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Pregledni članak

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UNDERGROUND BAUXITE EXPLOITATION IN THE WESTERN DINARIDS ESSENTIAL FACTS AND COMMENTS

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After a short information about the causes both for the deficiency of papers on bauxite underground mines and for the development of such mines, a concise sketch of the geologic structures of the bauxite regions in the Western Dinarids, inclusive the chemical composition of the bauxites, is given. The main portion of the paper is devoted to the description of the following bauxitic regions: Drniš (with the mines Kalun and Kumanovo), Obrovac (Dračevac, Ćukovac—Grižinice and Krš), Mostar (Orašnica, Tribošić, Trobukva, Dabrica), Jajce (Poljane, Crvene Stijene), Bosanska Krupa (Risovac), and Sinj (Visoka). Presented are the »bauxitic« history of the region as well as its mining characteristics, from the mode of opening to the used mining methods, with their adventages and disadvantages. Comments are made, but no conclusions drawn; the future remains open.

Ključne riječi: Jamska eksploatacija boksita, Geologija zapadnih Dinarida, Boksitna područja Drniš, Obrovac, Mostar, Jajce, Bosanska Krupa, Sinj, Historijat, Otkopne metode, Uspjesi i neuspjesi

Nakon kratke informacije kako o razlozima za nedostatak objavljenih radova o boksitnim podzemnim radovima i za otvaranje takvih rudnika, dat je sažet prikaz geološke građe boksitnih područja u zapadnim Dinaridima, uključivo kemijskog sastava boksita. Glavni dio studije posvećen je opisu sljedećih boksitnih područja: Drniš (s jamama Kalun i Kumanovo), Obrovac (Dračevac, Ćukovac—Grižnice i Krš), Mostar (Orašnica, Tribošić, Trobukva i Dabrica), Jajce (Poljane i Crvene Stijene), Bosanska Krupa (Risovac), i Sinj (Visoka). Izneseni su i »boksitaški« historijat pojedinog područja kao i njegove rudarske karakteristike, počev od načina otvaranja jama do otkopnih metoda, s njihovim prednostima i nedostacima. Dati su neki komentari, ali zaključka nema; budućnost ostaje otvorena.

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 have been, with the exception of just one deposit near Mostar, in the hands of foreign mining companies which very unwillingly delivered whatsoever data obout 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 develoment of the workings. Thirdly, the total share of undergorund 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 with 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

Fig. 1. The Western Dinarids with the mentioned bauxite regions, deposits and mines

were not yet known, or they are to far away, traffically unfavourable, »politically« inacessible, 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 Istrian 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 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 bauxitic features and mining objects (Fig. 2).

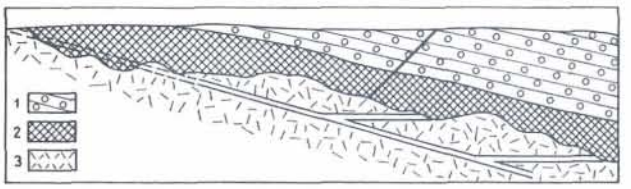

Fig. 2. Typical succesion from surface to underground works. **1** Roof layers, **2** bauxite, **3** floor layers

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 Balićko 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 selectioned, what of course was done, for in the selling contracts substantial premiums for exceeding alumina 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 becames 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 inoxerable logic forced out a dispatch concentratin 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

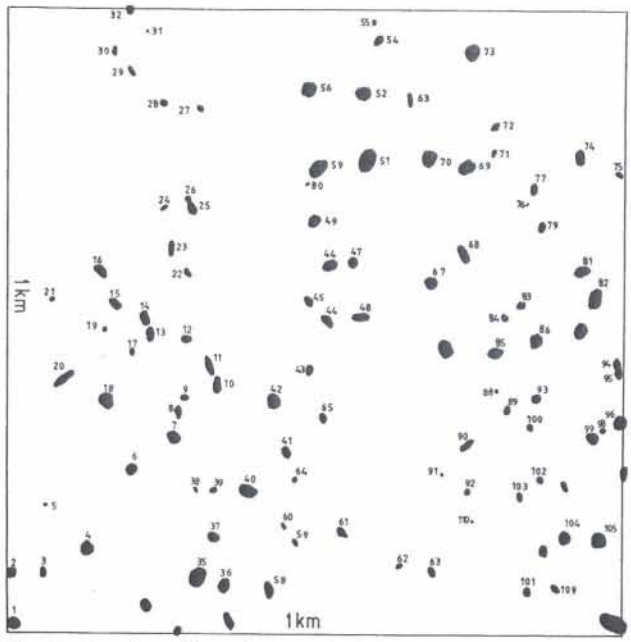

Fig. 3. Density of bauxite deposits in Istria. Area Balićko Polje

were leased). So, when the outcrop extended into undergorund, the bitter pill had to be swallowed, especially when rich ores were in question.

World war II radically changed the circumstances in bauxite mining, like in all other things. Therefore, in the following the »prewar« or »primary« 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 & Šinkovec, 1991), only three are of importance for the bauxite underground exploitation in the western part of the Dinarids. These are the Senonic bauxites of Western Bosnia, the bauxites of the Older Paleogene (mainly, Paleocene) in Istria, Dalmatia, and Western Herzegovina, and the Younger Paleogene (i. e. mainly the younger part of Eocene) in Dalmatia and Western Herzegovina. In the eastern part of the Dinarids, which here is not considered, in Montenegro bauxites of Upper Jura (Malm) have been exploited, and of Lower Cretaceous near Vlasenica in Eastern Bosnia.

Senonic bauxites, won by underground workings, in Western Bosnia, occur in two regions. The first is the region Bosanska Krupa between the places Bihać and Ključ, predominantly in some sectors of the Grmeč Mountain. The region covers an area of some 500 km^2. 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** limestonic breccias and limestones which upwards pass into Younger Senonic Paleocenic marls and sandstones. The relief under the ore in the Grmeč Mountain is, on the whole, poorly developed, near Jajce a little stronger. For the underground exploitation there strange occurrences of pseudopaleorelief in the immediate footwall are rather important: the Carbonaceous layers of Younger Senonic age have an inversed position, so far a practically unknown phenomenon with bauxites (Sakač, 1966); inconvenient are also »pyramides« 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 different both in size and form. Partly, that are thin orebodies, like sheets, only 1 to 1,5 meters thick (Grmeč); for the most part they form small lenses of various thickness (B. Krupa, Jajce); in the region Jajce there are bigger orebodies, too. All orebodies are incorporated to tectonic structures. Predominantly, that are synforms, in varying intensity, 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 inclined, like in the mine **Poljane** in the same region, or perpendicular, e. g. in the mine **Tihotina** near Bihać; and, finally, they also can be overthrown, in an inversed position, like in **Liskovica** near Jajce. A great deal of the deposits in the central part of Grmeč 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 composition with various, mainly low contents of kaolinite and other mineral components. In Grmeč there are also boehmitic-hematitic-diassporic bauxites; these are marked by a great hardness, so that they have been used in the industry of abrasives (at Ruše in Slovenia). Their composition is otherwise rather favourable: they contain 55 . . . 60% Al_2O_3, up to 5% SiO_2, 4 . . . 22% Fe_2O_3, and the ignition loss is about 14% (Sakač, 1966). In consequence of deferrification, the Fe_2O_3 content 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 underground, as in **Pritoka** near Bihać.

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 some North Adria isles, e. g. near **Stara Baška** on the island of Krk, and in Central Dalmatia on the Promina Mountain near **Drniš.** In Western Herzegovina during the world war II there were underground workings in the region of **Široki Brijeg:** at **Crne Lokve, Tribošić** and **Šudrova Glavica.** The **footwall** of these bauxites is built of Upper Cretaceous limestones and the **hanging wall** of well-bedded partly clayey bituminous limestones with clay lenses and coal occurrences (Kozina layers), sedimented in a freshwater, par-

tly marine and brackish environment. The immediate footwall relief is well developed. It is accentuated by hypergenetic processes, therefore the footwall layers are uneven and with many »pyramides«.

The Kozina layers are in the region where they appear incoherently sedimented. In consequence, the Paleocenic bauxite deposits present themselves inconsistently. They are numerous in Istria, where, as already shown (Fig. 3), their density on the surface is very great. On the Adriatic isles in Dalmatia the mineralization of the paleorelief is low and the deposits appear only in some parts of the region, then in groups. In Western Herzegovina big orebodies on strongly mineralized paleorelief are prominent.

The Paleocenic 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 m^2, 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 Šudrova 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 milion tons has been excavated.

The bauxites of Older Paleogene show an oölitic 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% Al_2O_3, 1 . . . 6% SiO_2, 17 . . . 24% Fe_2O_3, 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 relativelly narrow zone. It goes from Maslenica near Obrovac in the northwest over Ervenik, Drniš, Sinj and Imotski in Dalmatia and then over Posušje, Čitluk 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 (Dabrica), and a part of the region Mostar (Čitluk, 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 **Grižinice—Ćukovac** near Obrovac, **Jukići** near Drniš, and **Dabrica** 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 Eocenic Foraminifera limestones. This footwall is very uneven, with numerous deep bauxitic fillings in carbonaceous rocks and many »pyramides« as a regular feature, especially in horizontal and gentle inclined deposits, where hypergenetic transformations of the carbonatic 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 Eocen) — Lower Oligocene age. These layers consist of various limestones, conglomerates, sandstones, marls, clay lenses and occurences 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—Jasenice and Kruševo near Obrovac, in parts of the region Drniš, and arround Posušje and Čitluk (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, Čitluk in Herzegovina etc. Some structures have the form of anticlynes, e. g. Kalun near Drniš and the main tectonic structure of the Moseć Mountain in Dalmatia. There are complex structures, too, formed by reversible overthrust of the footwall over the bauxite and roof layers, the case, e. g., in Jasenice near Obrovac and a sector of Dabrica 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 Al_2O_3 content is 45 . . . 52%, SiO_2 may amount to more than 10% but in the average holds 2 to 6%. The content of Fe_2O_3 equals 17 . . . 25% and the ignition loss is between 17 and 25. With regard to the siutable 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 chliachit resp. wocheinit we don't know, but by these descriptions it's obvious that already then there have been prospection 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 Deskovich, 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 Domanović and says that it was investigated by pits but is rebuking that the shafts were sunk only to 7 m, »but had to be sunk to 15 m«.

The first published article on the Mostar bauxites comes from Jakšić, 1926, (of unpublished expert and »expert« opinions about the Mostar bauxite region there is a whole lot). Jakšić (1937) published also the first scientific essay about the Bosnian deposits in a limited sense (Bosanska Krupa and Jajce).

As can be seen, e. g. after Katzer's writings, bauxite has been prospected by standard mining methods already before world war I. That was continued during the period between the first and second war too; during that time, for shallow surface deposits hand boring very much was used. Hollow rods of 35 mm profile have been in use, 2 m long, with a spiral auger of 50 mm profile. The average borehole depth was 7 to 10 m, the maximum being 10 m.

In Istria a specific »Istrian method« for locating blind deposits under Eocenic covering »patches« has been developed. That is a system of hand boring with iron rods, called »baramina«, in a rhombic net with a hole distance of 4 . . . 5 m. When the deposit is pierced, it is contoured by hand probes in distances of 2 . . . 3 m and then sampling trenches are dug. In decades of application, the method proved very efficient.

Machine boring before world war II practically was nonexistent, but some attempts have been made. So, immediately before the second world war a Swiss firm, engaged in the Mostar region, purchased directly in Stockholm a »Craelius« drilling machine, transported it to Široki Brijeg and there from by horses and donkeys to the exploration site on the Varda Mountain, by bridlepaths some 15 km away and 1200 m high. The attempt did not work. The »Craelius« boring is wet boring and on the Varda there is no water for the drilling fluid. For a short time, water was carried in kegs by donkeys, than by »water-girls« in the same kegs, but because of costs that had to be abandoned, like the whole undertaking.

During world war II the Germans also in two or three cases made attempts with »Craelius« drills, thus, e. g., in the locality Nugli in the region Imotski. Here they finished one borehole of 30 m, and the same depth reached a second hole at Krehin Gradac in the region of Mostar. Both drilling campaigns were of short duration, just the summer and winter 1942. They both were stopped because of Partisan raids and for the impossibility to secure spare parts.

At Krehin Gradac, near Čitluk, also 1942, geophysical methods were employed, too, for the first time on bauxite, so far we know. This mining district, roughly 10 km long and about 2 km wide, was investigated by the Berlin »Reichsamt für Bodenforschung«, mainly by geoelectrical methods of apparent resistance. The results were uncertain, as practically everywhere in the world so far, when bauxite is in question. However, as a suplementary method in the reconnaissance of the terrain, geophysical methods have latter, in the postwar period, been applied in all Dinaric regions — with variable success.

In the sixties and seventies in some Dalmatian and Herzegovinian areas a second specific drilling method came to use — pneumatic boring, i. e. boring 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.

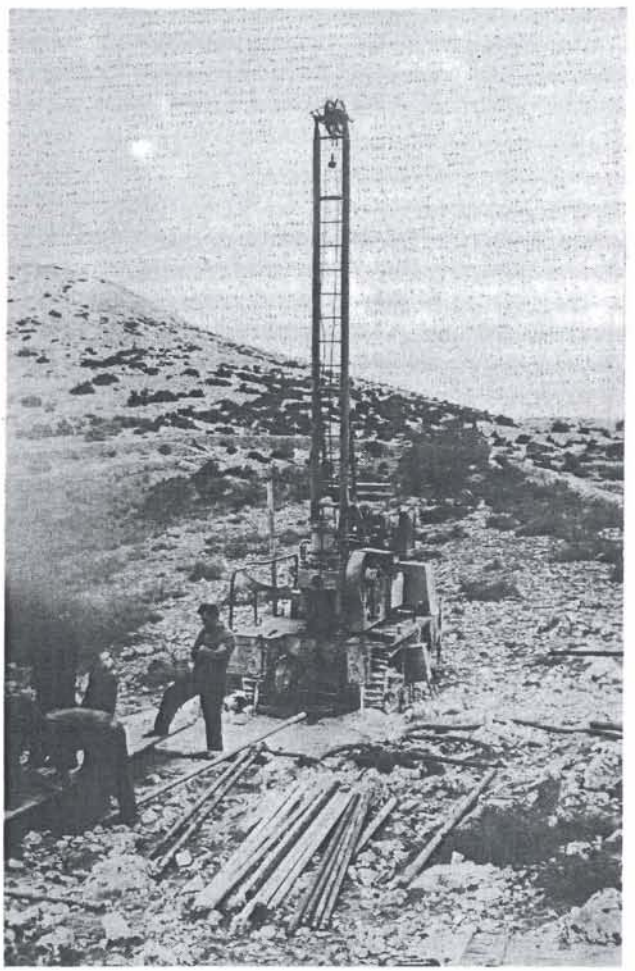

Fig. 4. Caterpillar drill rig in exploration work

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 applicated, 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.

Fig. 5. Exploration works with helicopter help

Fig. 6. Surface prospection sampling (Dračevac, 1961)

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, adit is the most favourable access to an underground deposit, and moreover is conditioned by a mountaneous 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 m^2, 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

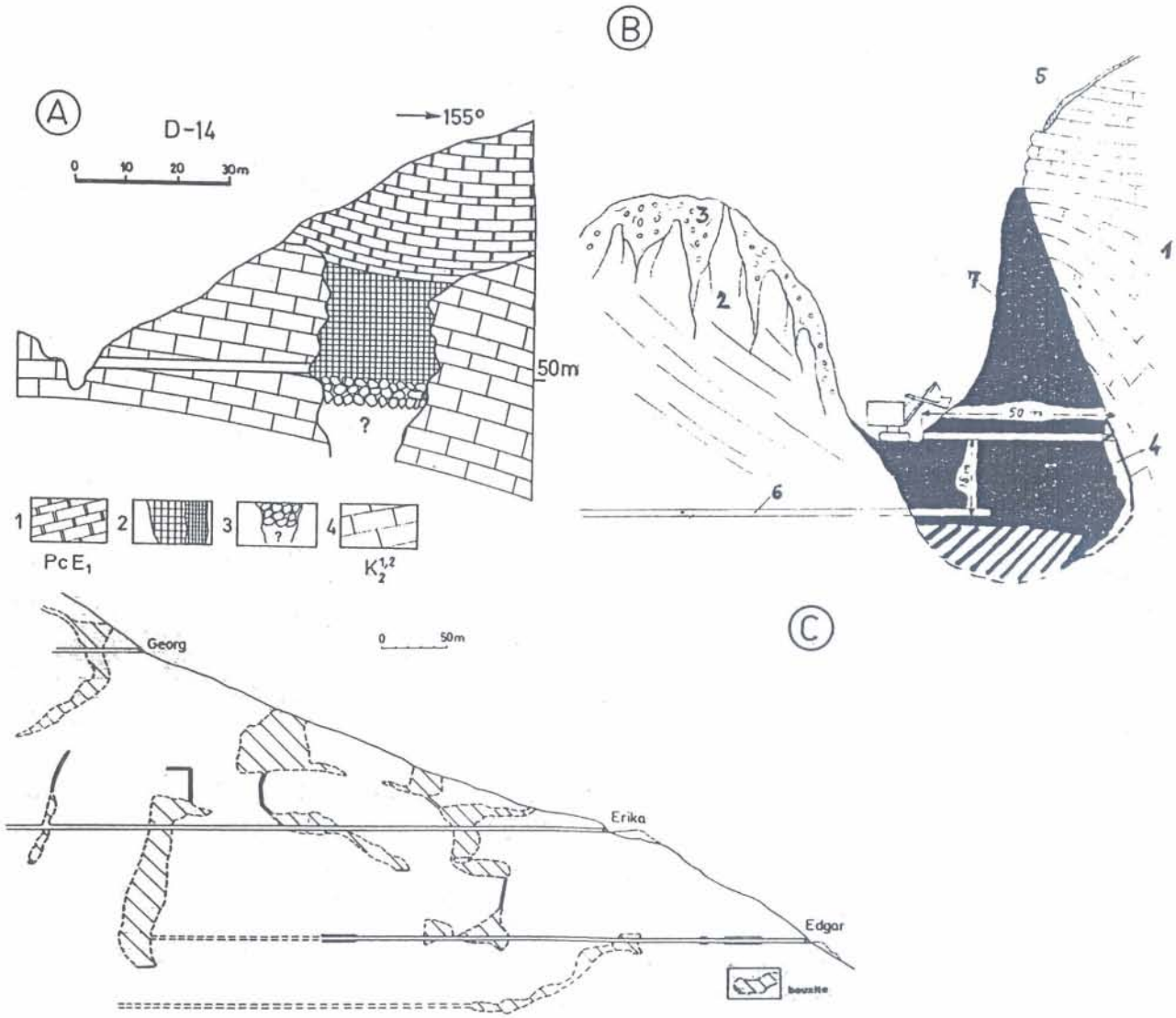

Fig. 7. Mine opening by adits. **A** Small deposit D-14. **1** Roof layers, **2** bauxite (excavated), **3** collapse structure, **4** floor layers; **B** Small deposit Palež; **1** roof limestones, **2** floor »pyramids«, **3** conglomerates, **4** cavity, **5** humus, **6** haulage adit, **7** bauxite; **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 m^2.

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 Šudrova Glavica near Široki Brijeg. The depth there did not exceed 30 m and the ground-plan came to 6 m^2. 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 incovenience 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.

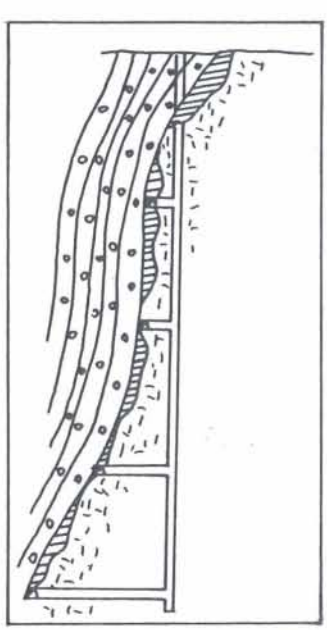

Fig. 8. Mine opening by shaft (»Kalun« principle)

* Knešpolje is a village on the road Mostar—Široki Brijeg, with (long ago excavated) deposits of outstanding quality, with less than 1% silica and more than 60% alumina.

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 (Krste 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 **Ćukovac—Grižinice** a main haulage incline of 412 m with a dip of 12° (with conveyor belt) was constructed, Fig. 10 (Perić and Vujec, 1992).

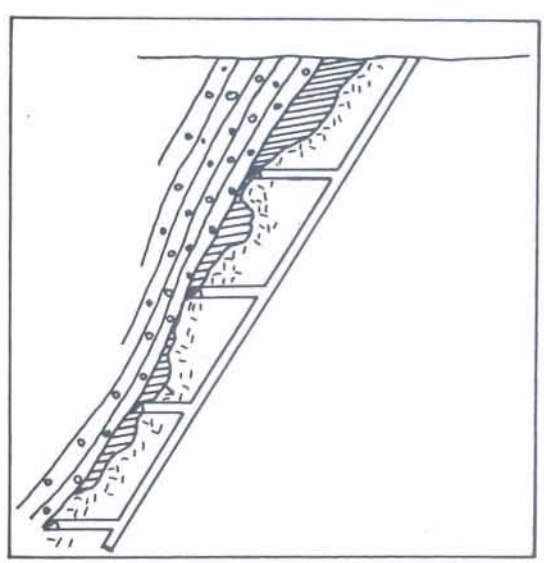

Fig. 9. Mine opening by steep inclines resp. inclined shafts (»Foča« principle)

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 Ćukovac—Grižinice 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 pursuited from the excavated outcrop into the depth. This dictated the further

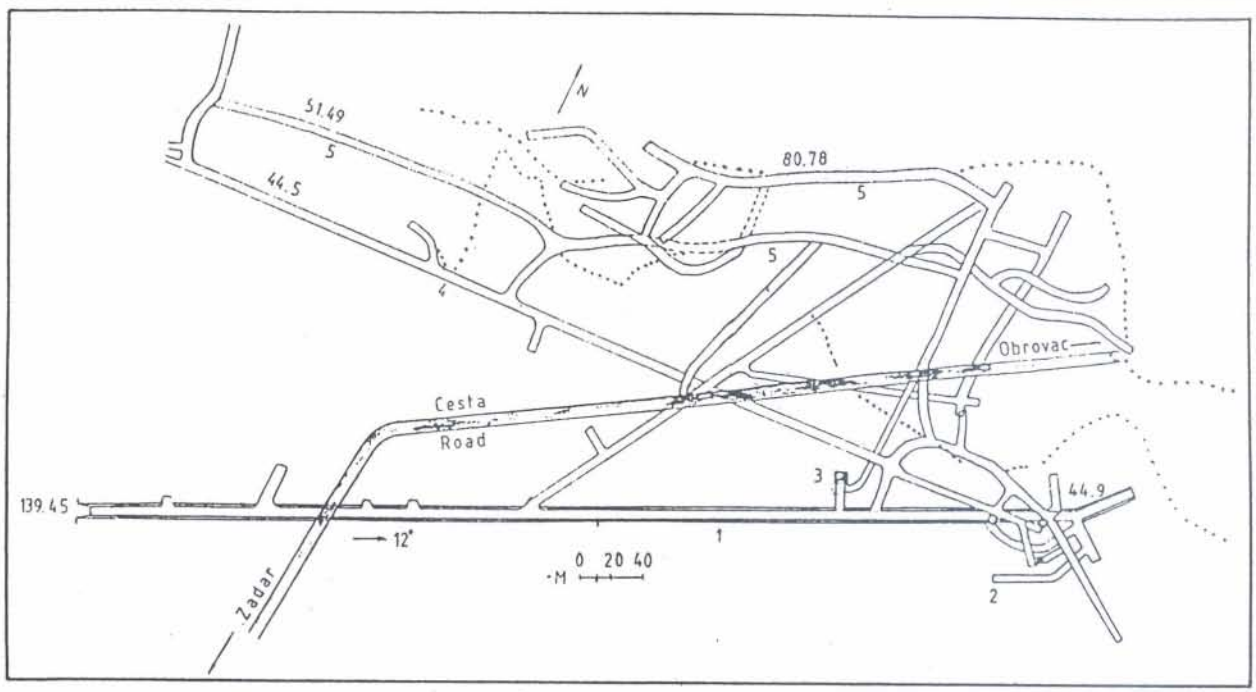

Fig. 10. Opening by incline for big deposits (type Ćukovac—Grižinica). **1** Adit, **2** sump, **3** ventilation shaft, **4** haulage adit, **5** levels

development of the doings insofar as then the »developing« 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 nedeed 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 Seguiti, 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 selectivelly; 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 ba-

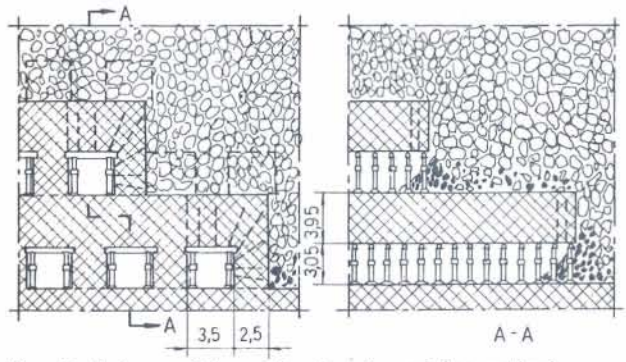

Fig. 11. Scheme of the sublevel caving mining method

uxite 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 becáme unavoidable; they amount to 20 . . . 30, and exceptionally to 50%, too. Neverheless, the method has also advantages

— 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 only by spans of 20 up to 60 m, and so open spaces even up to 3000 m^2 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 ton of bauxite resp. arround 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 Ljubić (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—Umci 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 Ljubić (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« (booth 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.

gest 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, mark 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-

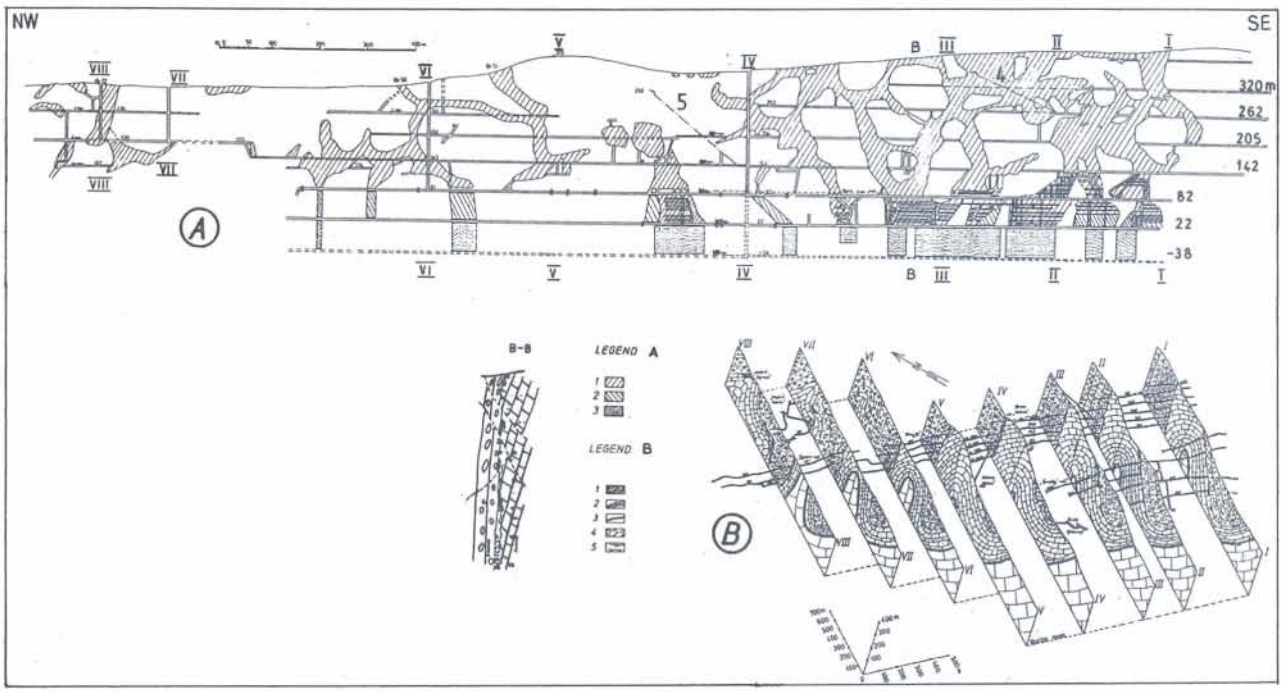

Fig. 12.I. Mine Kalun (after Franotović, 1955 and 1969), general longitudinal section;
A **1** excavated, **2** developed for exploitation, **3** probable ore, **4** incline in the roof, **5** incline in the floor;
B **1** hanging Promina layers, **2** footwall Foraminiferal limestones, **3** Liburnian limestones, **4** footwall Rudist limestones, **5** bauxite

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, geologues (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 big-

tion in the Dalmatian bauxite mining. From the beginning of war, about 1940, and up to 1952 here the production mainly lay still, especially in the Kalun mine. Contrary to the relatively autonomous »Independent State of Croatia«, were during the war, too, at least from the end of 1941 to the end of 1944, in Herzegovina bauxite has been exploited, in Dalmatia this mining activity has been suppressed; here was Italy that from »her« Istria derived bauxite ore enough.

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 m^3/min during heavy

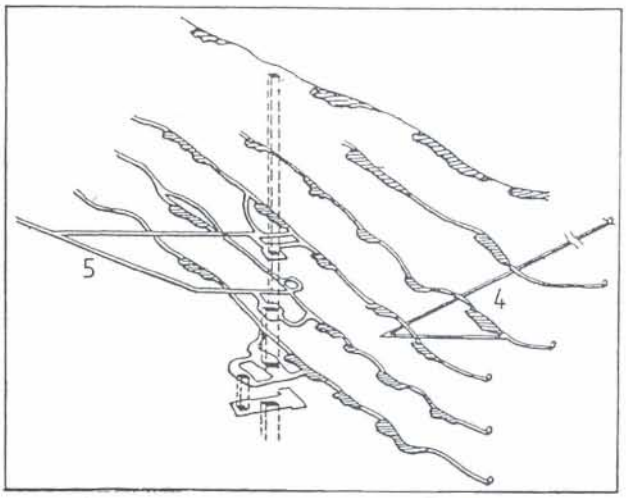

Fig. 12.II. Mine Kalun (after Franotović, 1955 and 1969), opening situation 1955; **4** roof incline, **5** floor incline (v. 12.I.A)

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 outcroping of this orebody has had an area of 2500 × 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-IIIA). 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 has 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

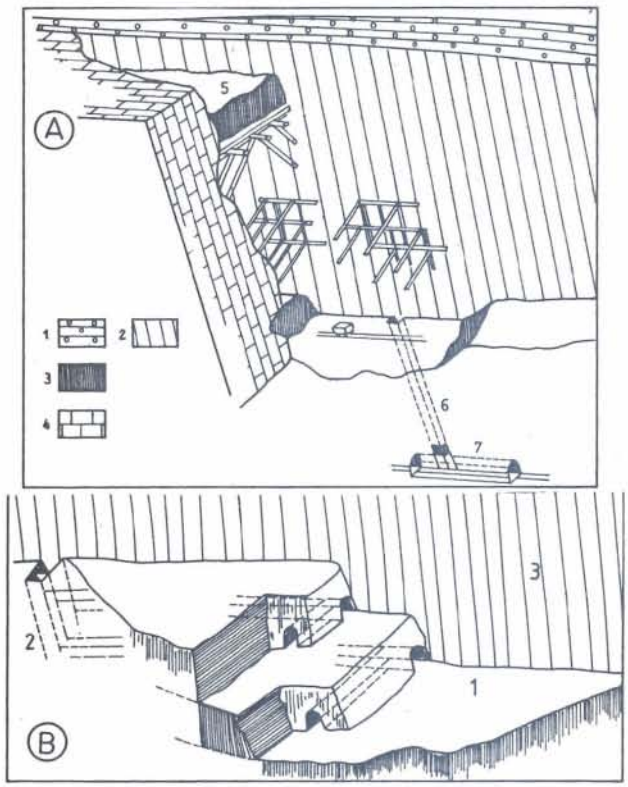

Fig. 12.III. Mine Kalun, former mining methods, axonometric views;
A Open stoping: **1, 2** roof, **3** bauxite, **4** floor, **5** barrier pillar, **6** ore chute, **7** haulage level
B Top slicing: **1** ore body, **2** ore chute, **3** roof

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-IIIB). »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

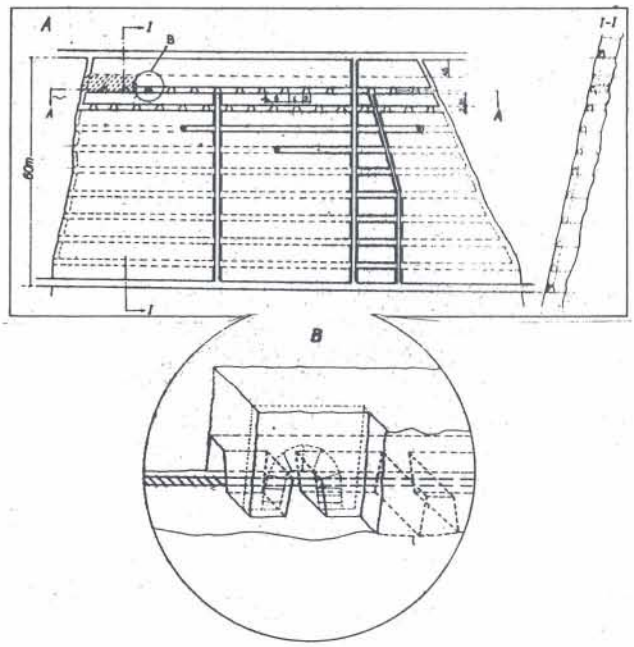

Fig. 12.IV. Mine Kalun, sublevel caving:
A Longitudinal section across the levels
B Detail

level, i. e. including the levels with incline access. The animal haulage on the first four levels ... »was simple. The horses did go alone to the stopes and back, and were not endangered by water. Yet, the lowering and hoisting of horses (when needed) just to the 5th level was very complicated. And it wouldn't be possible at all if we hadn't had there dams for protection of the pumps ... Lowering of horses to the 6th level was never taken in consideration at all out of security reasons« (Ljubić, 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, Foča, Krstanćuša, Đidare, 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, probable, 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

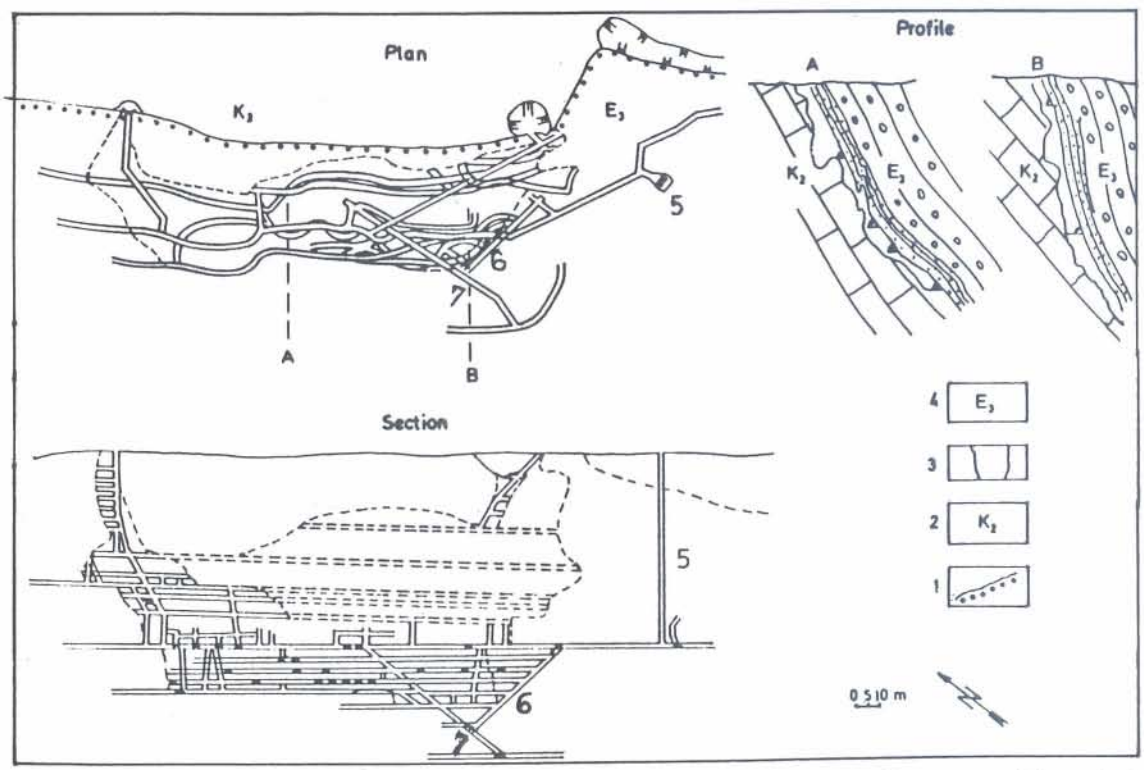

Fig. 13. Mine Kumanovo. **1** geological boundary, **2** Upper Cretaceous footwall limestones, **3** contours of the orebody, **4** hanging Promina layers, **5** main shaft, **6** incline dipping 45°, **7** incline dipping 37°

the Austrian fisc established a »K. K. Grubenleitung«, and during the war 1914—1918 the deposits of the Kruševo district have been exploited and the ore was sent to the German aluminium plant »Gebrüder Giulini« at Ludwigshafen; 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 work-shop 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 (»Lujo«), 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 Kruševo 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 Kruševo 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 excellent but alas unpublished presentation 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% Al_2O_3, 5,04% SiO_2 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 m^2; 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 m". As already mentioned, in the Kalun mine on a square meter of the orebody, reduced to the roof surface, 10 t bauxite can be alloted; 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 m^2, 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.

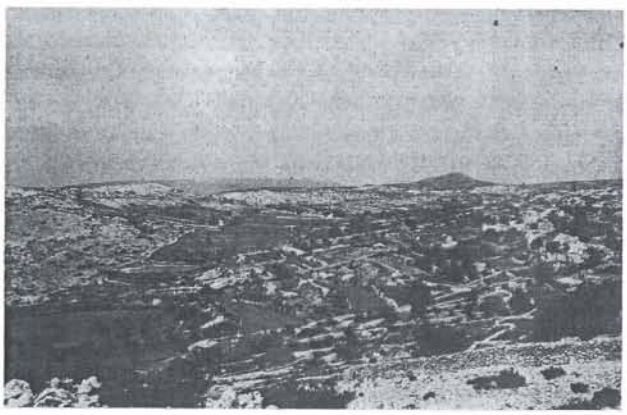

Fig. 14. The »relay« hill Dračevac; in the foreground the sinkhole of Jasenice, later on buried under waste rock excavated from the surrounding bauxite mines

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).

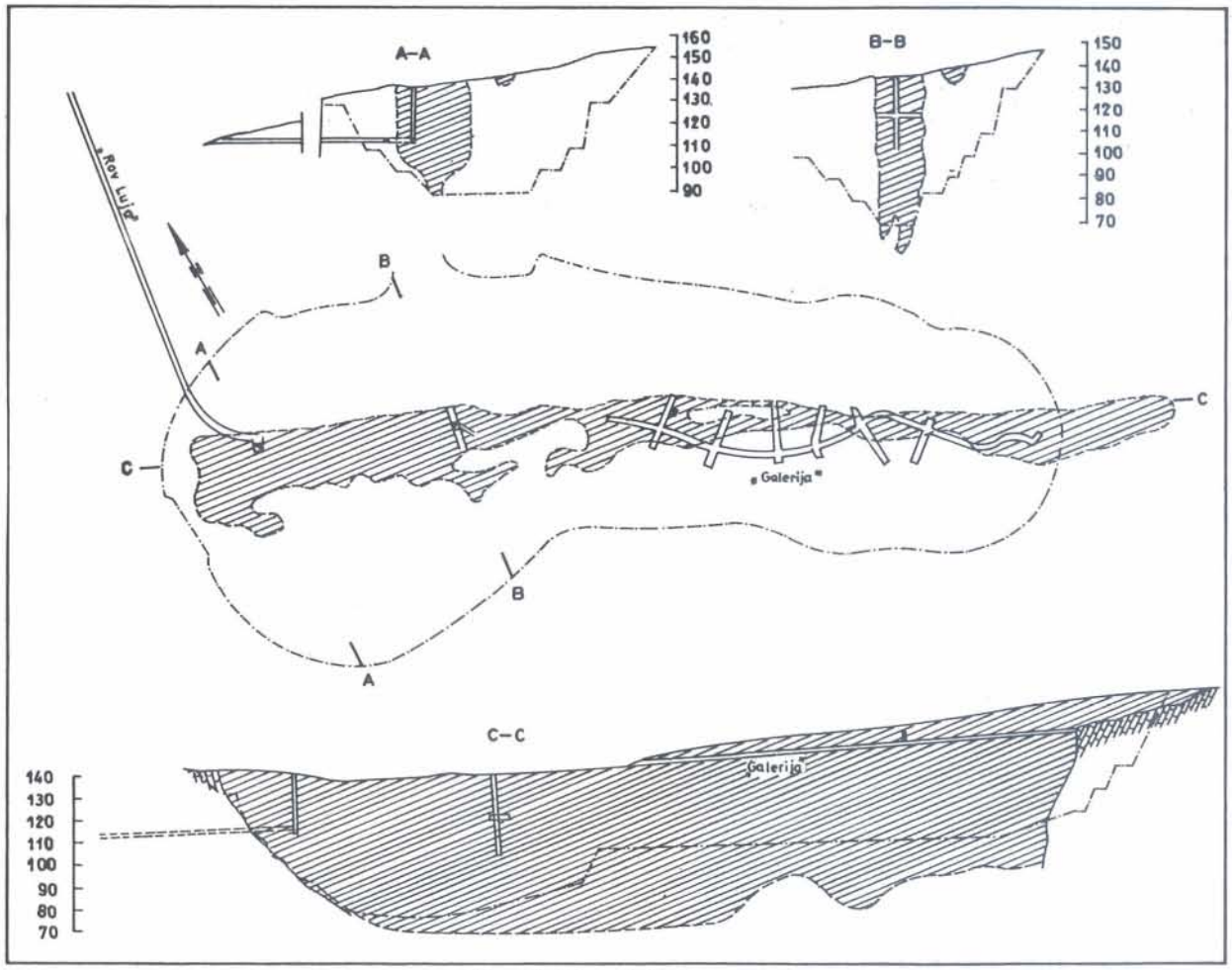

Fig. 15. Deposit Dračevac

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-

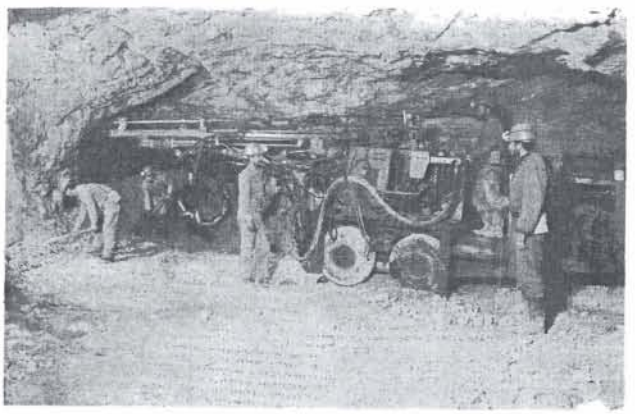

Fig. 16. »Jumbo« drilling in the mine Ćukovac—Grižinica, 150 m deep (Photo: Z. Kucelin)

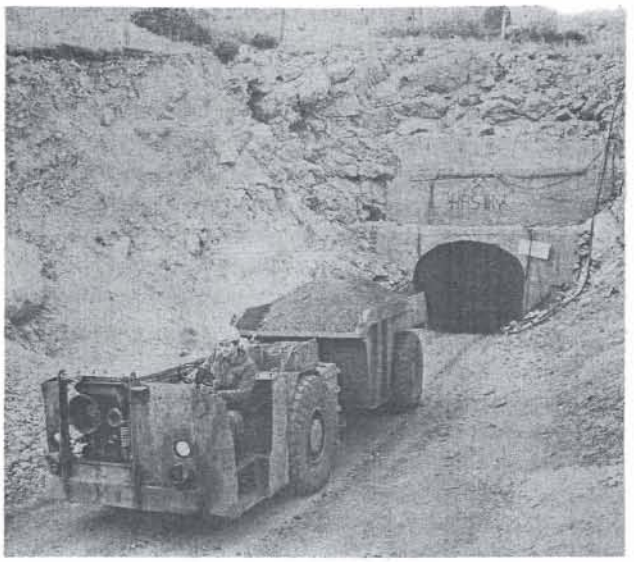

Fig. 17. Mine Krš, main portal with haulage equipment (Photo: Z. Kucelin)

ća; the width of the zone is undefined: if only the opened or at least slightly prospected territories are taken into consideration, the zone may have a width between 5 and 10 km, but if also the insufficiently prospected terrains are considered, for which it is known that there are bauxite deposits, then this narrow belt widens and includes entire Herzegovina. After various calculations and valuations, on that (wider) region more than 3000 deposits are strewn about; the most scrupulous inventory cames from Vučetić (1956), and the most circumstantial presentation of the Herzegovinian bauxites has written Lovrić (1984).

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, Dabrica). 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% Al_2O_3, 1,5 . . . 4,0% SiO_2 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 EXPLORATION, 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 reailway 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 Al_2O_3 from 52 to 62% and of SiO_2 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. Tribošić) and minor quantities at Blatnica by Čitluk. 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 ecploitation was almost exclusively by surface excavations, with the exception of small, by shaft opened, underground workings at Šudrova Glavica, a mining district of the mine Tribošić 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% (Žeravica, 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 m^3 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-

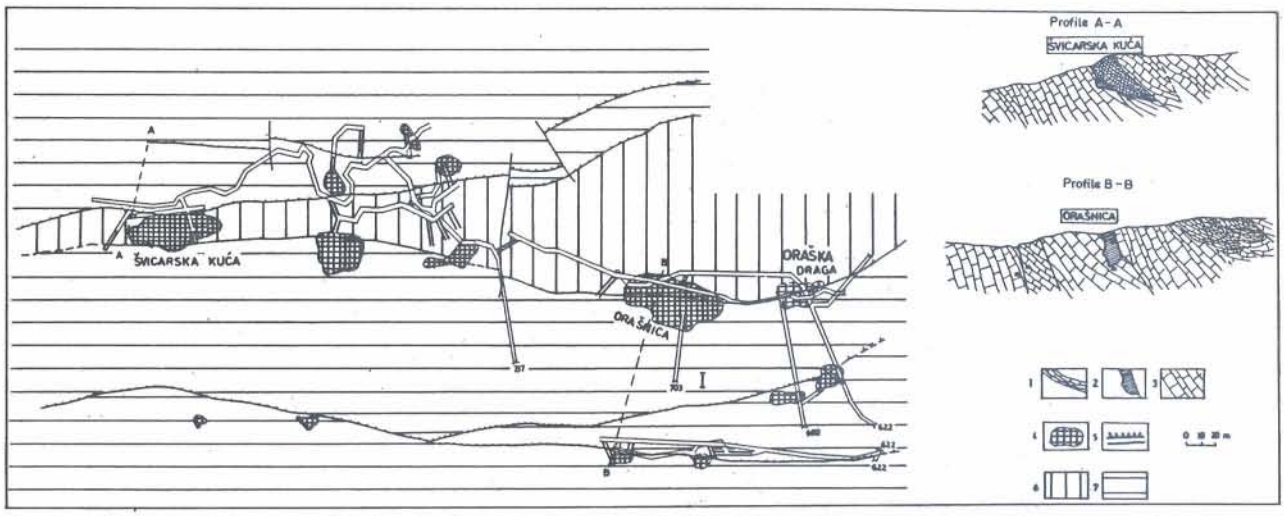

Fig. 18. Mine Crne Lokve. **1, 6** Hanging Kozina layers, **2, 4** bauxite, **3, 7** Upper Cretaceous footwall limestones, **5** faults, **I** first haulage adit (1938/39)

matia«, as it Franotović, (1956) has stated, then, also without doubt, Orašnica is a part of such a concentration in Herzegovina.

This Herzegovinian »concentration zone« etends in a length of some 45 km, from the district Studena Vrela on the very Bosnian-Herzegovinian frontier between Posušje and Duvno, and over the then (prewar) districts Vučipolje, Sobač, Krstače, Cerovi Doci, Crne Lokve and Ličtica 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 od 3,6 millions visible ore. The volume was obviously extremely understimated, 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 dayly bus-line Široki 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, »Krstače«, 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% Al_2O_3 and 1% SiO_2 (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), Laussane—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.

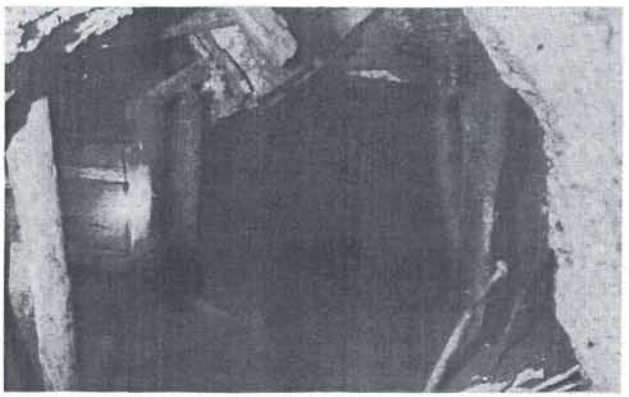

Fig. 19. Ore chute in adit I (Fig. 18)

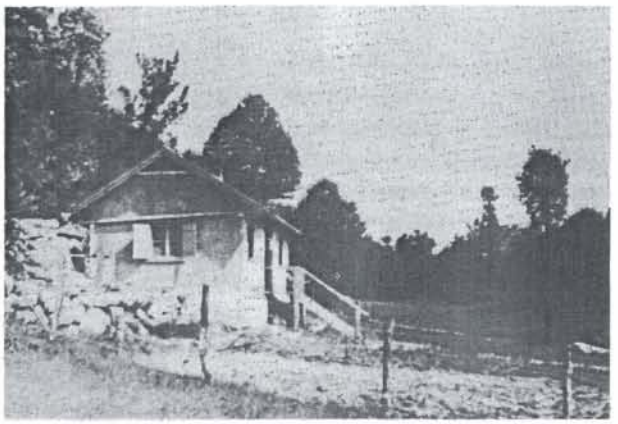

Fig. 20. The »Swiss House« (1942)

Also on the slopes of Tribošić, a rather prominent summit (815 m), with a characteristic name directly out of the old Slavic mythology (»Trigod's Top«), in that time some smaller deposit were exploited by adits. The entire district was distinguished by a typical excellent chemical composition of the ore, characteristic for this part of the contact zone: an average of 59% Al_2O_3 and 0,5% SiO_2! This the reason, too, for the decision not to abandon the district after the small deposits were excavated. So the new deposit Tribošić with attested 270 000 t could be opened.

This deposit is shown in Fig. 21. It is inserted in tectonic shells of Upper Cretaceous and Paleogenic 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 m^3; 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 applicating 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 Tribošić, 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-

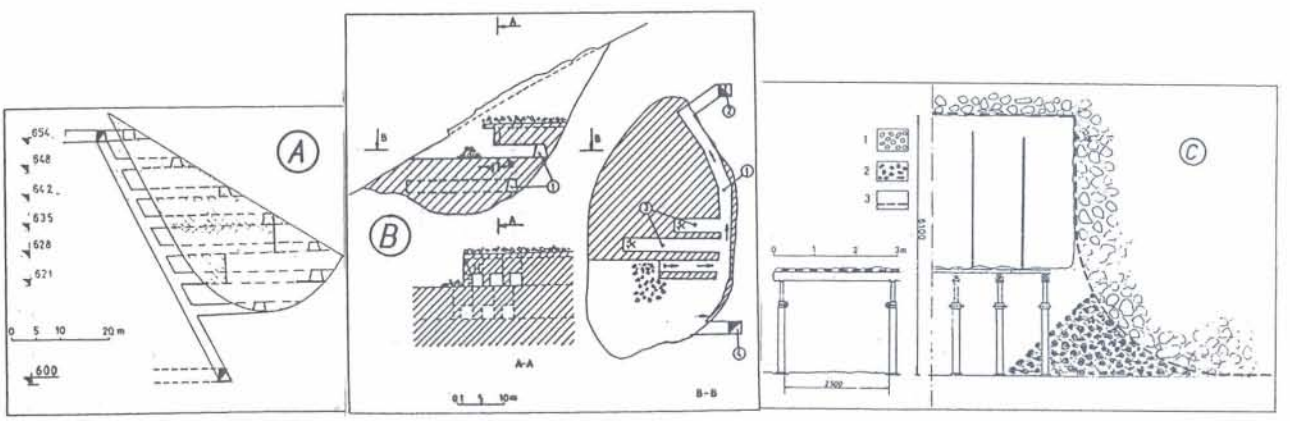

Fig. 21. Mine Tribošić. **A** Cross section; **B** Details of the mining method; **1** main (haulage) level, **2** ore chute, **3** drifts with stopes, **4** ventilation incline; **C** Application of wire mesh; **1** collapse structure, **2** bauxite, **3** wire mesh

hwork 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 to 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

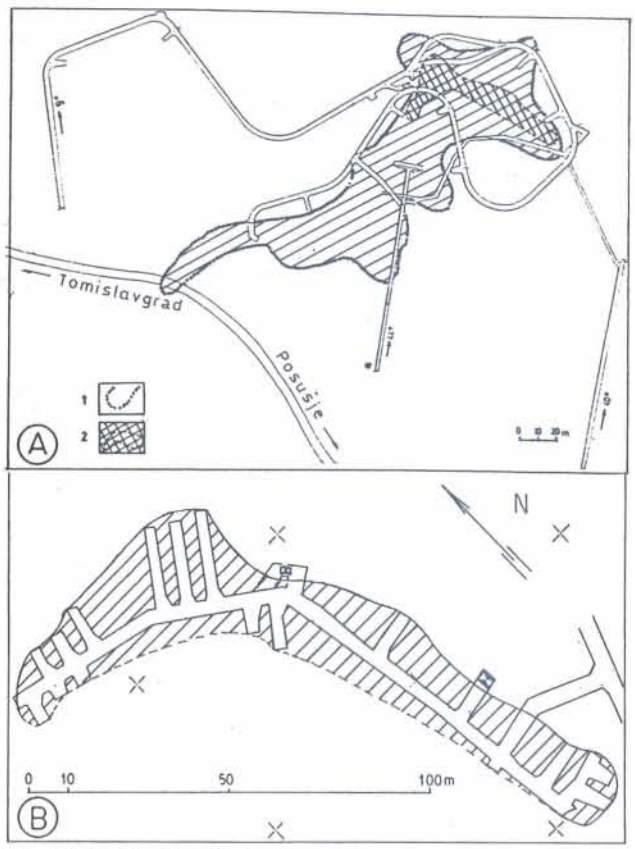

Fig. 22. A, B Mine Trobukva
A plan of the deposit: **1** contours of the orebody, **2** contours of a level
B level plan

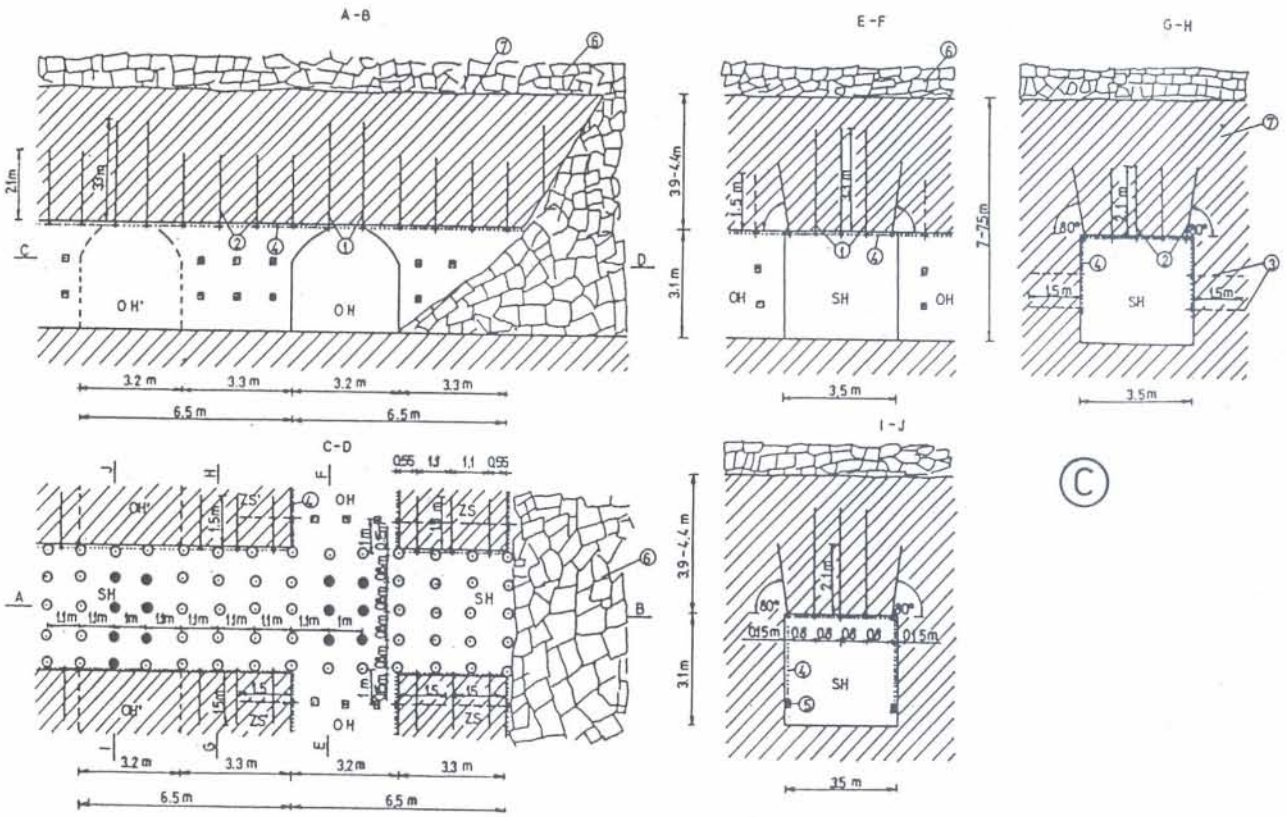

Fig. 22. C Mine Trobukva, support by roof bolting and wire mesh: **1** rock bolt of 3.3 m, **2** rock bolt of 2.1 m, **3** rock bolt of 1.5 m, **4** wire mesh 3.5 × 3.5 cm, **5** concrete weight, **6** collapsed roof, **7** hard bauxite, **SH** drift, **OH** stope level, **OH'** stope level (planned), **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 m^3 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 exhaust gases.

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 Swellex 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 Ćukovac—Grižinice, 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 occurence 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 so for forming of CO, CO_2, and CH_4; 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—Čapljina to Dabrica. Along with that they produced also some bauxite, altogether about 2500 t, with the composition of 49 . . . 56% Al_2O_3, and 1,5 . . . 6,15% SiO_2. 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.

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, withouth 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

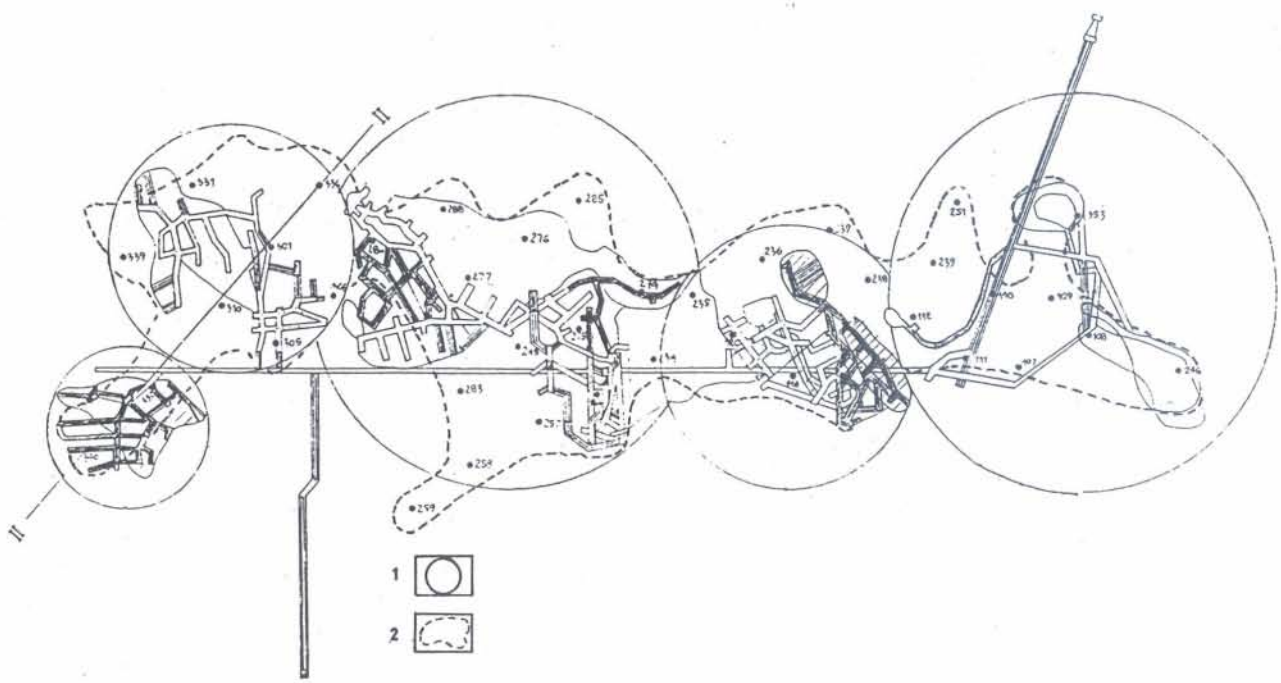

Fig. 23. Mine Dabrica. **1** mine section, **2** contours of the deposit

The rather complicated image of the mine, with a multitude of workings (Fig. 23), is a consequence of the fact that the deposit has been excavated by two mining methods. Originally, the deposit was developed for the room-and-pillar method, with rooms of 14 m width in the entire height of the orebody, and pillars 5 m wide. Due to unregularities of the orebody, the method ought to be abandoned, and the standard sublevel caving method was introduced, with sublevels of 6 m. In mine parts with a marly hanging, the excavated open spaces cave in immediately behind the stopes, of course accompanied by heavier ore losses. On the contrary, in parts with a hanging of hard sandstones and conglomerates, the caving does not follow the winning, and so uncontrolled open spaces up to 1500 m^2 are forming.

The ore is loaded and hauled to ore chutes by compressed-air loaders »Cavo 310« (Atlas Copco). In the main level the ore is transported by mine cars pulled by storage-battery locomotives to a

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 footwal 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 strorage-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 behing the stopes; so, big open spaces are created, even to 2500 m^2, 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 Grmeč 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 broking 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 110 000 t of ore has been produced.

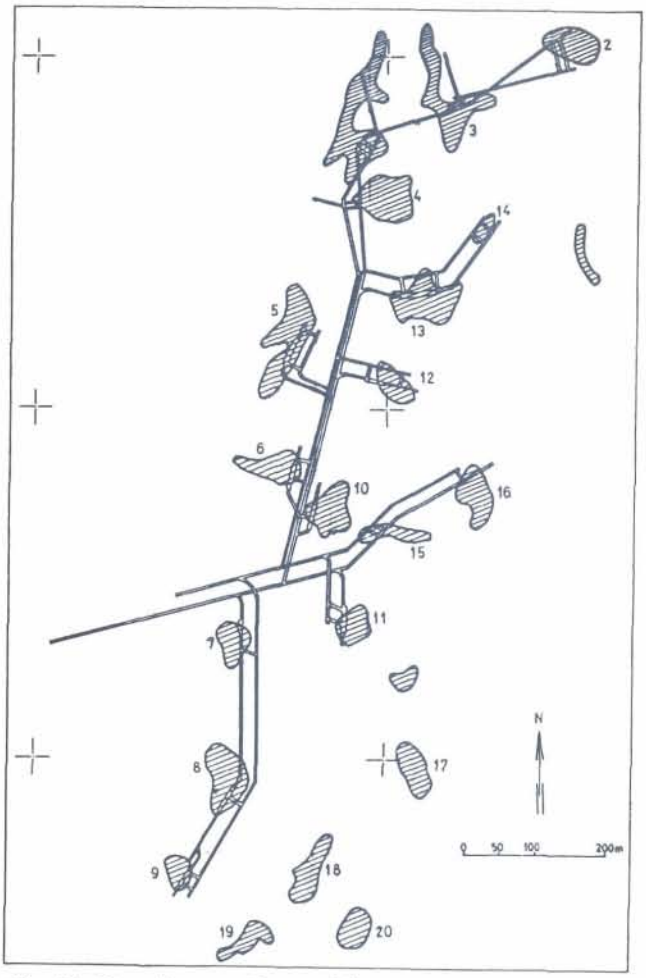

Fig. 24. Deposit group Crvene Stijene

After the war the plants were restored, and 1952 an autonomous firm was established. The new tonnage was modest, about 60 000 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 clair why the works have been stopped (there was no war yet). Here two analyses of Krupa bauxite (in %):

Locality	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	LOI
Pritoka	71,32	2,84	8,93	3,20	12,80
Risovac	65,34	3,40	14,86	2,40	14,00

(*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 characteristicum of white bauxites, with red ones it's very rare, except in diasporic 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 Al_2O_3; 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 exploration 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.

Region	Year of production beginning	Year of first prospection works	Total production t
Drniš	1915/16	1906	6 200 000
Obrovac	1926	(1903/09) 1906	9 000 000
Mostar	1917	1909	16 000 000
Jajce	1937	?	5 000 000
Bos. Krupa	1938	1937	1 800 000
Sinj	1916	1915	800 000

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