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Evaluation of research in a bauxite-bearing area at the "Crvene stijene" locality with emphasis on exploitation of the associated deposits

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ABSTRACT

In this paper we present and elaborate one research example when bauxite was the main target of the investigation. During reprocessing and reinterpretation of the original data from the "Crvene stijene" locality near Jajce in Bosnia and Herzegovina, it was established that bauxite hanging wall and footwall rocks in fact represent an even more valuable mineral resource, as "dimension stone". The final goal of the research was to optimize the ratio between research and exploration costs and total profit by exploration of all available mineral resources in the area. For that purpose, a new research evaluation method encompassing both bauxite (primary resource) and associated deposits was developed and named the "*integrated approach*". Integrated, joint evaluation of bauxite and associated deposits (dimension stone), gives a far greater economic significance to whole area. Finally, with this new method, the ratio between overall profit and cost will be optimized which results in significant increase in profit because all available deposits are considered for exploitation. Also this method can be applied on abandoned mining sites if there is some secondary profitable mineral deposit in the mine area.

Keywords: Bauxite Deposits, Dimension stone, Associated Deposits, Integrated approach, Jajce, Crvene stijene

1. INTRODUCTION

Due to its various applications, "dimension stone" is still very significant and indispensable in modern architecture. Stone is one of the most durable materials in the form of protection and decorative panels of construction elements. From environmental protection aspects, its small greenhouse gas emission makes it a very applicable material in civil engineering.

The Dinarides are potentially a very rich area for exploration of many types of dimension stone with sedimentary origins. In this work we analyze the „Crvene stijene" locality near Jajce in Bosnia and Herzegovina, which was studied for bauxite deposits throughout its long exploration history (Fig. 1), while other associated deposits, (that can be a significant resource), were neglected. Research without evaluation of every potentially profitable resource in the studied bauxite-bearing area can result with unnecessary costs and losses, which leads to significant uncertainty in terms of investment.

Therefore, the focus of this paper was to unify values of all profitable natural resources in the bauxite-bearing area of „Crvene stijene" with the new "integrated approach". The primary difference between "the integrated approach" and previously utilized methods, is that the integrated approach, evaluates all associated resources in the area (in our case it is dimension stone in the footwall and hanging wall of bauxite deposits), beside the primary resource. It is even possible that associated resources have a higher market value than the primary resource. An example of such a case is the bauxite-bearing area of „Crvene stijene", where "the integrated

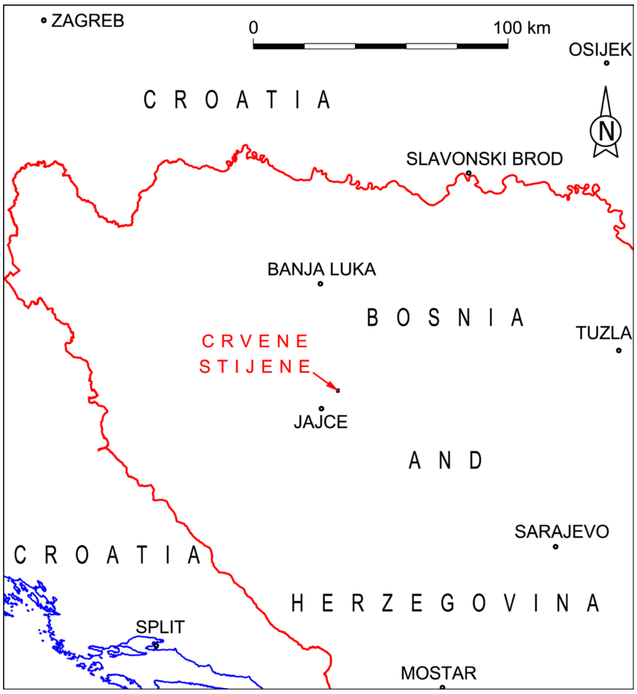

Figure 1: Geographical location of the investigated site at "Crvene stijene".

approach" shows that dimension stone is much more profitable to exploit than bauxite. The expenses for additional research of the associated deposits are minor. With "the integrated approach" it is possible to determine the value of individual or overall deposits in the area and optimize the ratio between research and exploration cost and total profit.

The primary goal of the investigation was to maximize the ratio between the total profit and research and exploration costs. Finally, with the newly developed, integrated approach, we show that the overall expenses can be reduced and total profit can be significantly increased.

1.1. Geological settings of the "Crvene stijene" bauxite-bearing area

Fundamental lithostratigraphic features of Cretaceous bauxites in the Jajce area (Localities: Poljane, Crvene stijene, Bešpelj, Liskovica) are defined on the Basic Geological Map, sheet Jajce, scale 1:100 000 (MARINKOVIĆ & AHAC, 1975) (Fig. 2). The authors determined the stratigraphic age based on the biostratigraphic assemblage composition in the footwall and hanging wall strata. The footwall of bauxite deposits is always composed of shallow marine, red to white,

Table 1: Results of bauxite research in the „Crvene stijene" area.

Year	Number of boreholes	The length of drilling	Reserve of bauxite	Research costs bauxite	The total revenue from bauxite	Assessment profit from bauxite	The share of research income
	N	D	Qb	Cb	Tb	Vb	Pb
	pieces	m'	t	monetary u.	monetary u.	monetary u.	%
1974	98	5 323	218 000	102 877	13 080 000	2 077 123	0,79%
1975	49	4 424	187 000	113 728	11 220 000	1 756 272	1,01%
1976	62	5 190	86 000	900 722	5 160 000	–40 722	17,46%
1977	60	6 622	92 870	588 893	5 572 200	339 807	10,57%
1978	67	6 298	146 430	414 494	8 785 800	1 049 806	4,72%
1979	48	6 315	164 760	661 787	9 885 600	985 813	6,69%
1980	35	6 169	61 824	441 777	3 709 440	176 463	11,91%
1981	27	4 747	2 000	407 252	120 000	–387 252	339,38%
1982	49	7 949	100 000	914 272	6 000 000	85 728	15,24%
1983	63	7 404	50 000	548 579	3 000 000	–48 579	18,29%
1984	81	10 968	2 000	623 728	120 000	–603 728	519,77%
1985	76	11 429	0	484 533	0	–484 533	–
1986	46	7 171	40 000	723 557	2 400 000	–323 557	30,15%
1987	10	2 194	20 740	130 869	1 244 400	76 531	10,52%
1988	11	3 189	10 000	135 731	600 000	–35 731	22,62%
1989	25	6 527	10 000	47 897	600 000	52 103	7,98%
Total	807	101 919	1 191 624	7 240 696	71 497 440	4 675 544	10,13%

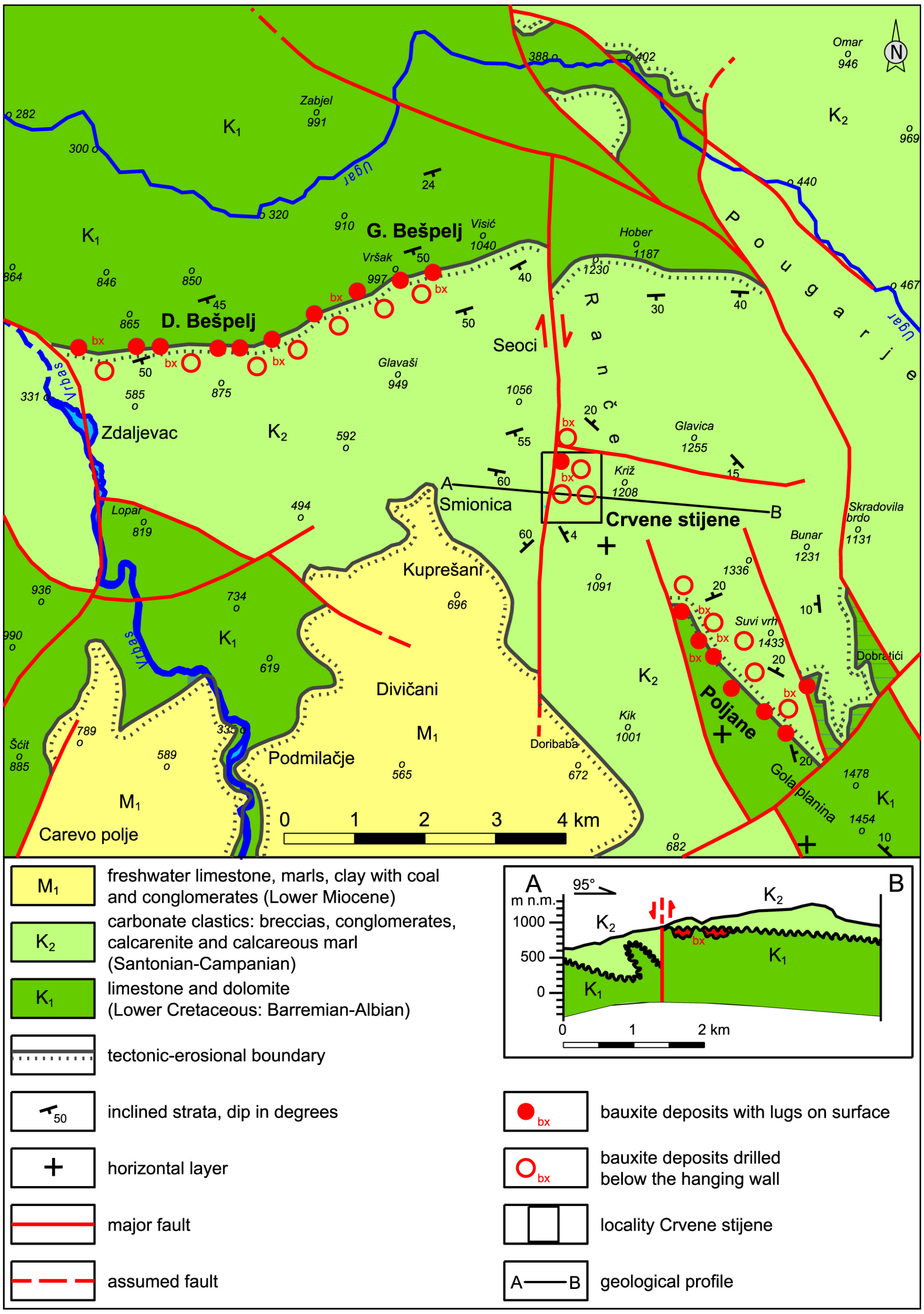

Figure 2: Basic geological map of the investigated area (modified after MARINKOVIĆ & AHAC, 1975).

well-layered limestones (Fig. 2). The stratigraphic age is determined based on fossil remains (e.g. Neoiraquia insolita, Rudists; Detail fossil determination in DRAGIČEVIĆ & VELIĆ, 2006) as Albian-Cenomanian ($K_{1,2}$).

Hanging wall strata of the bauxite deposits are composed of carbonate clastic rocks (carbonate breccia, calcarenites and marls). Their stratigraphic age is determined as Senonian-Campanian (${}_2K_2{}^3$) (Fig. 2).

Extensive and detailed research of the bauxite deposits (detailed geological mapping, geophysical, geochemical, palaeogeographic, investigations and especially drilling), that were undertaken after the Basic Geological Map was produced, set the standard for determination of the footwall and hanging wall strata sedimentological characteristics of bauxite deposits. The footwall is always composed of limestones of Albian-Cenomanian age and the hanging wall is represented by carbonate-clastic rocks of Senonian age. Guided by these findings, numerous wells were drilled in other bauxite-bearing areas nearby, but bauxite deposits were, unfortunately, not found.

A further step in defining the stratigraphic age of bauxite deposits in Jajce was made by Dragičević, 1987. Detailed investigations of the microfossil content (Fig. 5), defined the footwall rocks as Albian in age and the hanging wall, carbonate-clastics, as being Santonian-Campanian in age (DRAGIČEVIĆ, 1981, 1987 & 1997, DRAGIČEVIĆ & VELIĆ, 1994, 2006).

2. ANALYSIS OF PREVIOUS RESULTS OF RESEARCH ON THE FOOT WALL AND HANGING WALL DEPOSITS WITH EMPAHSSIS ON THEIR VALUATION AS A „DIMENSION STONE“

The “Crvene stijene” area, near Jajce was intensively studied from 1974 to 1989, with the focus on finding bauxite deposits and quantifying their reserves. More than 800 wells (with cores) and around 102 000 m’ of deposits were drilled (Tab. 1).

Geological settings of the bauxite-bearing areas near Jajce are shown on a detailed geological map (Fig. 3) and structural settings of the “Crvene stijene” locality are shown in a detailed geological section (Figs. 4 & 5).

2.1. Footwall deposits

According to field observations, footwall carbonate deposits are classified as well-bedded, up to several meters thick and composed of light-grey and pink to white fossiliferous rud-

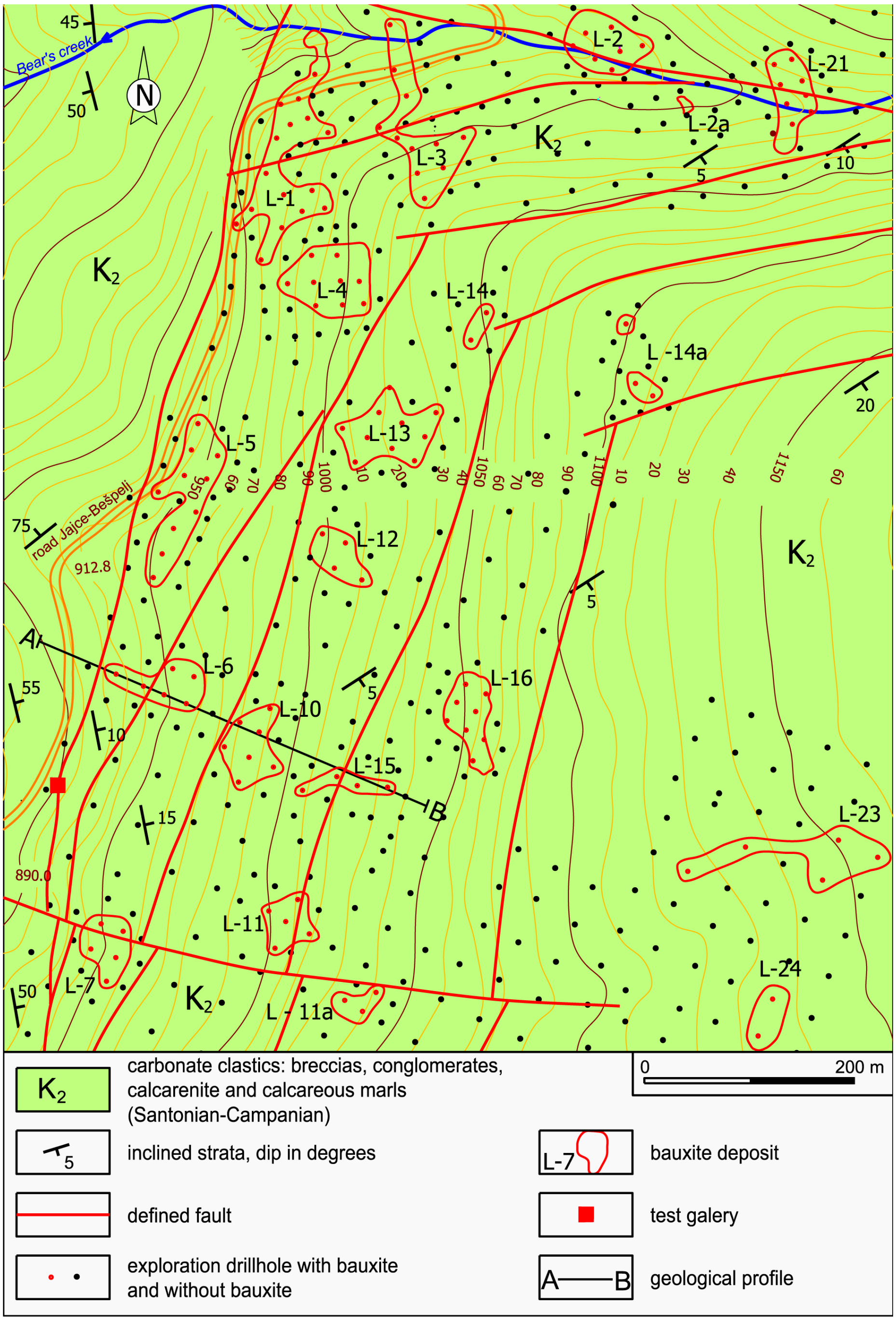

Figure 3: Detail geological map of the bauxite-bearing area near Jajce.

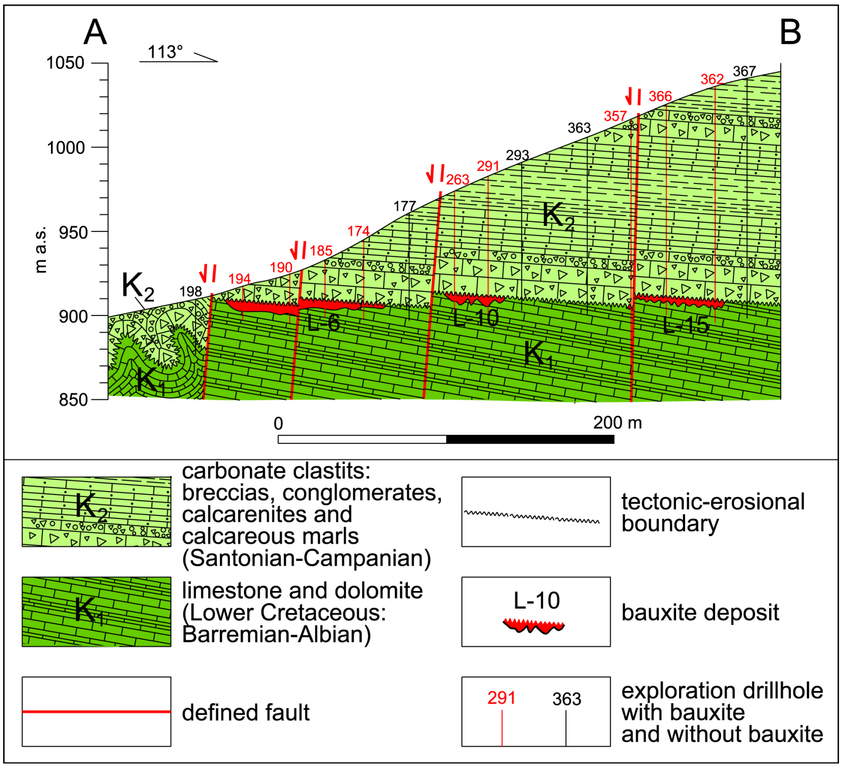

Figure 4: Detail geological section of the bauxite-bearing area of „Crvene stijene".

stone. Dominating macrofossils are remains of gastropods and bivalves. The majority of the footwall layers are composed of shallow marine limestones with microfossil assemblages (Fig. 5). Dominating lithotypes are biomicrites, fossiliferous micrites, bioclastic-intraclastic-skeletal packstones and grainstones, occasionally wackestones with remains of molluscs and calcareous algae (Fig. 5). Rare, but very significant are sections with foraminifera, on which the detailed and precise stratigraphic determination of footwall deposits was made (DRAGIČEVIĆ, 1987). The microfossil population is extremely low in the number of individual examples due to unfavourable palaeoenvironmental conditions during sedimentation. Strong micritisation and partial recrystallization made it difficult to perform a palaeontological analysis. However, the existing fossil population was undoubtedly the key to determine the Albian age of the footwall (DRAGIČEVIĆ, 1987; DRAGIČEVIĆ & VELIĆ, 2006). Data collected during later research in the Karst Dinarides indicates that the footwall carbonates with the bauxite deposits belong to the transition period from the Lower to Upper Albian (DRAGIČEVIĆ, 1987; DRAGIČEVIĆ & VELIĆ, 1994).

2.2. Bauxite

In the "Crvene stijene" area, bauxite deposits are the most significant mineral resource, which has been explored and exploited for more than fifty years (DRAGIČEVIĆ, 1987). Complex, long-term and detailed research with a focus on bauxite deposits resulted in numerous valuable data about the geological settings, source of bauxite material, accumulation time, shape, size and spatial distribution of the deposits. All these data enabled the estimation of the exploration potential of the bauxite-bearing area in the Jajce region.

There are numerous deposits of high-quality red bauxite of various shapes and sizes. Individual deposits reach up to 200 m in length, up to 100 m in width, and up to 40 m deep. The deposits are morphologically irregular in shape because some of them are elongated in the form of a channel, while others take the form of lenses. This morphological irregularity makes them difficult to research. The shape and size primarily depends on the palaeorelief depressions in the footwall carbonates which are primarily a result of chemical weathering during long-term emersions (approximately twenty million years) and the volume of transported bauxite-source material. Based on data from numerous wells, individual palaeogeographic provinces (islands that were surrounded by sea), including the "Crvene stijene" province, were determined. "Crvene stijene", just like other palaeogeographic provinces, is characterized by a number of bauxite deposits with significant volume of bauxite in a relatively small area. Studies show that the palaeorelief wasn't developed laterally from these provinces, so bauxite couldn't be deposited there. The directly transgressive hanging wall also points to the same conclusion.

In the bauxite-bearing area, the rocks of the hanging wall are usually coarse grained and composed of fragments of rudists, lithoclasts of basement limestones and fragments of bauxite. They are thick-layered, with variable thickness and composition of layers and laterally become fine grained with more stable thickness and petrographic composition in the flattened relief. Paleorelief formation was strongly influ-

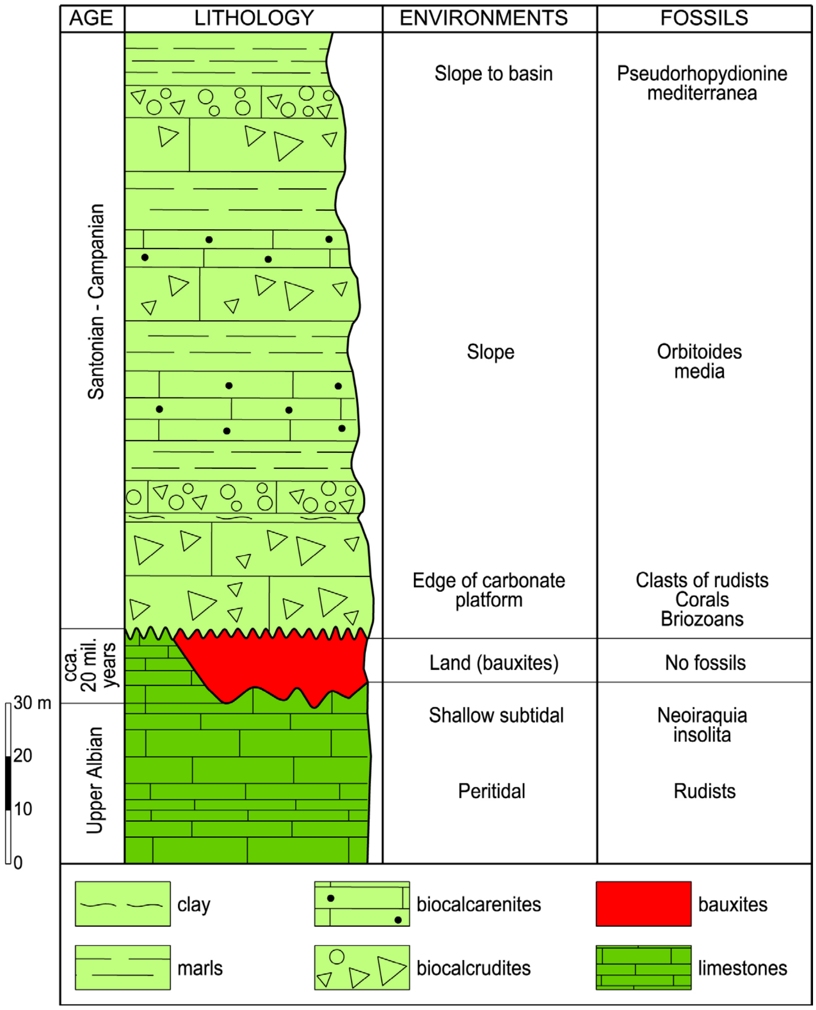

Figure 5: Lithostratigraphic column of the bauxite-bearing area of „Crvene stijene".

enced and controlled by tectonic fracturing of limestones in the basement. Fracturing due to tectonics was the most intense in zones of the major faults, in which the biggest vertical movements occurred. Intense tectonic activity also occurred on the margin of the carbonate shelf, where these rocks were exposed on the surface. Tectonic activity created conditions for the formation of coarse-grained clastic sediments and regulated the growth of many rudist biohermas. Clasts of rudist bioherms are often the constructive parts of the overlying carbonate breccias (DRAGIČEVIĆ, 1987; DRAGIČEVIĆ & VELIĆ, 1994).

The described paleoambiental settings of the hanging wall can be used in bauxite deposit analysis, because potential areas can be distinguished by analyzing core data from wells. More than a thousand analyses were made from which the average composition of the basic components is presented (Tab. 2) (DRAGIČEVIĆ, 1981) determined the chemical composition of the bauxite deposits. The mineral composition was also determined for several hundred analyses and is presented in Table 3 (DRAGIČEVIĆ, 1981).

The stratigraphic gap, or the terrestrial phase, during which conditions for bauxite sedimentation existed, lasted for about 23 million years. The phase started during the transition from the Lower to Upper Albian, during which the youngest footwall rocks were formed and lasted until the Upper Santonian-Lower Campanian age when the sedimen-

Table 2: The average chemical composition of bauxite (in wt. %) (DRAGIČEVIĆ, 1981).

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	CaO	lost of ignition
57.66	2.00	24.77	2.60	0.05	28,83

Table 3: The average mineral composition of bauxite (in wt. %) (DRAGIČEVIĆ, 1981).

Boehmite	64.1
Kaolinite	3.9
Hematite	28.4
Anatase	0.7
Calcite	1.5
Other	1.4

Figure 6: Hanging wall sequence of carbonate breccia in the „Crvene stijene" area.

tation of the oldest hanging wall began. According to the actual geological time-scales, this period lasted between 105 million and -83 million years.

2.3. Hanging wall deposits

Hanging wall deposits to bauxites are calcareous breccia. Layers are developed in the basal part of the hanging wall sequence. The layer thickness can exceed over ten meters but it is very variable both laterally and vertically. Thickness variations are the result of sedimentation mechanisms and the shape of the basement of the accommodation space during deposition. Breccia clasts are exclusively composed of footwall limestones (Lower to Upper Albian age). Fragments of rudists occur rarely and their size varies from the cm to m scale. They are usually angular or slightly rounded which indicates short or even practically no transport distances. The carbonate matrix varies in size from silt to sand sized particles

Subsequent processes of cementation and diagenesis resulted in the formation of a solid and homogenous rock with a massive habit. Detailed documented structural settings for the "Crvene stijene" area suggested a good structural condition and significant potential for obtaining blocks of dimension stone. Layers are horizontal to slightly inclined (up to fifteen degrees), generally to the northeast, east and southeast (Fig. 3).

Based on numerous fossil remains from the carbonate matrix in the breccia, hanging wall strata in the "Crvene stijene" area are of Upper Santonian to Lower Campanian age (DRAGIČEVIĆ, 1987).

3. MATERIALS AND METHODS

From 2009 to present, new field and laboratory investigations were undertaken on rocks from the "Crvene stijene" area. The focus was on the potential for exploiting the associated deposits in the footwall and the hanging wall of bau-

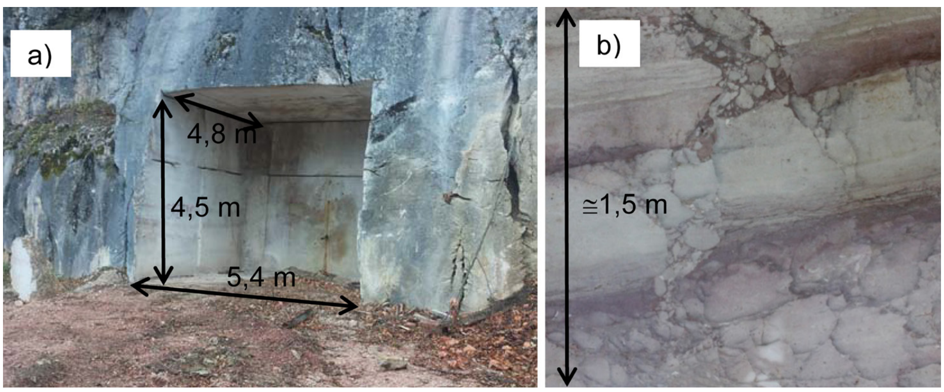

Figure 7: a) Mine gallery b) Carbonate breccia in the walls of mining gallery. Location of the mine gallery is in Fig. 3.

xite deposits. Both can be exploited as dimension stone. In the lower part of the productive hanging wall layer there is a mining tunnel, which represents an upper horizon for the “Crvene stijene” pit, at an altitude of 900 m (Fig. 6).

In order to evaluate the quality of coarse grained breccia, a mine gallery was constructed about 200 meters to the North from the entrance to the mine, near the road to Bešpelj (Figs. 7a & b). A total volume of 110 m^3 of coarse grained carbonate breccia was extracted from the mine gallery. 70 m^3 of the extracted rocks could be used as a high quality dimension stone.

100 m to the south from the test gallery, a test cut for exploitation of the breccia dimension stone was made (Fig. 8). From this location, blocks of breccia were also extracted for samples on which laboratory analysis were conducted.

During 2015, five drill holes were made with a total core length of 520 m. The locations of all five wells are within 50-100 m from the mining gallery (Fig. 7) and the test cut (Fig. 8).

Samples from cores were analyzed in the commercial CEMTRA Ltd laboratory in Zagreb. The following physical and mechanical characteristics were determined: uniaxial compressive strength in the dry state and in water saturated conditions, uniaxial compressive strength, and flexural strength of the concentrated load, water absorption at atmospheric pressure, apparent density and density. Furthermore, reinterpretation of the logs of earlier exploration drill holes (drilled from 1973 to 1989) was undertaken with the purpose of evaluating the associated deposits.

4. RESULTS

Results of the analyses are presented separately for bauxite and dimension stone, performed on an individual approach (i.e. each considered alone as a resource without reference to the other) and then according to the new, integrated method where both are considered together.

4.1. The results of bauxite analysis performed on an individual approach

Analysis of lithological columns from 807 well cores, resulting in the collection of detailed and precise data about the bauxite deposits (Tab. 1). Technical data about drilling, number of wells, drilling length and bauxite reserves were used for estimation of economic variables: research cost, profit from bauxite exploration and the significance of the conducted research in terms of the total profit.

To obtain the total profit, the average production cost of bauxite, 20 €/ton (without drilling costs) with market cost of the mine, 30 €/ton were assumed. All economic categories are revalued at today’s value. Prices are based on calculations that were made for the main mining project of bauxite exploitation in Bešpelj (GALIĆ et al., 2006).

With such an individual approach to the bauxite research, the share of bauxite research costs in terms of total profit is 10,13 %, which is a very large amount. Compared to the total profit, research costs are too high, which makes the exploitation economically unviable.

4.2. The results of analysis of dimension stone performed by an individual approach

The research of dimension stone was based on prior interpretation of lithological columns from drill holes.

The physical and mechanical characteristics of „dimension stone“ are presented in Table 4.

4.3. VALUATION OF RESERVES OF DIMENSION STONE

Productive layers of dimension stone are up to 30 m thick but a thickness of 20 m was taken for further calculation to account for inconsistencies across the whole area. The area of investigation is 30 ha, but only 10 ha is considered in the

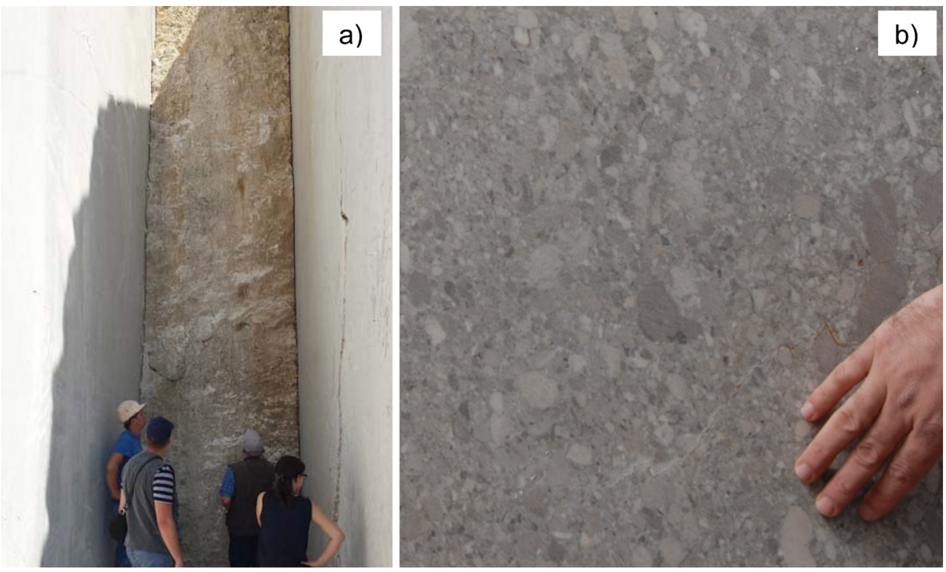

Figure 8: a) test cut b) carbonate breccia from the test cut.

Table 4: Physical and mechanical characteristics of dimension stone (breccia) determined from laboratory tests conducted on cores that were drilled in 2015 in the bauxite bearing area "Crvene stijene".

Type of test	Tested to	Results
Determination of uniaxial compressive strength in the dry state	HRN EN 1926 (EN 1926)	max.= 119.8 MPa min.= 98.3 MPa ave. = 104.2 MPa
Determination of uniaxial compressive strength in the water saturated condition	HRN EN 1926 (EN 1926)	max.= 109.1 MPa min.= 99.5 MPa ave. = 103.7 MPa
Determination of flexural strength of the concentrated load	HRN EN 12372 (EN 12372)	max.= 18.3 MPa min.= 12.3 MPa ave. = 13.7 MPa
Determination of water absorption at atmospheric pressure	HRN EN 13755 (EN 13755)	= 0.06 % (mas.)
Determination of apparent density	HRN EN 1936 (EN 1936)	= 2 675 kg/m3
Determination of density	HRN EN 1936 (EN 1936)	= 2 680 kg/m3

research because of underground mining and protected zones in the potential underground mining area.

Estimation of the reserves of dimension stone was necessary in order to calculate other economic variables. The volume of dimension stone was estimated with the arithmetic mean value (POPOVIĆ, 1984):

$$V = A_B \cdot d_A \qquad (1)$$

V – Volume of dimension stone (m^3)
A_B – Area of base (m^2)
d_A – average depth (thickness) of layers (m)

$$d_A = \frac{\sum_{i=1}^{n} d_i}{n} \qquad (2)$$

d_i – depth of i layer (m)
n – total number of wells

Total rock volume is calculated by applying the formulae (1) and (2) and reduced by a coefficient of efficiency which leads to dimension stone reserves. A coefficient of efficiency is the ratio of usable excavated rock to the total amount of excavated rock (GALIĆ et al., 2011; VIDIĆ et al., 2012). Coefficients of efficiency in the mining gallery have reached a value of 0.60. A value of 0.15 was used for calculation since it is empirically determined for this type of deposit. The cause of such a low coefficient of efficiency are protective pillars and expected deposit countering losses. These losses are result of geological settings (faults, folds, fractures and fracture systems) in the deposit and exploitation losses.

Some economic variables like total cost, income, profit and research cost were calculated based on data about the market and production cost from previous research (DRAGIČEVIĆ et al., 2009). According to this, a production price of 500 units and market price of 700 monetary units was achieved. These values are listed in the research budget in the planned income. The fundamental expression for the net value of the reserves (GALIĆ, 2002) is:

$$Vs = Qs \cdot (C_t - C_{pr}) \qquad (3)$$

Vs – net income of monetary units (m.u.)
C_t – market price (m.u./m^3)
C_{pr} – production cost (m.u./m^3)
Qs – the total amount of mineral resources, expressed in equivalent (eq), which will be exploited within the contours of the mine (for stone m^3)

Based on input data, individual approach values for dimension stone in "Crvene stijene" area were calculated (Tab. 5).

During the estimation of the proportion of research costs in total income, it was assumed that expenses will be identical to the expenses in previous analysis (analysis of bauxite deposits).

Results show that the market value of the dimension stone is multiples greater than the value of bauxite. Also, the share of research costs in the total income is lower. This therefore emphasizes dimension stone as a more valuable mineral resource than bauxite and justifies the hypothesis that the overall, integrated evaluation of mineral resources facilitates the determination of their relative order of priority in exploitation.

5. DISCUSSION

The results presented show that the final and decisive estimation of value of some mineral resource-bearing areas and share of research costs in total income value is only possible using

Table 5: Research results of the individual approach for assessment of dimension stone in "Crvene stijene" area.

Average debth dimension stone	Area of base	Total volume	Coefficient of efficincey	Reserve dimension stone	Research costs dimension stone	The total revenue from dimension stone	Assessment profit from dimension stone	The share of research income
d_A	A_B	V	Ce	Qs	Cds	Tds	Vds	Pds
m'	ha	m^3	–	m^3	monetary u.	monetary u.	monetary u.	%
20	10	2 000 000	0.15	300 000	7 240 696	210 000 000	60 000 000	3.45%

Table 6: Relations of relevant variables in the integrated approach to the research of bauxite-bearing area "Crvene stijene".

mineral resources	research costs	sales revenue	profit	the share of research income	index of research flexibility
	Cr	T	V	Pr	Ir
	monetary unit	monetary unit	monetary unit	%	Ir = V : Cr
bauxite	7 240 696	71 497 440	4 675 544	10.13%	0.65
dimension stone	7 240 696	210 000 000	60 000 000	3.45%	8.29
total	7 240 696	281 497 440	64 675 544	2.57%	8.93

an integrated approach to their evaluation. The integrated approach analyses all mineral deposits in the chosen area, evaluates them and arranges them by economic priority.

The fundamental equation for the calculation of total income of all mineral resources is:

$$V = \sum_{i=1}^{m} V_i \tag{4}$$

V_i – income of i-nd mineral resource where m is number of mineral resources

Partial values, presented in the previous chapter are summarized and shown in Tab. 6.

The second column shows the research costs that are nominally identical to the individual approach research costs. The third column shows the income and the fourth column shows total profit, which is significantly higher for the integrated than the individual approach. Still, these data are indicative and should only be considered as orientation and not as exact values. It is important to remember the fact that the research cost for individual and all-inclusive deposits are almost the same. This is the main reason for the significant decrease in the share of research costs as a proportion of total income for both the individual and integrated approach methods.

The final column, shows the conclusion of the analysis of the integrated approach. It presents the ratio between total profit and research cost. This parameter is the best indicator of the impact that research costs have on total profit. The indicator is named index of research flexibility and it can be evaluated by the following rankings:

Ir > 0 – Profit is greater than the costs of research
Ir = 0 – Neutral Index, income is equal to the cost of research
Ir < 0 – No profit

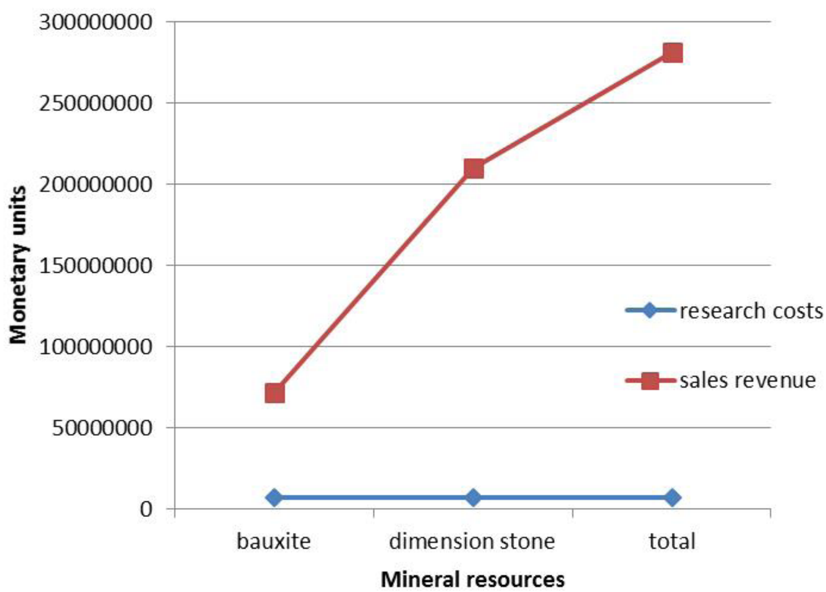

Figure 9: Relation between research cost and sales revenue (income).

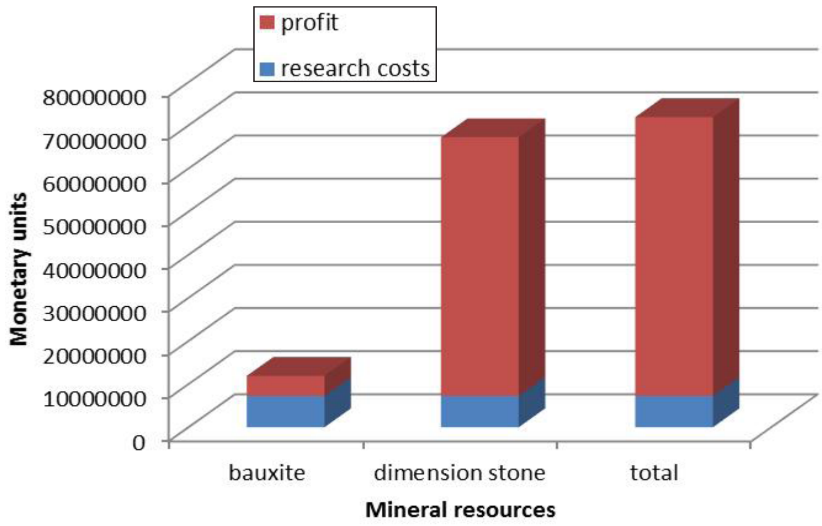

Figure 10: Relation between research costs and total profit.

By the proposed ranking, bauxite research (with individual approach) achieved positive results but on the edge of profitability, which makes the exploitation financially extremely risky. This confirms that the integrated approach to the exploration and exploitation of mineral resources is justified. Further research of dimension stone, individually and integrated, with already existing input data from bauxite research, results in a very high index of flexibility. A high index of flexibility confirms the initial assumption that the integrated approach is justified and needed in the study of mineral resources in this particular area (Figs. 9 & 10). These figures clearly show that research costs are constant. Research costs can slightly increase if laboratory analyses are included but that is insignificant when considering the consequent increase in income.

In Figure 11, results of both the individual and integrated approach to analysis of research cost share in total income are shown. It is clear that individual costs share have a decreasing trend. The curve would be flatter if the analysis would include several mineral resources.

Figure 12. shows the relation between the index of flexibility and the border line in terms of profit, which clearly indicates the existence of the point of transition from positive to negative areas of viability. Based on this, a deposit with overburden which has a negative index of flexibility was assumed. A negative index of flexibility means that there is no profit, only expenses. The diagram in Figure 12 shows that the curve goes from a positive to a negative value which means that the research limits can be approximated.

Considering the location and the size of the bauxite-bearing area (approximately 120 m below the surface, 75000 tons), the depth of the tectonic-erosional discordance and significant faults, drilling from the surface is uneconomical

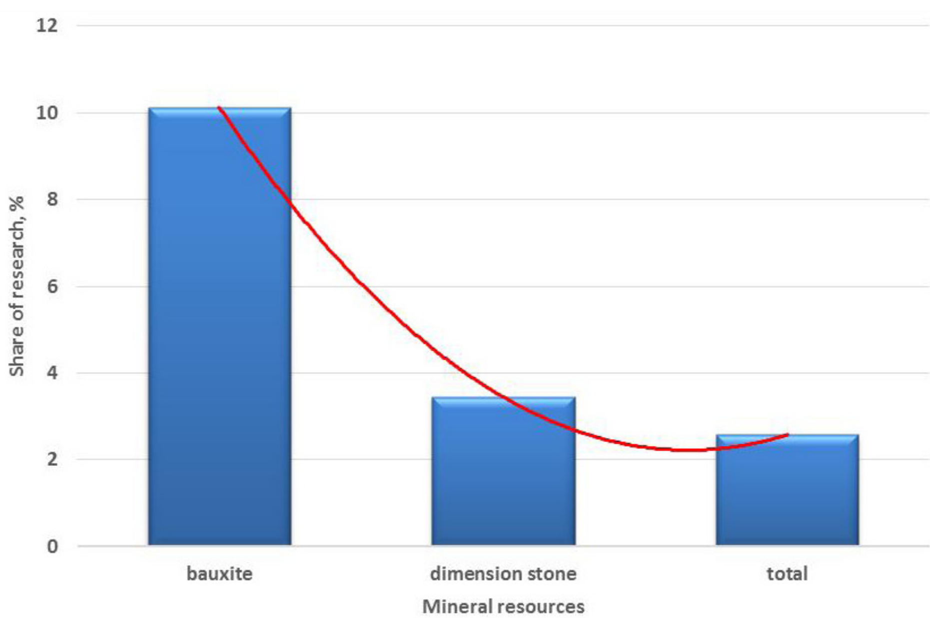

Figure 11: Relation between income and share of research costs.

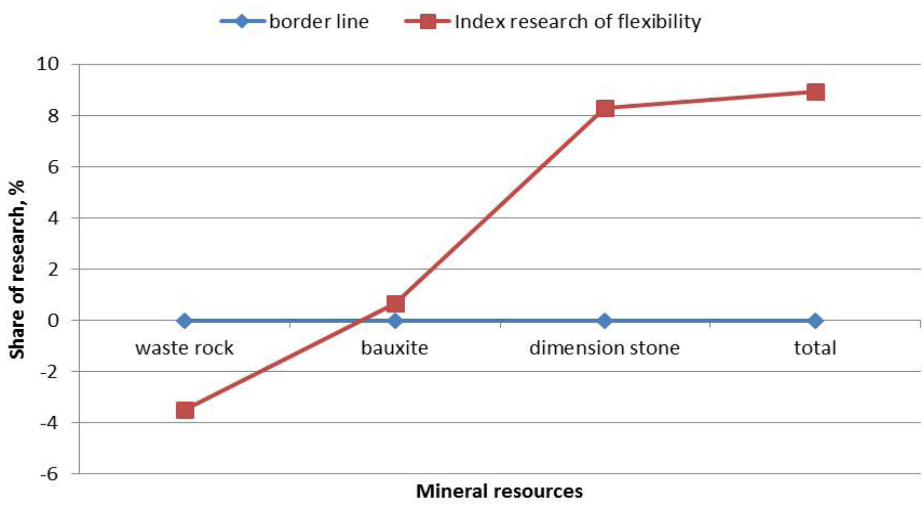

Figure 12: Relationship between the index of flexibility and the border line.

for the existing conditions. Therefore, new research and exploration methods should be developed and implemented in order to utilize these resources for exploitation.

6. CONCLUSION

Research in the bauxite-bearing area of "Crvene stijene" was extremely extensive and significant investment was made for finding bauxite and determining reserves. High quality limestones, dolomites and carbonate breccias compose the footwall and hanging wall of the bauxite deposits. High quality footwall and hanging wall rocks were never evaluated for any purpose. However, analyses of these footwall and hanging wall carbonate rocks show that these rocks can be very valuable dimension stones. With the proposal to evaluate these associated deposits, a new approach for evaluating resources for exploitation was developed. Individual analysis of each of the deposits separately does not provide realistic results of the relationships between research costs, income and total profit. Based on these drawbacks of the individual approach, a new, integrated method was developed which suggests the economic analysis of all - primary and associated deposits altogether.

Bauxite deposits are located approximately 120 m below the surface, which increases the price of exploration and exploitation. Reducing the price can be principally achieved by two methods: by introducing the integrated approach to research and by combining exploration methods.

The integrated approach of research includes all the available resources in a particular area, which creates a synergic effect and reduces the overall share of costs in terms of total income. Combined research methods can also increase efficiency by determining the depths of exploration wells. When the depth is known, exploration continues with underground mining techniques.

REFERENCES

DRAGIČEVIĆ, I. (1981): Geological settings in the bauxite-baering area Jajce (in Croatian).– Master's thesis. Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Zagreb, 65 p.

DRAGIČEVIĆ, I. (1987): Palaeogeographic evolution of the edge of the Mesozoic carbonate platform of Dinarides between the Vrbas and Bosnia (in Croatian).– PhD Thesis, Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Zagreb, 90 p.

DRAGIČEVIĆ, I. & VELIĆ, I. (1994): Stratigraphical position and significance of reef facies at the Northern margin of the Dinaric carbonate platform during the Late Jurassic and Cretaceous in Croatia and Bosnia.– Geologie Mediterranee, Tome XXI, N^{O} 3-4, 59–63, Marseille.

DRAGIČEVIĆ, I. (1997): The Bauxites of the Northern Margin of the Dinarides Carbonate Platform (Area of Jajce, Bosnia). 8th Internat. Congress of ICSOBA, Milan, April 16/18-1997, Travaux, ICSOBA, Vol. 24, 64–73, Milan.

DRAGIČEVIĆ, I. & VELIĆ, I. (2006): Litostratigraphic settings of bauxite in the Bešpelj Area (in Croatian).– GEOECO.ing d.o.o. 30 p., Zagreb.

DRAGIČEVIĆ, I., GALIĆ, I., VRANJKOVIĆ, A. & GALIĆ, M. (2009): Elaborate of the reserves of dimension stone in exploitation field "Kusačko brdo" in Široki Brijeg (in Croatian).– Proin 21 d.o.o., Široki Brijeg, 40 p.

GALIĆ, I. (2002): Mining Design using specialized software, Master's thesis, Faculty of Mining, geology and Petroleum Engineering, Zagreb, 95 p.

GALIĆ, I., DRAGIČEVIĆ, I.I., ŽIVKOVIĆ, S.A., JANKOVIĆ, B., RADOVAC, T., KOVACSICS, Á., HEDERICS, J., PODANYI, T. & HAJSEK, D. (2006): The main mining project of exploitation bauxite deposits on Bešpelj (In Croatian).– Faculty of Mining, Geology and Petroleum Engineering, 495 p., Zagreb.

GALIĆ, I., VIDIĆ D. & JEMBRICH, Ž. (2011): The influence of The coefficient of utilization of reservoir feasibility of dimension stone production and improvement opportunities.– Mining and Geology Bulletin, Vol. 15, 117–130, Mostar.

GALIĆ, I. KRASIĆ, D. & KNEŽIČEK, T. (2014): A defining the optimal point of opening and developing a surface pit mine.– Acta Montanistica Slovaca, Vol. 19, N^{O} 1, 47–59, Košice.

MARINKOVIĆ, R. & AHAC, A. (1981): Basic Geological Map SFRY, 1:100.000. sheet Jajce, l33–131, "Geoinženjering" Institute of Geology-Sarajevo, Federal Geological Institute, Beograd.

MARINKOVIĆ, R. & AHAC, A. (1981): Explanatory notes for Basic Geological Map SFRY, 1:100.000. sheet Jajce, l33–131, "Geoinženjering" Institute of Geology-Sarajevo, Federal Geological Institute, Beograd.

POPOVIĆ, N. (1984): The scientific basis of the design of open pit mines, II. edition, Veselin Masleša, 971 p., Sarajevo.

VIDIĆ, D., GALIĆ, I. & FARKAŠ, B. (2012): The profitability of dimension stone deposit exploitation in relation to the coefficient of utilization.– Mining-Geology-Petroleum Engineering bulletin, Vol. 24, 123–130, Zagreb.

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