand ton, has to be taken as an exception and is mentioned here out of historical motives. But big deposits, e.g. in Montenegro, more often have been opened by shafts. A particular case is the deposit on (and in) the Kalun Mountain near Drniš which is described below. In Fig. 8 a characteristic sketch of the »Kalun shaft access« is given.

Inclines were the opening mode for a rather big number of deposits, especially in Dalmatia, less in Herzegovina and Bosnia. Sometimes, in fact, that have been inclined shafts, thus in the, from that viewpoint famous, deposit Foča (Kriste Radas) in the Drniš region, where the incline, with a total length of 120 m, has had a dip of 65° (Fig. 9). The fundamental drawback of inclines, the fatiguing »mountaineer« climbing, there was especially accentuated. However, it must be said that this was an extreme case, of the first period, whilst later on the inclines have been executed according to usual, more human, standards. Thus, after a project from the year 1991 for the mine Čukovac—Grizićine a main haulage incline of 412 m with a dip of 12° (with conveyor belt) was constructed, Fig. 10 (Perić and Vujec, 1992).

During the post-war period, in the Western Dinarids inclines were realized generally after the standards:
- with a dip till 9°: haulage by Diesel trucks,
- with a dip from 9 to 16°: haulage by conveyor belts.

Conveyor belts are envisaged for larger deposits with a significant yearly output; so, for Čukovac—Grizićine 100 000 t yearly have been disposed. Transport by trucks had been envisaged for mines with a lower yearly production, e.g. Krš in the region Obrovac, Đidare (Drniš), Trobukva near Posušje in Herzegovina.

Development

Before and during the second world war in bauxite mining there has been no development in the exact sense of the word, even in the not very numerous veritable underground workings. As said already in the Introduction, bauxite underground mines evolved more by chance, »spontaneously«, so that the ore was pursued from the excavated outcrop into the depth. This dictated the further
development of the doings insofar as then the developings headings just followed further the contact between the ore and the roof or the floor. For that reason, on old mining charts the headings are mostly winding.

After the war, with obligatory mine planning after the orebodies have been documented by reliable prospecting and exploration works, the development was carried out to the customary rules. Today the needed mine openings (headings, inclines, raises) most often are executed by help of Diesel loaders, more rarely with pneumatic or electrical loaders.

The support was formerly exclusively wooden, now, in consequence of large profiles, it is often substituted by steel support. In ore headings experiments with roof boltings have been undertaken; good results have been achieved (Majić and Vujec 1990).

Excavation

The dilution grade of the mining product, i. e. of the unwanted mixing of ore and waste, is one of the fundamental indexes for the valuation of the applied mine exploration method. That is especially true in the case of bauxite as raw material for the aluminium industry, because the main, in fact universal, technological process for the alumina winning — the Bayer process — requires, for a profitable operation, a qualitatively strongly conditioned feed. With other ores such a qualitative feed may be acquired by beneficiation. With bauxite, however, up to now by none beneficiation method have been obtained practically applicable results. Still the judgement from 1941 of the classic author in this field, Tulio Seguitti, which investigated the beneficiability of bauxite by all known methods, is valid: »The results are very modest: low recoveries have been obtained, and the costs for the ore preparation and the reagents would considerably influence the concentrate price« (1941).

Accordingly, in bauxite exploitation a »clean« excavation must be aimed. During the surface exploitation, i. e. in the first period, there were no difficulties in that sense, for manual, not mechanized, excavation could easily be conducted selectively; practically, no losses were registered then. Losses became evident with the passing over to underground work.

With regard to low strength of the limestone roof, which collapses immediately after the ore is excavated, very soon it became certain that in bauxite underground winning as main mining method sublevel caving has to be used (Fig. 11). With this method, mixing of ore and waste cannot be avoided, so losses became unavoidable; they amount to 20...30, and exceptionally to 50%, too. Nevertheless, the method has also advantages

Fig. 10. Opening by incline for big deposits (type Čukovac—Gržinica). 1 Adit, 2 sump, 3 ventilation shaft, 4 haulage adit, 5 levels

Fig. 11. Scheme of the sublevel caving mining method
— for them it was introduced to a technically primitive and in mining matters inexperienced environment. The fundamental advantage is a small number of necessary workers, what is of special importance just in countrysides where there no experiences whatsoever with underground work has existed. Further, production costs are low, at relatively high productivity. However, as there is no method which couldn’t be improved by adapting to local circumstances, often attempts with variants of the method have been undertaken, and in mines with a strong roof other methods, too, have been introduced, so as, for example, the sublevel open stope method, with or without roof bolting, the room-and-pillar method, or excavation under a protective ore layer. Such experiments have been made, e. g. in some mines around Jajce and, partly, at Dabrica near Stolac and Trobukva near Posušje; here in the hanging wall also harder rocks are present — sandstones and conglomerates resp. strong marls (Trobukva). Details are given below, in the descriptions of individual mines.

It should be borne in mind that the sublevel caving method, alone or in variants, is the main mining method in many French, Hungarian and Greek bauxite mines, too.

Sublevel caving remained the main method also after the introduction of mechanization. The introduction of new drilling garniture and loading machines made it possible to enlarge the stope dimensions. The height could be doubled, up to 7...10 m. The width by one-sided excavation — the most often in practice — formerly 4.5 to 5 m, now amounts to 6.5...7 m.

The ore quantity won by one blasting practically is doubled or even tripled. But this is accompanied by larger cave in of the roof, especially in weak rocks, thus a stronger mixing of ore and waste happens, too, i. e. greater losses are the result. That’s the main drawback of the sublevel caving method and the main instigation to the search for a more adequate excavation method.

When excavating under strong rocks, the hanging wall cave in by spans of 20 up to 60 m, and so open spaces even up to 3000 m² are formed. In such circumstances the security is greatly reduced, even when remote controlled loaders are used. As already said, in such mines other excavation methods have been tested, too.

As to man-shift (duties), the data fluctuate in rather wide limits. In the pre-war period and long after, on the average the value of 1 t per man-shift as the mine duty by manual work could be taken as sure. Out of prestige motives, sometimes higher values, up to 2 t, were alleged. A stope duty of 3...5 t was the average; exceptionally or exceptionally, the double value, 10 t, was said to have been achieved.

After the mines have been mechanized, the stope duty rose to the average of 7...10 t, and in completely mechanized mines, e. g. where the haulage was effectuated by Cavo-loaders (Jajce 1973), the stope duty could amount even to 20 t.

The mine duty in mechanized mines can be noted as an average of 5 t per man-shift.

Selected case-stories of underground exploitation

Region Drniš

In the Drniš region more than 300 deposits have been registered, of which a great deal are excavated. As has been said, the terrain was explored already 1906, but the exploitation began not earlier than during the world war I. Since then, it lasted, with interruptions, till 1990/91, when it ceased, like in the entire Western Dinarids, as a consequence of the barbarous Serbian sudden attack on Croatia. Till 1969 the administration has had its seat at Drniš, then the enterprise was joined to the bauxite firm with the seat at Obrovac. Till 1969 in Drniš has been produced about 5.2 million tons of bauxite resp. around 100,000 t yearly. It can be supposed that from 1969 to 1991 the Drniš zone has given one million ton bauxite more, what means that in the region Drniš altogether has been excavated up to now about 6 200 000 t of bauxite.

After data, kindly supplied by our colleague Ing. Zlatko Ljubič (1988 and 1994), whom we, here also, are thanking for his exhaustive and expertly help, the initial production 1915 began on the outcrops »5<, »6<, »7<, and »8< of the district Kalun—Umći and was »of a modest volume« and has been »several times interrupted and continued...«. A more substantial production began 1929/30, when the 'Continental Mining & Industrial Co.' (with the seat in Budapest) took on lease a row of deposits on the Mountain Kalun... In view of the limitations of its mining property, the 'Continental' was the first (of several mining companies on that territory, authors' note) »which had to think of underground exploitation« — obviously after the surface deposits have been excavated.

Mine Kalun

To an earnest thinking of underground exploitation for the »Continental« it came very soon, by the end of 1931.

The development of the underground exploitation in the region Drniš are here depicted on the ground of accounts of two engineers who worked there during periods when important decisions concerning the mine Kalun have been made: Damir Franotović (illustrations, 1969 and later) and Zlatko Ljubič (text, at our request 1988 and 1994).

Our report is rather extensive because the theme merits it: The mine Kalun is not only chronologically the first bauxite underground mine on the Balkan, and thus also a »miners’ school« (both for engineers and foremen), but also because this is very likely the last description of that deepest underground bauxite mine in the world based on authentic data furnished by cooperators in its development.

Lastly, also with regard to its form, position and magnitude, the Kalun deposit is unusual, as
can be seen in Fig. 9. There are other perpendicular bauxite deposits in the Western Dinarids too, e. g. Tihotina near Bihać, Dračevac near Obrovac, also some others, but Kalun became a celebrity both as a »miners' school« and by its mineral wealth; as to the wealth, the story was elaborated all over particularly after the shut-down, because the immersed level remained under water over the whole width, and the orebody's extension into the depth is not known ...

The mine Kalun itself was opened 1931 by an incline from the hanging wall of the excavated surface deposits on the northern slope of the Kalun Mountain. Thus the 1. and 2. level of the future mine were opened and then developed: Fig. 12-I. As can be seen, the levels were on marks 312 resp. 262 m, i.e. they were driven at an interval of 50 m; the distance between the deeper levels was about 60 m.

This initial, »northern« or »hanging«, incline reached, on the plane of the 2nd level, a vertical depth of 120 m — and no discontinuance of the ore extension to the depth was in sight. It must be noted that this fact then as well for the mining as for the geological experts represented at least a surprise. As Ljubić (1988) put it in his records, »nobody at that time could foresee or even guess what these deposit in fact do represent... Foreign experts, geologists (Austrian and Hungarian), who visited the surface workings during and after world war I, advocated the opinion that the bauxite could descend at most 40 m below the surface. Also later on... nothing more was known... The company opened level after level without reliable exploration works whatever... On the biggest surface deposit, after finished excavation works, as near as possible to the hanging layers (which dipped vertically), one or two manual derrick-mounted borings of 30...35 m were sunk — and this was the basis for the development of underground level 1.«

From the second level it was confirmed by boreholes (also manual) that the ore extends deeper down, and so the next levels, the 3rd and 4th, were opened by a new, the second, incline, this time through the foot layers from the southern side (Fig. 12—I, Foot incline). The 4th level (mark 142) excavated, again by manual drilling from this level it was confirmed that the ore extends further down. Therefore, 1954/55, from mark 142 the next levels, the 5th and 6th, marked 82 and 22, were opened, but by a shaft. The development situation of that time is shown in Fig. 12-II. That was a period of a gradual recovery and work intensifica-

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Fig. 12.1. Mine Kalun (after Franotović, 1955 and 1969), general longitudinal section: 
A 1 excavated, 2 developed for exploitation, 3 probable ore, 4 incline in the roof, 5 incline in the floor; 
B 1 hanging Promina layers, 2 footwall Foraminiferal limestones, 3 Liburnian limestones, 4 footwall Rudist limestones, 5 bauxite

Within the 6th level the mine Kalun reached the depth of 360 m and thus became the deepest bauxite mine on the Balkan and probably in the world. But during the development of the 5th level, on mark 82 m, mighty water sources were met, up to a capacity of 15 m³/min during heavy
rainfalls. Yes, the stopes and other workings were protected by a system of underground dams, but this, with the costs of water pumping, increased the production cost to such a measure that the mine 1963 had to be closed, before the ore on the 6th level could be excavated. The mine is now flooded by a permanent water level slightly over the mark 82 m on the 5th level.

Franotović carried out in the years 1952/53 some measurings and calculations in order to determine the form and the size of the Kalun orebody. After that, the surface outcropping of this orebody has had an area of 2500 x 3000 m. The ratio mineralized versus barren contact plains comes on average for the whole orebody to 1:2.16, for the upper zone up to the 2nd level 1:1.44, and for the lower zone down to the 4th level 1:4.20. From that one can deduce an average thickness of the orebody of about 4 m resp. 10 t of ore per square meter. In the middle parts, the thickness can reach up to 13 m, and in tectonic dislocations even 20 m.

Thus it's clear that Kalun was, and partly is, a very irregular orebody with enlargements and narrow passages, vertically pressed into the hiatus between the hanging and footwall layers for a length of more than 300 m. Only that was not known in the year 1931, when the deposit was tapped by underground development. Of course, neither a mining method was known. In the beginning, and for a long time, downward open stoping in horizontal slices was applied (Fig. 12-III A). In fact, it was breast stoping, for the ore was excavated in full width, from roof to floor. The method could be used because the sidewalls (roof and floor limestones) were hard, and, moreover, the method had the advantage of a clean excavation and a fast and inexpensive timbering. But it also had a big drawback wherefore it in the end has to be abandoned: Unsatisfactory safety because of large open cavities above the stopes. True, a safety pillar of 4 m between the levels was left, but for that purpose very long timbering logs were needed, with cumbersome transportation. Besides that, thick ore nests couldn't be excavated completely.

The first attempt to change the mining method, after some ten years of open stopes, was made immediately before the war 1941, by introducing an upward excavation system with filling. The attempt failed. After the war, 1945/46, » of a sort of magazine mining or shrinkage stoping was thought, and so a combination of magazine mining and block caving was applied« (Fig. 12-III B). Thus a block of 25 000 t was won. Although the excavation itself was successful, two essential shortcomings aroused: the ore quality suffered and there were difficulties with irregular and insufficiently steep nests« (Franotović, 1954). Finally, the now already »classical« method in bauxite mining was adopted, the sublevel caving method, with sublevels at distances from 4 to 5 m (Fig. 12-IV). In the Kalun mine it was found that the method is infested by the following deficiencies: unsatisfactory duty, high timbering expenditures, difficult maintaining of discipline as to strict observance of working rules, and partly, however subordinated, the unrealized aim of a clean excavation.

The mining district Kalun was unique also as to the transportation system: from 1928 to 1956 animal haulage by horses was used. Practically, from the very beginning of exploitation, as yet open-cut mining was carried out, horses have been used, but they promptly were transferred to underground work. They did work down to the 4th
The ring of horses to the 6th level was never taken in consideration at all out of security reasons (Ljubič, 1994).

When, 1963, the work at Kalun due to water inflow was stopped, the tonnage excavated from this mine together with the organically connected deposits amounted roughly to 2,500,000 t, i.e. nearly 40% of the total production of the Drniš region.

Beside Kalun, in this region also some other deposits have been exploited underground: Kumanovo, Foća, Krstančuša, Didare, and others.

**Mine Kumanovo**

The mine Kumanovo is situated 14 km northwest of Drniš. It was exploited for ten odd years, from 1953 till 1963, and is shown in Fig. 13. It was opened by a shaft of 100 m and an incline, dipping 45°, to the mark 152 m. Under the sump it was further developed by an incline of 37°; thus the total depth of the mine was reaching 155 m. Like at Kalun, the exploitation took place parallel to development, by usual surface exploration methods. Thus the haulage was executed by incline/rise to mark 152 and then to the surface by shaft.

**Region Obrovac**

The Obrovac bauxite is, probably, the first bauxite from the Balkan which under that name has been scientifically documented: it is mentioned in the geological map of the Austro-Hungarian Monarchy of R. I. Schubert 1:75,000 of 1903—05, sheet Novigrad—Benkovac, zone 29, Col XIII. In the year 1906 one French consortium even carried out some prospection works, 1914...
the Austrian fisc established a »K. K. Grubenleitungs«, and during the war 1914—1918 the deposits of the Krusevo district have been exploited and the ore was sent to the German aluminium plant »Gebrüder Giulini« at Ludwighafien; besides local labourers, also Russian war prisoners worked there — as in other Dalmatian and Istrian bauxite mines, too. After the war, a vehement fight between French and German, even American, aluminium companies broke out about concessions for this in the meantime famed region. In the end, a French—German consortium set first steps in really grandiose development works — at least for bauxite at that time: a very imposing administration building and a solid mechanical workshop were erected at Maslenica (both used till 1990/91, when they were destroyed and burnt out during the Serbian aggression on these territories); further, two steel loading bridges for ships up to 10 000 BRT were erected (one of them still stands, and was in service for years, from 1962 till the shut-down of all work 1989/90); to the main deposits access roads had been constructed, tracks had been laid; special attention was given to the biggest, most remarkable, deposit Dračevac, where massive development works were carried out: a 180 m long adit in the hanging was driven (»Lujoc«), thus securing an overhand height of 26 m, also a level course of 200 m through the ore (»Galerija«) was driven, with six crosscuts from the footwall to the hanging wall, and two brake inclines to the sea. Furthermore, during the new beggining in the Dalmatian bauxite mining, in the middle of the sixties, here once more extensive exploration works have been undertaken; among others, also three borings down to the footwall rocks, of 53, 74, and 70 m, were carried out.

The following exploitation of the first period does not correspond to this spectacular overture: the exploitation lasted only three years, from 1926 to 1929; during that time three shipments of bauxite were effectuated, two of bauxite from the district Krusevo and one from Dračevac. The owners being aliens, who virtually did not contact with the public, it’s not known for sure why 1929 all activities were totally stopped, why even the installations were abandoned. True, it’s a fact that 1929 in Krusevo in an accident seven miners came to death, and it was said that this, allegedly, was the real reason for the suspension of all work.

But it is more likely that the main reason was the ore quality. Yes, the region Obrovac was in the professional public known by its big reserves, especially by the imposing deposit Dračevac — but also by the low ore quality. Franotović in his unpublished prospect in the mid-fifties of the Obrovac bauxites from 1956/57 brought their average grade on the basis of several hundreds of analyses both from the period of the first prospection and exploration works as from his own time; here this average: 48,50% Al₂O₃, 5,04% SiO₂ and 23,70% ignition loss. Happy times when the exploitation of such a trihydratic bauxite has been abandoned for low quality. Till the nationalization of all ownership rights after the year 1945, in the region Obrovac every work lay still. An exploitation, of lacking vigour, was set in motion only 1955, under the management of the Drniš firm, and 1957 an autonomous administration for the Obrovac region with the seat in Zadar was founded which 1969 included the Drniš bauxites, too, and thus was operated till the shut-down 1990/91. Operated, maybe, with an unreasonable vigour, so that Obrovac in the year 1972, with an output of 720 000 t, became the biggest bauxite mine as to the production in Yugoslavia of that time. Substracting the volume excavated in Drniš during the common administration, a tonnage of one million, for Obrovac alone it comes to about 9 million tons as the total of won bauxite from the beginning »up to now«...  

**Mine Dračevac**

The deposit Dračevac is a part of the »contact« line Maslenica—Jasenice, »without doubt the biggest known bauxite concentration among the productive contact of Dalmatia«, how it stated Franotović 1956. He further about this contact writes: »In the contact section of 6.4 km, where the bauxite accumulations are disposed, the outcrops have a total length of 2,225 km. In that participate 14 larger uninterrupted outcrops, each averaging 137 m, from 30 m with the smallest to 500 m with the longest. The total area of these 14 outcrops is 30 150 m²; whereof a mean thickness of 13,7 m results, from a minimum of 1 to a maximum of 50 m. Disposing the bauxitic filling on the total length of the contact line of 6400 m, a theoretical outcrop of 4,7 m equal thickness is obtained. In a comparison with the Kalun: there the mean thickness of the bauxitic filling is 4 m, and the thickness on the total contact length of only 2500 m is 1,7 m². As already mentioned, in the Kalun mine on a square meter of the orebody, reduced to the roof surface, 10 t bauxite can be allotted; the same index for the contact line Maslenica—Jasenice amounts to 35 t.

The deposit Dračevac is named after a close by dominant conical hill (mark 200 m) supposed to have served as a relay station on the very Venetian—Turkish frontier in the 17. and 18. century, and that as the first on the Turkish side; the next could have be on the nearby summit Zelengrad (552 m) to south—east, and then further ahead to Istanbul, all by fire resp. smoke signals... (Fig. 14).

The deposit Dračevac is represented in Figs. 6 and 15. The area of the outcrop was 6500 m², at an average altitude of 140 m (Fig. 6). The unhatched part in Fig. 15 has been excavated in the seventies by open-cut mining; that means that also the part which in the old days of the first period was envisaged and developed for underground exploitation has been excavated by surface workings. Obviously, at that time no sufficient experience has been acquired as yet: by the expensive »Galerija« practically none overhand height was gained, and so the presumption is allowed that it was driven for exploration purposes, as well as the crosscuts.
explored by manual boring: one of the boreholes on Ćukovac, reached a depth of 75 m in bauxite. 1955/56 the exploration works were continued by shallow shafts and trenches, and during the years 1979—1983 the deposit was exploited by surface operations down to the mark +65 m.

As can be seen in Fig. 10, the mine is opened by an incline of 12° in a length of about 410 m, with the bottom at mark 44.9 m; the incline is equipped by a hoisting conveyor. The mine is fully mechanized (Fig. 16): the loading was effected by Diesel loaders, the transportation by cars. The mine is endangered by sudden flooding due to heavy rains in the winter (of mine flooding problems in the Mediterranean Climatic Zone v. below).

Fig. 14. The »relay« hill Dračevac; in the foreground the sinkhole of Jasenice, later on buried under waste rock excavated from the surrounding bauxite mines.

Mine Ćukovac—Grižinice

The deposit Gnojine/Ćukovac—Grižinice is also a part of the famous »contact« line Maslenica—Jasenice and in fact is a direct continuation of Dračevac to south-east. It is represented in Fig. 11, and more detailed it is described by the designers of the mining method, Perić and Vujec 1992.

It is situated at an altitude of 150 m. Before the war 1941/45, in the twenties, the deposit has been

Deposits Krš I to IV

The group of deposits Krš I/IV in the district of Kruševo is remarkable because, in the close of the eighties, it was excavated underground, and that, like Gnojine-Ćukovac, fully mechanized (Fig. 17).

Region Mostar

As region Mostar usually the Herzegovinian part of the Dinaric bauxite bearing zone is taken, in a length of about 150 km, from Aržano to Bile-
The deposit tonnage varies from some hundreds to one million tons. Big deposits are rare and so far only a few deposits of million tons have been found (Orašnica, Trobukva, Okrugli Brijeg, Lokvice, Dubrava). Yet, the quality of these bauxites is such that they must be included among the most suitable for the Bayer process. After Marušić (1945), the ore prepared for production in the first postwar period 1945 has had the composition of 55.5 ... 62.4% Al₂O₃, 1.5 ... 4.0% SiO₂ and 11.3 ... 13.3% loss of ignition and after Lovrić (1984) the corresponding minimum and maximum values for the ore produced from 1951 to 1975 have been: 53.9 ... 56.4, 1.8 ... 3.6, and 9.1 ... 10.6.

As already mentioned in the chapter EXPLO-RATION, the Herzegovinian bauxites have been known already at the dawn of this century, and the first exploration works took place 1909/1912 near Domanovići (obviously because they were situated just on the main traffic road Metković—Mostar—Sarajevo); here, too, began the first exploration: the firm »Bosansko d.d.« from Zagreb excavated 1917 about 4000 t and transported it by motor trucks, over a bad freight-bridge on the Neretva, to the railway station at Čapljina and therefrom by the narrow-gauge railroad to the port Gruž by Dubrovnik. The ore quality was, for that time, relatively low, and, because the total costs couldn’t be paid, the production was stopped (Lovrić 1984). The second attempt was made immediately after the first world war. The »Bosnian Mining Society« from Sarajevo realized during two or three years a tonnage of some 10,000 t, but the production once more stopped for the low quality (Marušić, 1945). Here some analyses of that despised ore: content of Al₂O₃ from 52 to 62% and of SiO₂ from 1 to 3%.

A real production begins 1935; in that year about 80,000 t was excavated, predominantly from districts immediately east and west around Široki Brijeg (Knešpolje, Uzarići resp. Trbošić) and minor quantities at Blatnica by Citluk. Since then, with an interruption during the last wartime year 1945, the production went on until the outbreak of the Serbian aggression 1991. All in all, in the region Mostar about 16 millions of bauxite has been excavated.

Till the period 1939/40 the exploitation was almost exclusively by surface excavations, with the exception of small, by shaft opened, underground workings at Sudrova Glavica, a mining district of the mine Trbošić near Široki Brijeg. In the year 1940, the big deposit Orašnica was taken in production, and that by underground operations. Successively, other mines, too, were opened, thus already 1952/53 the share of underground workings amounted to 60% (Zeravica, 1953). That portion increases yet further till the year 1958, when the relation mine: surface reaches 68,5:31,5, then decreases till 1962, when the relation approximately is 50:50. The volume of ore won on the surface from then on steadily rises, and thus 1983 comes to 94%. In the second half of the nineties, the last production period so far, the underground participation was always under 15% (Lovrić, 1984). In Mostar it’s regarded that there the limit-line of profitability between underground and surface exploitation can be expressed by the relation 1 t of ore: 6 m³ overburden.

**Deposit Orašnica**

If the deposit Dračevac by Obrovac is a part of the »without doubt biggest known bauxite concentration among the productive contacts in Dal-
mateia», as it Franotović, (1956) has stated, then, also without doubt, Orašnica is a part of such a concentration in Herzegovina.

This Herzegovinian «concentration zone» extends in a length of some 45 km, from the district Studena Vrela on the very Bosnian-Herzegovinian frontier between Posušje and Duvo, and over the then (prewar) districts Vučipolje, Sobač, Krstaće, Cerovi Đoci, Crne Lokve and Lištica to Mostar. After prospection works have been effectuated in the period from 1935 to 1942, mainly in the form of geologic reconnaissance and of shallow trenches and manual borings, this zone figured in the calculations of would-be purchasers of that time with the volume of 3.6 millions visible ore. The volume was obviously extremely underestimated, but then in the ruling mining wealth broking climate such a pose was the inflexible attitude of potential buyers.

Orašnica is situated in the areal of the village Crne Lokve, the richest part of the mentioned zone. Here 19 deposits have been registered on a line of 4 km; after an extensive exploration, already during the sixties an exploitable tonnage of 4 millions bauxite was officially attested (Lovrić, 1984) (in former Yugoslavia official bodies existed which yearly examined by the managements produced proofs on the executed exploration works and attested /or demanded supplements for the tonnage).

NOTE: Of course, the «potential buyers», too, did know very well the real wealth of the region. A nice evidence is the case with the road Privalj—Crne Lokve. Privalj is a spot on the provincial road Mostar—Posušje, from where till 1939/40 only a bridlepath led to Crne Lokve; then a foreign firm, one of the «potential buyers», constructed a road, capable for heavy traffic, too. The road is 14 km long and was 4 m wide. Today, it’s widened and asphalted, and frequented by a daily bus-line Siroki Brijeg—Crne Lokve — for old bauxite-men an unbelievable amazement . . .

Orašnica is the first big underground object in Herzegovina. Due to a suitable site on a slope, from the very beginning it was opened as an underground mine, by an adit through the footwall, about 80 m long, driven approximately during the same time as the road was under construction, 1938/39; in Fig. 18 this adit is marked by I, and the Fig. 19 is a snapshot of old days of the ore chute there. When the orebody Orašnica was coming to end, it was connected by a level along the hanging wall with other neighbouring deposits, some ten-odd of them. These deposits were opened, by reason of more favourable ore haulage, by separate adits, too, thus in the end the »Mine Crne Lokve« was opened by four adits (v. Fig. 18); the longest, »Krstaće«, has had roughly 800 m and comes as far as to the last, western, deposit in that »rich string«, to the »Swiss House«.

The mine Crne Lokve was active till the mid-sixties. Altogether here about 4 million t bauxites was excavated, approximately so much as estimated; Orašnica alone, as already said, yielded something over one million tons, on the total average of 56% Al₂O₃ and 1% SiO₂ (Lovrić, 1984).

Deposit Tribošić

The mining district Soldi—Tribošić—Šudrova Glavica is situated some 4 km of bee-line east of Crne Lokve, but over the deep canyon of the, mostly dry, rivulet Ugrovača; Šudrova Glavica is already mentioned in the chapter OPENING as the locality where yet before world war II underground exploitation works have been in progress.

* We consider here as indispensable to make known how this deposit, the spot itself for that, came to its name: it was a real Swiss, the late Godefroy de Weisse, the world’s authority on bauxite geology, who dwelt here. His firm, Aluminium-Industrie-Aktien-Gesellschaft (AIAG), Lausanne—Ouchy, erected a small house for him (he himself chose the site) to facilitate his prospecting and exploration works on the spot. The house is shown in Fig. 20. De Weisse lived here, with interruptions, from 1936 to 1939/40. Partly on here gained experiences he founded his classic book »Les bauxites de l’Europe centrale« (1948), as yet the most quoted book on bauxite in the world.
tectonic shells of Upper Cretaceous and Paleogenetic limestone layers. Due to strong tectonic disturbances, the ore is of low hardness and has many fissures. In the roof are thinbedded clayey limestones and breccias; these layers very readily cave in during the mining operations. In the floor are Cretaceous limestones suitable to permanent mine rooms.

The mine was opened by an adit on the 600 m level; from there two raises of 60° were driven (S. Fig. 21A), up to level 654. On that niveau a ventilation drift is situated (1 in Fig 21B).

The deposit is divided in sublevels of 6 to 7 m, and is exploited by the usual sublevel caving method (Fig. 21B). The loading is effected by electro-loaders with a bucket volume of 0.3 m³; satisfactory duties were achieved, of 15 to 25 t/shift. But, on the other hand, the purity of the won ore is very unsatisfactory: the weak hanging caves in immediately behind the stopes, what causes such a mixing of bauxite and waste that the excavation losses rise even to 50%. Attempts were made to reduce the losses by applying wire meshes. Such appliances are known from exploitation of thick coal beds by long-wall methods, but also from the important Ural bauxite mines in the former Soviet Union. In former Yugoslavia it was envisaged for the Vlasenica bauxite mines in Eastern Bosnia; practical experiences so far are not known.

After the primary idea for Trbošić the wire mesh had to be placed on the floor of the first, highest, level, thus a mixing of the ore with waste during the excavation of the lower levels should be prevented. In Fig. 21B is can be seen that, due to the form (dip) of the orebody, the levels are folded vertically each over the other only partially. In the project it was planned that the first level has to be excavated by mutually parallel drifts, thus enabling the deposition of the meshwork on the drift floor, with folding over the neighbouring drift. The overfolded meshwork parts are bound together by PVC-strips. After caving of the hanging on the second and the next levels, the meshwork should have prevented the mixing of ore and waste (Fig. 21C). For that purpose, in advance of the excavation on the next level, the mes-
Meshwork had to be deposited on the part where the lower level oversteps the vertical limit of the upper level. This had to be secured by driving of parallel raises through bauxite under the contact of ore and hanging, from the niveau of the lower to the niveau of the upper level. The meshwork laid out in the raises should fold over the previous deposited meshwork. A system of raises under the floor has been projected also on all lower levels where, due to the orebody position, the lower level steps out under the upper one.

The experiment in the end did not work because in the realization there have been some omissions due to insufficient experience and lacking discipline. So, the deposition of the meshwork was too late, and in one part of the first level it was not deposited at all. Therefore, after the second level the attempt was abandoned. However, on the basis of the experiences gained, the conviction is strengthened that, by better preparation, the application of meshwork for prevention of ore dilution could yield valuable results.

**Deposit Trobukva**

The mining district Posušje, where the deposit Trobukva is located, opened as the last in the Mostar region, not earlier than 1956. Trobukva is situated some 5 km north of Posušje, just on the road to Duvno/Tomislavgrad. It's the most important deposit of the district Posušje. With reserves of about one million tons it ranks among the biggest deposit of the Mostar region, in the class of Orašnica, but with less favourable exploitation.

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**Fig. 22. A, B** Mine Trobukva

A plan of the deposit: 1 contours of the orebody, 2 contours of a level

B level plan

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**Fig. 22. C** Mine Trobukva, support by roof bolting and wire mesh: 1 rock bolt of 3.3 m, 2 rock bolt of 2.1 m, 3 rock bolt of 1.5 m, 4 wire mesh 3.5 x 3.5 cm, 5 concrete weight, 6 collapsed roof, 7 hard bauxite, SH drift, OH stope level, OH' stope level (planned), ZS protective pillar, ZS' protective pillar (planned)
conditions and, especially, with unfavourable hydrogeological conditions; which will be considered more in detail below.

The footwall is built up of hard limestones, suitable for underground open spaces without support, pierced by a system of discontinuities and caverns. In the immediate hanging are 20 to 40 m thick hard marls and further up mainly conglomerates.

The deposit is shown in Fig. 22A. Underground exploitation should have begun 1971, and the deposit was then opened by two steep inclines, of 40 and 44°. But the works had to be stopped because of unexpectedly high water influx during the rainy period. During the next years from the mine were pumped, as a permanent flood, 8 to 16 l/s water, what heavy rains yet rapidly enlarged.

A new project was elaborated and the mine was 1983 opened once more, by a new incline of 9° which follows the orebody and thus made it possible to reach each level by the shortest crosscut. The height of a level is 7 m, therefore for the excavation of the entire orebody, from mark 820 to 728, the development of 13 levels are planned. The mine map of the fourth level, Fig. 22B, presents the principle of development and exploitation of each level by sublevel caving. The mine is mechanized. Opening, winning, and haulage is by Diesel equipment. By Diesel loaders with buckets of 1,7 m³ also the loading at stopes and the haulage by the main levels is effectuated. The ore is hoisted in the hoisting incline by Diesel trucks of 10 ... 16 t. Boring is carried out by hydraulic autonomous drill rigs. The earlier driven inclines serve for ventilation. Compression ventilation is used, for preventing a contamination of the stopes by truck exhaustgases.

Support is not mechanized; timbering and steel supporting is used (Fig 22C). For high costs of this mode of support, at Trobukva roof bolting was tested. Experiments with Swelllex bolt extraction have given satisfactory results, in spite of the marked discontinuity of the bauxite, and therefore in the future classic support shall be replaced by roof bolting. The disposition and dimensions of the bolts can be seen in Fig. 22C.

The unexpectedly high water influx to the mine Trobukva during excavation works could not be foreseen, and so the second project, too, could be designed only on assumptions. Assumed was an influx maximum of 120 l/s but the possibility of a higher water amount was however envisaged; therefore the drainage was realized by sinking pumps. Three of such pumps were installed, each of 120 l/s, with a manometric height of 150 m. The control panel of the pumping station is situated on the surface. For all other equipment, including the machines, it's provided to be withdrawn from the mine in case of an inflow greater than 360 l/s.

After a few working years without water trouble, during a heavy and longlasting rainy period in the year 1987 an influx of 533 l/s sprang out and drowned the mine in a short time up to the incline entrance. After the rainy period came to end, the water was partly pumped out and partly flowed off by the discontinuity system in the floor.

Water pumping from mines which are located below water-table is well known from Hungary. The problem is, e. g., elaborated by Kis (1985). But rare are cases where the deposits are located some tens or even hundreds of meters above the water-table and, besides that, have a carstified floor; here, one should expect that such mines couldn't be flooded. However, only in this paper three such cases are described. First, there is the mine Kalun. But here big water masses appeared not earlier than the exploitation touched the water-table, and that during heavy rains. In the mine Cukovac—Grizinice, and especially Trobukva, to inundations it comes mainly by two reasons. Both mines are surrounded by relatively high mountains, collectors of large water masses which by systems of discontinuity pass through the orebody to the drainage level; that’s one thing. Second, during the mining works the discontinuity systems very fast are choked by bauxite, what, of course, prevents the inherent mine drainage. That is the reason why the drainage trenches in all workings of bauxite mines always must be held clean with utmost care, otherwise the bauxite mud very fast almost hermetically chokes up all passages.

The example of the mine Trobukva is an impressive warning of unexpected phenomena in the Dinaric carst.

With Trobukva still yet another rather uncommon phenomena in bauxite mines is connected. That’s the occurrence of methane, carbon dioxide and monoxide. In the roof of Trobukva’s orebody occur thin intercalations of brown coal. In the course of roof caving, conditions for spontaneous coal combustion are created, and also for forming of CO, CO₂, and CH₄; therefore in the mine a specific regime had to be introduced. This, too, is not an isolated case in the underground exploitation of bauxite ore.

Mine Dabrica

The mine Dabrica belongs to the sector Stolac and is situated about 28 km north of that place. The deposits were known from the beginning of this century, but insufficiently, and, moreover, the region is away from roads, therefore the first real exploitation took place only 1952, when about 35 000 t have been produced. Nevertheless, some works were carried out also during the war 1941/45. The owner of the terrain was a Czechoslovakian combine which by all means tried to avoid any production work and subterfuged itself with a road construction. The deposit, in fact, were unapproachable for trucks, and the Czechoslovakians constructed in the years 1941/42 an industrial road of 13 km, from the crossing with the provincial road Stolac—Capljina to Dabrica. Along with that they produced also some bauxite, altogether about 2500 t, with the composition of 49 ... 56% Al₂O₃, and 1,5 ... 6,15% SiO₂. Also later on the production was irregular, sometimes it lay still for years (1964—1974), to become constant not until the Mostar alumina plant started.
1976. In course of efforts for securing resources for this plant, in the seventies extensive exploration works have been undertaken, and there in the district Dabrica in a few deposits reserves about one million tons have been determined. For the biggest, underground exploitation was provided.

The main deposit is 420 m long and 130 m wide. The depth is from 70 to 140 m, the ore thickness varies from 1 to 19 m. In the footwall are hard Rudist limestones, in the hanging wall sandstones, conglomerates and, partly, marls. The mine is opened by an incline of 44°, with a length of 188 m (Fig. 23); the incline is the main entrance to the mine, and serves for hoisting, ventilation and men handling. In the footwall, the main haulage and ventilation drift are located.

The ore is loaded and hauled to ore chutes by compressed-air loaders Kavo 310ii (Atlas Copco). In the main level the ore is transported by mine cars pulled by storage-battery locomotives to a bin at the incline bottom; through the incline the ore is hoisted by skips.

The ventilation of the mine is satisfactory, for the entire mechanization is by compressed air, without Diesel engines. Satisfactory is also the situation with water because the inflow is small and constant even during the most heavy rains.

An open problem remains the transport, specifically the manifold broken haulage, the complicated material handling, and the unsettled men transportation.

**Region Jajce**

The Jajce region has been known yet during former Yugoslavia, when it was prospected and in the year 1937 some bauxite also was produced from the deposit Bešpelj, 9 km north of Jajce. However, a real exploitation begins but 1958. Till 1990 the region has given about 5 million tons of bauxite.

Important are the underground mine Poljane, Crvene Stijene, Bešpelj and (in the last period) also Liskovica. Only one open-cut is of some importance, Baraći, insofar as its low-grade ore was used to get a balanced grade according to selling contracts. The relation between underground and surface exploitation 1990 may have been 90:10% or even 95:5%. Thus the underground exploitation predominates in a high degree, what is conditioned by the geologic circumstances. These circumstances, chiefly the dip of the contact plane, conditioned also the opening mode and development of the mines. The contact between the hanging wall and footwall varies from east to west: at Poljane this dip is 17°, at Crvene Stijene it's horizontal, at Bešpelj vertical, and at Liskovica, on the left bank of the Vrbas, the structure of the layers is inversed, too.
Mine Poljane

The district Poljane comprises several deposits with one common haulageway. The mine is opened by two parallel inclines on the »contact«, with a dip of 17°. Both inclines are hauling ones. The mine is mechanized by compressed air equipment, so for ventilation purposes small profiled workings could satisfy.

There are no problems with water: even during the heaviest rainfalls it penetrates and flows out through the rock discontinuity system, without any pumping.

Mine Crvene Stijene

Like at Poljane, here, too, the district comprises quite a lot of deposits, Fig. 24. With regard to the horizontal contact between the hanging wall and footwall as well to the favourable terrain configuration, the mine is opened by two parallel adits. The hoisting adit is in the floor and the ventilation adit above the main part of the deposits. In that way, by a pair of chutes in each deposit it's at the same time made possible to use the adits both for gravitational ore transport and handling of men and equipment. Hoisting is by cars pulled by storage-battery locomotives. The loading in stopes and the level haulage in the first period was effectuated by loaders »Cavo 310«, later Diesel loaders of larger capacity were used.

Here, too, the standard sublevel caving method is in use, but here, due to hanging wall characteristics, it displays its large disadvantages. Namely, the hanging wall consists of hard limestones and conglomerates and does not cave in behind the stopes; so, big open spaces are created, even to 2500 m², which cannot be controlled. That is a big danger, and therefore extensive investigations have been carried out to remove it. Mathematical modelling in order to establish the stability conditions has shown that the problem could be solved in the best way by cable bolting. By investigations in situ the correctness of this possibility shall be verified.

Region Bosanska Krupa

The region Bosanska Krupa belongs to the group of less important bauxite regions in former Yugoslavia (Imotski, Sinj, Kosovo . . .); all in all, up to this day there about 1,8 millions tons of bauxite was excavated. Strictly speaking, it comprises (as in this paper treated) the west part of the Grmec Mountain in Northwestern Bosnia.

The region attracted some interest only when in Dalmatia and Herzegovina all potential bauxite-bearing territories have been covered by leases and for further breaking the turn came to practically unprospected areas for which, moreover, it was rumoured that there lie immense masses of firstclass bauxite. First exploration works were carried out by the end of 1937, and in the spring of 1938 begins an exploitation, too, which lasts till 1941, when all works must be abandoned due to the outbreak of war. In that period about 110000 t of ore has been produced.

After the war the plants were restored, and 1952 an autonomous firm was established. The new tonnage was modest, about 60000 t yearly. From 1991 on, no information on bauxite from Bosanska Krupa was heard.

The underground exploitation was concentrated on the so called »contact line« which is described in the chapter GEOLOGICAL SITUATION. On its eastern end, at Risovac, a mine was opened by an incline of 70 m through the hanging; from this incline, levels, 15 m high, through the ore were planned, but only the first, in a length of 130 m, was excavated. It's not perfectly clear why the works have been stopped (there was no war yet). Here two analyses of Krupa bauxite (in %):

<table>
<thead>
<tr>
<th>Locality</th>
<th>( \text{Al}_2\text{O}_3 )</th>
<th>( \text{SiO}_2 )</th>
<th>( \text{Fe}_2\text{O}_3 )</th>
<th>( \text{TiO}_2 )</th>
<th>LOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pritoka</td>
<td>71.32</td>
<td>2.84</td>
<td>8.93</td>
<td>3.20</td>
<td>12.80</td>
</tr>
<tr>
<td>Risovac</td>
<td>65.34</td>
<td>3.40</td>
<td>14.86</td>
<td>2.40</td>
<td>14.00</td>
</tr>
</tbody>
</table>

(\text{Laboratory: Bauxite Mines Mostar, 1951})

It is a monohydratic boehmitic bauxite with little iron and an extremely high alumina component. Such a high share of the aluminium component is commonly a characteristic of white bauxites, with red ones it's very rare, except in diaspore bauxites. The Krupa »contact« red bauxi-
tes partly are diasporic, what can be proved by their high hardness which raises even to 7 of the Mohs scale. In the literature there are very few examples of red bauxites with such high values of Al₂O₃; we have found such red bauxites but of the Indian Jammu Province, quoted by I. Valeton 1972.

The fact that these bauxites are very hard diasporic ones was also a cause of the waning interest for the Krupa contact bauxites. They later on mainly were exported just as raw material for the industry of abrasive and cement.

Region Sinj

The region Sinj is the smallest in the Dinarids: its share in the bauxite production of former Yugoslavia was but 1% (altogether, there about 800 000 t has been excavated). Here it is mentioned because of the mine Visoka, Fig. 7C, which has been exploited simultaneously with the Drniš Kalun, and even was thought that it may contain similar reserves. This hope did not realize. The »bauxite« hill was opened by exploitation adits along a contact of Eocenic limestones and conglomerates; during the exploitation these adits served as haulage levels.

Recapitulation of the bauxite production in the Western Dinarids

At the end, here a table with the bauxite production realized in the represented regions. Also the years of the exploration beginning as well as the first mention of prospecting-exploration works are given. These quoted years are precarious — we think that this should be mentioned. Of course, we have made all usual efforts in order to check these years and to give authenticated data. During that operation we experienced the same like all researchers of written documents: we found different data. The differences are not great, especially with the first production year, but they are considerably greater when the data of first prospecting is in question. And, further, where is the strict boundary between »prospection« and »exploration«?

Framed in such enclosures, the quoted years are »correct«. The tonnage is much more reliable: the unreliability does not exceed some ten thousands tons.

<table>
<thead>
<tr>
<th>Region</th>
<th>Year of production beginning</th>
<th>Year of first prospecting works</th>
<th>Total production t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drniš</td>
<td>1915/16</td>
<td>1906</td>
<td>6 200 000</td>
</tr>
<tr>
<td>Obrovac</td>
<td>1926 (1903/09)</td>
<td>1906</td>
<td>9 000 000</td>
</tr>
<tr>
<td>Mostar</td>
<td>1917</td>
<td>1909</td>
<td>16 000 000</td>
</tr>
<tr>
<td>Jajce</td>
<td>1937</td>
<td>1937</td>
<td>5 000 000</td>
</tr>
<tr>
<td>Bos. Krupa</td>
<td>1938</td>
<td>1937</td>
<td>1 800 000</td>
</tr>
<tr>
<td>Sinj</td>
<td>1916</td>
<td>1915</td>
<td>800 000</td>
</tr>
</tbody>
</table>

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REFERENCES

Crapo, c. (1921): Le bauxites dell’Istria e della Dalmazia. La miniera italiana, 4, 1—2, 492/496, Roma.


Lovric, Lj. (1984): Historijat eksploatacije boksita u Hercegovini (History of the bauxite exploitation in Hercegovina), Mostar.


