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POTENTIALITY OF THE BUGOJNO COAL BASIN, BOSNIA AND HERZEGOVINA

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SUMMARY

This paper presents research results of the Bugojno coal basin, which contains very significant, but still insufficiently explored lignite reserves. Based on the determined borders of surface distribution and the research results in the northwestern part of the Bugojno coal basin, proved are four coal layers with reserves of over one billion tons of coal.

Discussed are geological characteristics of coal layers, their qualitative-quantitative characteristics, spatial potential of deposit and classification of coal layers. Considering the raw material potential and the possibility of expanding the existing raw material base, the Bugojno coal basin has particular importance for the long-term development of lignite exploitation and its use for thermal energy purposes.

Key words: *potentiality, the Bugojno coal basin, qualitative-quantitative characteristics, spatial potentiality, coal layers.*

INTRODUCTION

Bugojno coal basin includes a part of the terrain located in the central part of Bosnia and Herzegovina between Gornji Vakuf-Uskoplje in the southeast and Donji Vakuf in the northwest. The area of the basin is about 130 km^2, which makes it one of the larger basins with terrestrial-limnic coal deposits in Bosnia and Herzegovina (Figure 1). Four coal layers are situated in the northwestern part of the Bugojno basin and one in the southeastern part [1]. Basin is irregular in shape, extending northwest-southeast, about 31 km long. The width and length of the basin are in the ratio 1: 3.4. The smallest width of the basin is 1.4 km, south of Gračanica, and the largest is 9 km, north of Bugojno.

In the relief of central Bosnia, Bugojno basin represents a significant geomorphological unit. Genetically speaking, it is a medium-high intermountain depression surrounded by medium-high and high mountains. It is surrounded on the east and southeast by the prominent heights of the Vranica mountain (2112 m above sea level), on the north and northeast by the Komar mountain (1510 m above sea level), and on the west by the Raduša mountain (1956 m above sea level). The basin is dominated by slightly rounded hilly morphological forms and quite wide valleys along rivers and larger streams. It was formed by lowering of the terrain between the northeastern Vrbas-Voljevac fault and southwestern Porič fault.

Regional geological researches were conducted from 1983 to 1987; detailed from 2014 to the end of 2018, while exploitation geological research is performed every year at the active surface mine Dimnjača. Based on the elaborated results of geological research, the potentiality of the Bugojno coal basin was analyzed.

Coal of the Bugojno basin is a quality coal of brown-black color, has brown streak and it is without a distinct lignite structure, because its general habitus resembles younger bituminous coals. It is hard and without luster, has plate or uneven fracture [2]. The Bugojno basin contains very significant, but insufficiently explored lignite reserves.

It should be noted that only shallower parts of the deposit have been explored, so it is justified to predict significantly larger reserves in the basin [3].

Figure 1 Location of the Bugojno coal basin (Google Earth 2020)

GEOLOGICAL CHARACTERISTICS OF THE BUGOJNO BASIN

Bugojno coal basin (Figure 1) is divided into northwestern and southeastern parts in relation to the spatial distribution of coal deposits [1]. Neogene sediments of the northwestern part of the Bugojno basin are represented with freshwater lake formations, situated discordantly over the older basement. This basement consists of Middle Triassic and partly Upper Cretaceous sediments.

In the development of the Neogene, the Middle and Upper Miocene were separated (Figure 2), which is divided into seven lithostratigraphic units: basal ($^1M_{2,3}$), the second bottom coal layer ($^2M_{2,3}$), clay, clayey sandstones and marls ($^3M_{2,3}$), first bottom coal layer ($^4M_{2,3}$), marly limestones and marls ($^5M_{2,3}$), main coal layer ($^6M_{2,3}$), clays and sandy clays ($^7M_{2,3}$), Miocene is followed by Pliocene-Quaternary (Pl,Q) and Quaternary (Q) sediments [4,5,6,7,8,9,10,11,12].

In this part of the basin there are two coal deposits, namely: Kotezi with four coal layers and Čipuljić-Šumelji with one (main) coal layer.

Neogene sediments of the southeastern part of the Bugojno basin represent freshwater lake formations, which are discordant over the older basement. This basement consists of Permian, Lower Triassic and Middle Triassic (Anisian) sediments.

In this polyfacial complex, the Middle Miocene (Figure 3) is distinguished. This unit is divided into three lithostratigraphic units (unlike the northwestern Bugojno Neogene basin, which is divided into seven units), then the Pliocene-Quaternary (Pl, Q), which is much simpler in structure and Quaternary [5].

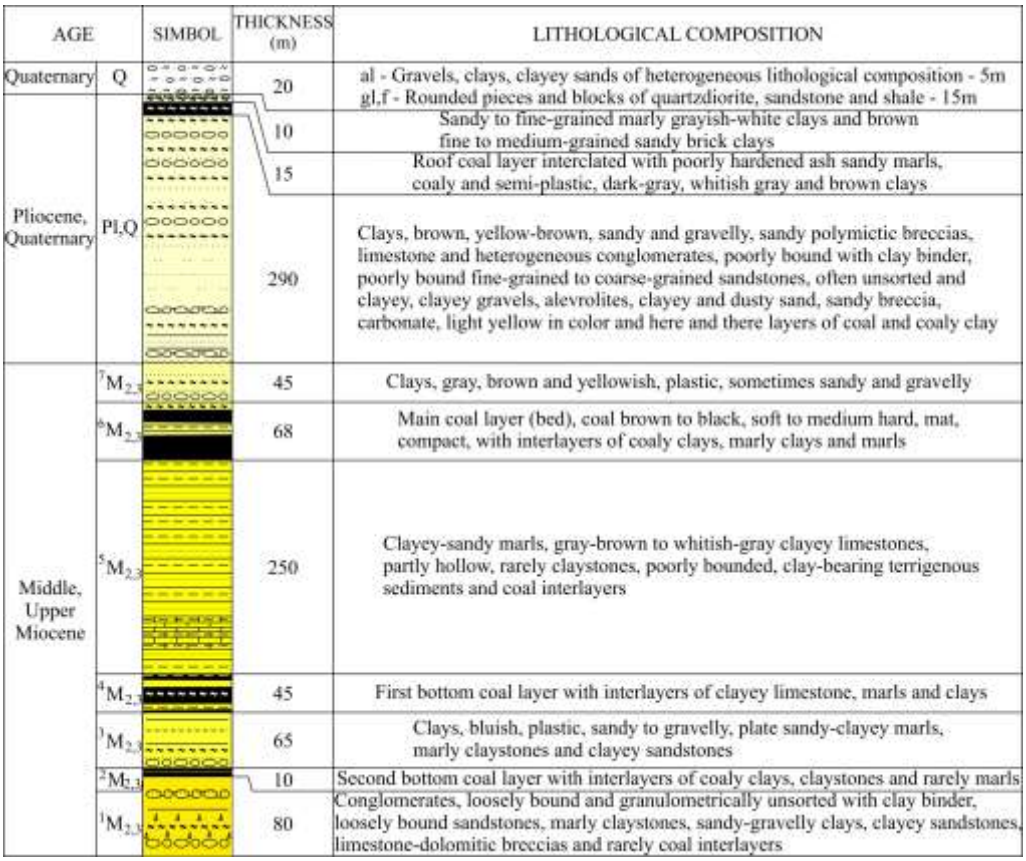

Figure 2 Synthesized geological column of the northwestern part of the Bugojno basin (Forčaković Dž.)

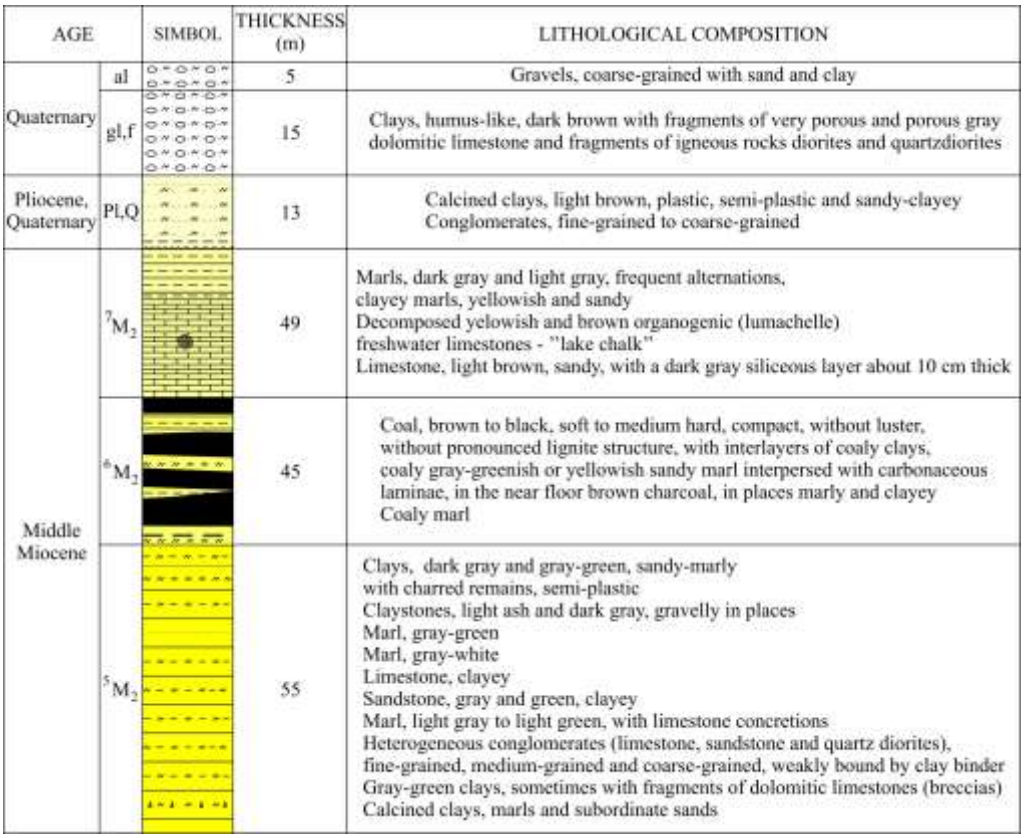

Figure 3 Synthesized geological column of the southeastern part of the Bugojno basin (Forčaković Dž.)

Within this part of the basin, three coal deposits are situated: Dimnjače, Donja Ričica and Odžak-Zanesovići with one (main) coal layer.

BASIC CHARACTERISTICS OF THE COAL LAYERS

The analysis of geologically investigated coal-bearing contoured productive areas of the northwestern part of the Bugojno basin identified four coal layers, in which $1{,}3x10^9$ tons of coal were determined (Tabla 2). Coal layers were formed under conditions of uneven accumulation of plant material in peatlands, ie when the accumulation happened with occasional longer or shorter interruptions.

Due to the sudden sinking of the bottom of the peat bog, seasonal floods of peat bogs etc, coal layers have a variable thickness and qualitative characteristics. (Tables 1, 3 and 4). Based on laboratory tests, the coal of the Bugojno basin is classified in the group of soft to medium hard brown lignite coals of relatively low degree of carbonization, with a slightly increased content of sulfur and ash [1,2,13].

Table 1 Basic parameters of the coal layers in the Kotezi deposit

Coal layers	Pure coal thickness in the layer [m]	Volumetric mass [t/m^3]	Coal content [t/m^2]	Economic significance
II bottom	4,34	1,32	5,7	No
I bottom	5,55	1,28	7,1	No
Main	22,24	1,29	28,68	Yes
*Roof	7,7	1,12	8,62	Yes?

*Potentially economically significant, limited in space, roofing coal layer is perspective for small-scale surface mining and could be exploited together with the main coal layer [1,3].

They are of different thicknesses, heterogeneous, belong to complex coal layers, and are characterized by a significant percentage of thicker or thinner barren interlayers, clay lenses, coaly clay, coaly marls, colorful marls, between 20 and 25% [1,3,14,15]. Parts of the complex coal layer are heterogeneous in terms of genesis, petrographic composition and chemical-technological properties of coal [3].

The interlayers are thicker in the upper part of the layer, while the thinner interlayers of the inorganic component are located in the lower part. The coal mass is divided by barren interlayers into two, three or more parts. The inequalities of the main and roof coal layers are within the limits that can be overcome during selective exploitation.

Classification of coal layers according to characteristics, depth of deposition and exploitability:

- Roof coal layer - quite complex structure (conditionally exploitable) - It is spread over a relatively small area in the northwestern part of the Basin
- Main coal layer - relatively complex structure (exploitable) - Has the greatest distribution in both parts of the Basin
- The first bottom coal layer - very complex structure (non-exploitable) - It is widespread in the northwestern part of the Basin
- Second bottom coal layer - extremely complex structure (non-exploitable) - It is widespread in the northwestern part of the Basin. It has a smaller distribution than the first bottom coal layer

The coal content of the Bugojno basin is shown in the diagrams (Figures 4, 5 and 6), and was calculated from the average thickness of pure coal in layers (pure coal is coal containing up to 20 cm of tailings) and mean bulk density (Tables 1 and 2).

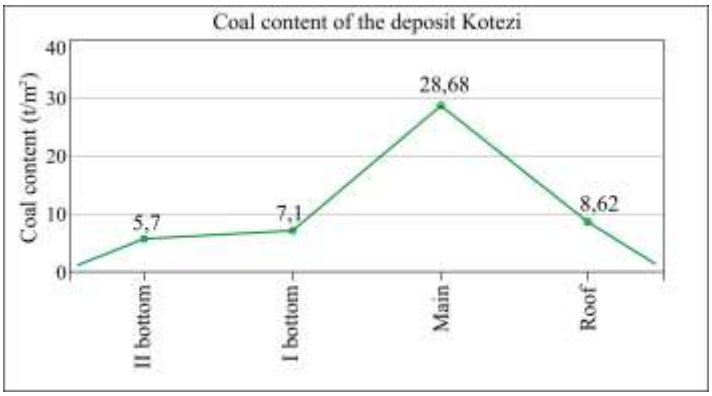

Figure 4 Diagram of coal content variation by layers of the deposit Kotezi

Table 2 Basic parameters of coal deposits of Bugojno basin - main coal layer

Deposits	Pure coal thickness in the layer [m]	Volumetric mass [t/m^3]	Coal content [t/m^2]	Economic significance
Dimnjače	11,55	1,30	15,0	Yes
Donja Ričica	7,6	1,27	9,65	Yes
*Odžak-Zanesovići	9,30	1,28	11,9	Excavated
Čipuljić-Šumelji	14,98	1,28	19,18	Yes
Kotezi	22,24	1,29	28,69	Yes

*****Coal deposit Odžak-Zanesovići was an economically significant deposit - the exploitation was completed.

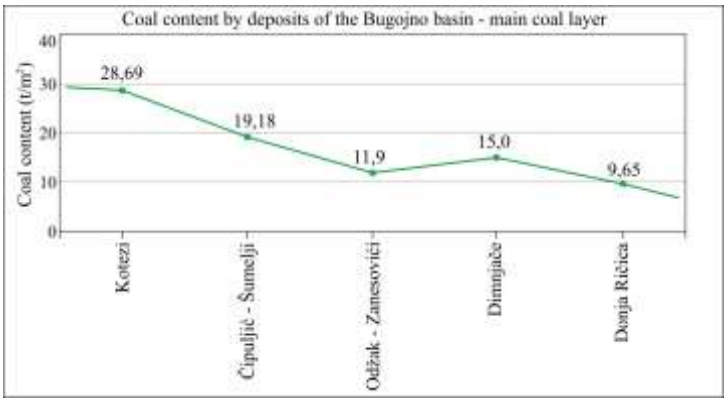

Figure 5 Diagram of coal content variation by line of strike in the Bugojno basin - main coal layer

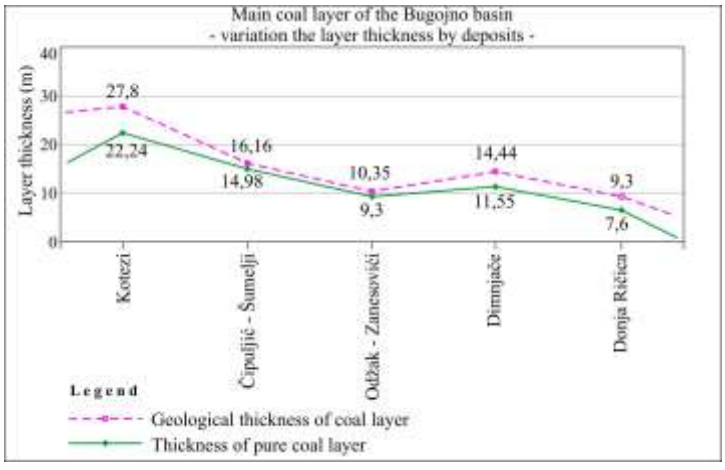

Figure 6 Diagram of variation in thickness by strike line of main coal layer in the Bugojno basin

QUALITATIVE-QUANTITATIVE CHARACTERISTICS OF COAL IN THE BUGOJNO BASIN

Quality of the coal layers of the Bugojno basin (Tables 3,4,5) was determined by laboratory and industrial tests performed within the framework of regional and detailed research [6,13,14,15,16,17].

Table 3 Quality of coal layers in the northwestern part of the Bugojno basin

Components	Coal layers				
	Gaj Berića-Karalinka-Kotezi-Guvna-Prusac				Čipuljić-Šumelji
	Roof	Main	I bottom	II bottom	Main
Air-dry moisture [%]	23,95	28,11	22,37	24,99	26,41
Hygro moisture [%]	6,6	10,12	6,06	6,67	10,40
Total moisture [%]	30,55	38,23	28,43	31,66	36,81
Ash [%]	20,49	18,18	19,52	23,6	20,49
Volatile substances [%]	30,77	26,65	30,94	26,07	28,40
Combustible substances [%]	49,19	46,03	51,73	44,74	43,90
C-fix [%]	18,41	16,34	20,77	18,70	17,61
Coke [%]	38,67	33,91	40,62	42,27	35,40
Combustible sulfur [%]	0,48	1,0	2,19	1,45	1,39
Bound sulfur [%]	3,20	1,26	1,87	2,32	1,23
Total sulfur [%]	3,68	2,26	4,06	3,77	2,62
Upper calorific value [MJ/kg]	12,8	11,0	12,7	13,0	11,0
Lower calorific value [MJ/kg]	11,5	10,0	11,5	11,3	9,6

Table 4 Quality of the main coal layer in the deposits of the southeastern part of the Bugojno basin

Components	Dimnjače	Donja Ričica	Odžak-Zanesovići
Air-dry moisture [%]	19,74	26,97	21,83
Hygro moisture [%]	12,73	7,93	13,33
Total moisture [%]	32,47	34,90	35,16
Ash [%]	16,09	18,16	11,53
Volatile substances [%]	30,89	29,22	29,42
Combustible substances [%]	49,07	46,31	52,82
C-fix [%]	19,18	14,92	23,40
Coke [%]	35,14	34,41	37,40
Combustible sulfur [%]	1,68	0,96	1,52
Bound sulfur [%]	1,45	1,78	1,16
Total sulfur [%]	3,13	2,74	2,68
Upper calorific value [MJ/kg]	13,1	11,5	14,4
Lower calorific value [MJ/kg]	11,7	10,3	12,9

Table 5 Total coal reserves of the Bugojno coal basin

Reserve classes	RESERVE CHATEGORIES					Total [10^6 t]
	A	B	C_1	C_2	D_1	
SOUTHEASTERN PART OF THE BUGOJNO COAL BASIN						
Balance	1, 89	2,49	0,17	-	-	4,5
Off-balance reserves	0,19	0,13	0,35	-	-	0,67
TOTAL:	2,0	2,6	0,52	-	-	5,2
NORTHWESTERN PART OF THE BUGOJNO COAL BASIN						
Balance	37,37	66,68	1,5	-	-	105,6
Off-balance reserves	-	78,88	48,6	-	-	127,5
Potential	-	-	-	656	396	1052
TOTAL:	37,37	145,57	50,17	656	396	1285
ALL TOGETHER:	39,46	148,18	50,70	656	396	1290

Reserves of quality coal in the main and partially roof coal layer of the northwestern part of the Bugojno basin are quite large and can serve as a solid basis for further development of mining and construction of new thermal energy capacities in this part of Bosnia and Herzegovina.

Table 6 Comparison of the Rulebook on Classification, Categorization and Calculation of Reserves of Solid Mineral Raw Materials and keeping records on them FBiH (36/12) with the UN Framework Classification of Reserves and Mineral Resources [18,19]

Rulebook FBiH (36/12)	Reserves of solid mineral raw materials						
	Probable reserves	Forecast reserves	Possible reserves	Proven geological reserves		Exploitation reserves	
	D_2	D_1	C_2	C_1	A i B	C_1	A i B
UNFC						Mineral reserves	
		334	223	222	221	112	111

Calculated geological reserves of coal have uneven degree of exploration.

In the structure of total geological reserves of coal of the Bugojno basin, balance reserves participate with only 11,71%, off-balance with 10,07% and potential with 78,22%. They have a very low and uneven level of exploration, which implies a large share of potential and off-balance coal reserves in total reserves. Based on the determined boundaries of surface distribution and the results of research of the Bugojno coal basin, the achieved level of research in the basin proved four coal layers with about 1,3 billion tons of coal.

SPATIAL POTENTIALITY AND CLASSIFICATION OF COAL LAYERS

The spatial potential of coal from the Bugojno basin (Figure 8) is divided into four classes:

- The first class is represented by the main coal layer, these are areas with proved economic reserves of coal - economically most important in the Basin
- The second class is represented by the roof coal layer and the main one, which lies deeper than 160 meters depth - areas with potentially economic coal reserves
- The third class includes areas represented with the first and second bottom coal layers - coal reserves do not have economic significance, and
- The fourth class includes areas where coal reserves have been excavated

Based on the results of extensive, complex detailed geological research of the deposit, zoning or contouring of the entire Bugojno basin was performed for surface (up to 160 meters depth) and underground exploitation (from 160 meters to the bottom of the main coal layer) [3].These areas (Figure 9) represent potential future mines with surface or underground coal mining. Taking into account coal content, quality, degree of economy and method of exploitation, they are divided into four classes:

- The first class consists of an area represented with main coal layer up to 160 meters deep, perspective for surface exploitation
- The second class consists of an area represented with roof coal layer, perspective for surface exploitation of a smaller volume (which could be exploited together with the main coal layer)
- The third class consists of an area represented with main coal layer for underground exploitation (from a depth of 160 meters to the bottom of the main coal layer), and
- IV category class of the first and second bottom coal layerss that are not economically significant as well as the excavated areas in the southeastern part of the Bugojno basin

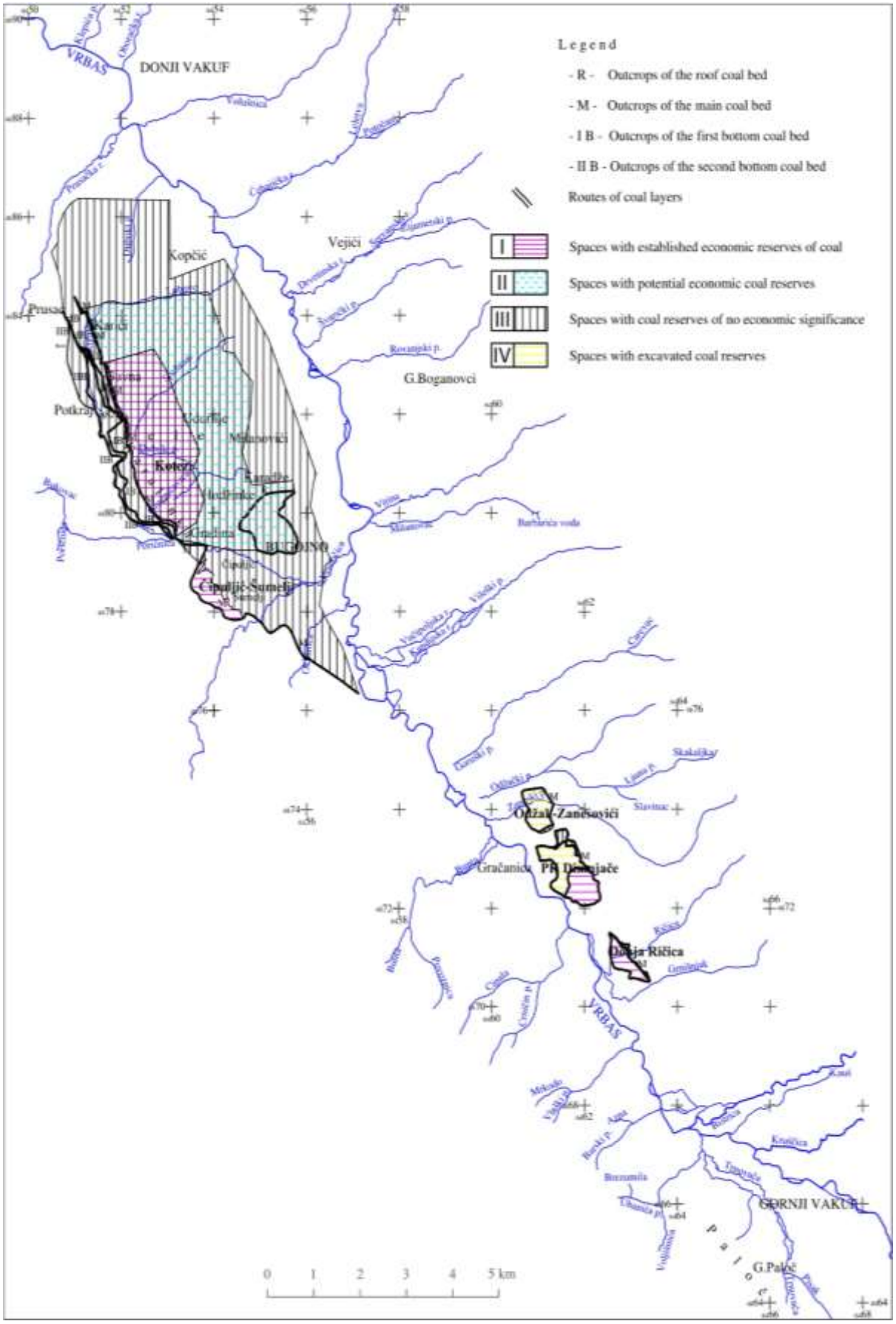

Figure 8 Spatial potentiality of coal in the Bugojno basin (Forčaković Dž.)

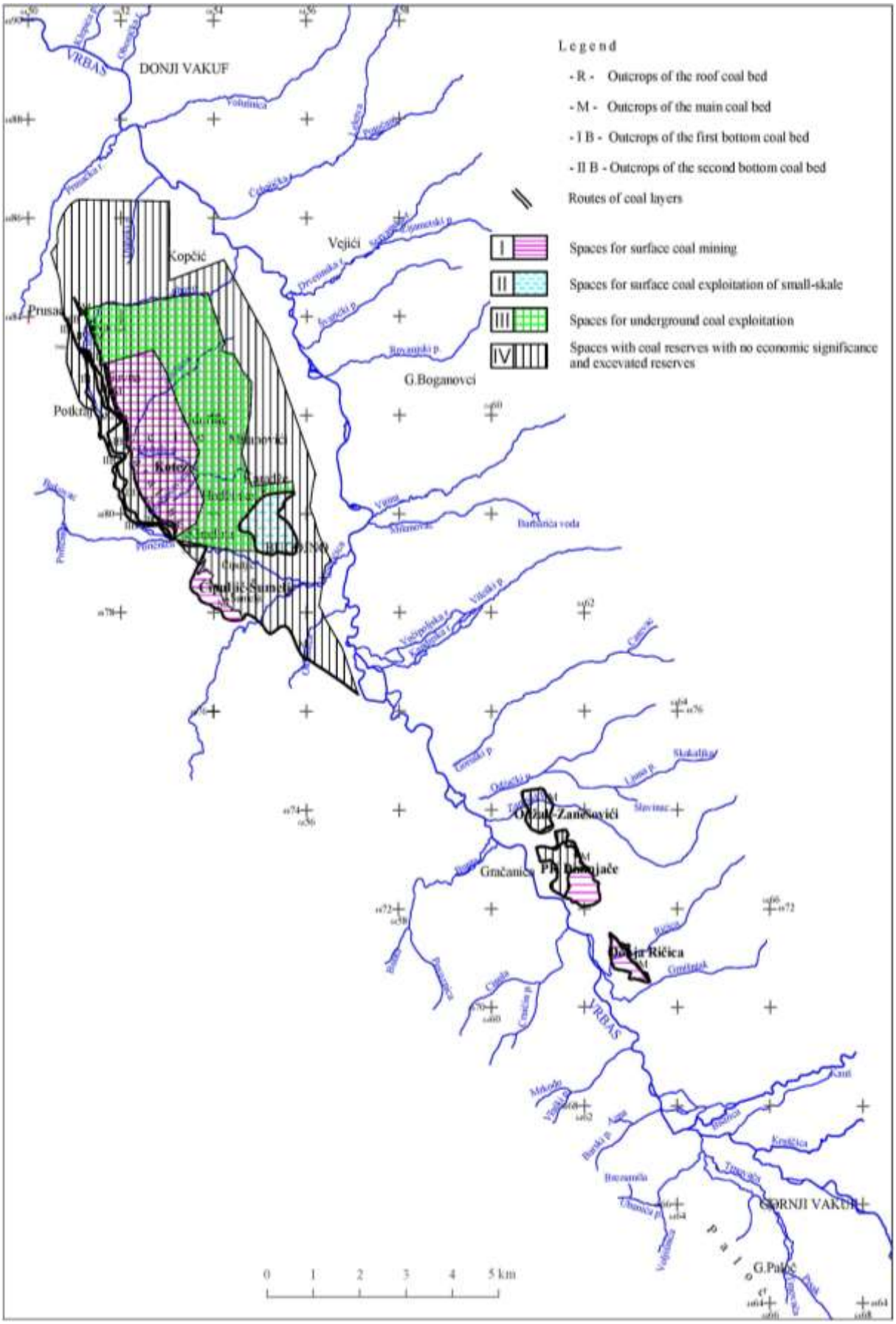

Figure 9 Classification of the area covered with coal layers and the exploitability of coal in the Bugojno basin

DISCUSSION

Comparing the results of basic coal layers parameters of the Kotezi deposit, and taking into account the scope of performed works, it was proved that the main coal layer has the highest coal content. The first and second bottom coal layers have relatively small deviations. The roof layer has a slightly higher coal content than the first coal layer.

The main coal layer has the greatest distribution in both parts of the Basin. It is exploitable in both parts of the Basin and has the highest economic significance.

Coal deposits in the northwestern part of the Bugojno basin are of much greater economic importance compared to the deposits in the southeastern part.

Coal deposit Kotezi is the most important deposit in the Bugojno basin, which is very important due to continuity of coal exploitation (reserves of about 96 million tons of coal have been proven in the deposit). The Kotezi deposit is followed by the Čipuljić-Šumelji coal deposit, while the third and fourth are the coal deposits located in the southeastern part of the Dimnjača and Donja Ričica basins.

Quality of coal in represented coal layers of the Bugojno basin is very variable, both vertically and laterally. In the vertical profile of the coal seams, the highest quality batches are from the upper part of the layer. They are represented by black to black-brown, matte coal. Slightly lower quality are the batches from the middle, and especially from the lower part of the layer. There is coal with wood laminates that is more stratified.

In terms of calorific value, the best quality has coal of the roof and main layer. However, the roof coal layer has a very low degree of exploration and a small contouring area, and for now it is potentially economically significant. Differences between the qualitative values of the represented coal layerss, ie the coal deposits of the Bugojno basin, are most probably based on differences of the parent plant matter, conditions of its accumulation or the unequal duration of microbiological processes.

Analysis of the coal content of the Bugojno basin identified parts of the basin with a pronounced potential in which it is possible to realize surface and underground coal exploitation. Proven economic and potentially exploitation reserves of coal presuppose possible exploitation and opening of new mining plants, but also construction of new thermal energy capacities in this basin. Coal reserves of the Bugojno basin are at a low level of geological research.

For now in operation is only the main coal layer located in the southeastern part of the basin, which has the highest economic value in the entire Basin. The coal deposits of the Bugojno basin have the potential and perspective which represents the basis for economical exploitation of lignite coal and choosing priority localities for exploitation. Based on discussion and assessments, comparing the conditions on similar deposits, it can be concluded that the general geological and technical-exploitation factors are relatively favorable and indicate a possible profitable exploitation of the deposit.

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LITERATURE

[1] Forčaković, Dž. (2014). Potentiality of coal in deposits of Bugojno basin. Master's thesis. University of Tuzla. *[Bosnian language]*

[2] Jovović, M., Jovović, N. (2015-2018). Report on petrographic qualitative-quantitative maceral and microlithotypes analysis of coal samples from locality Kotezi near Bugojna. Geo-Minis Beograd. *[Serbian language]*

[3] Forčaković Dž., Dervišević R., Isaković H. (2020). Potentiality of the northwestern part of the Bugojno coal basin. Journal of faculty of mining, geology, and civil engineering, 8. University of Tuzla. *[Bosnian language]*

[4] Becker, D., Tissier J. (2019). Rhinocerotidae from the early middle Miocene locality Gračanica (Bugojno Basin, Bosnia-Herzegovina). Palaeobiodiversity and Palaeoenvironments.

[5] Göhlich U. B., Mandić O. (2020). Introduction to the special issue The drowning swamp of Gračanica (Bosnia-Herzegovina) - a diversity hotspot from the middle Miocene in the Bugojno Basin. Palaeobiodiversity and Palaeoenvironments.

[6] Džonlagić, Dž., Žugić, M. (1983-1987). Final annual report on regional geological researches of coal in the Bugojano basin. Geological Survey - Sarajevo. [Bosnian language]

[7] Soklić, I. (2000). Fossil flora and fauna of the Bosnia and Herzegovina, ANU BiH, Sarajevo. *[Bosnian language]*

[8] Vrabac, S., Đulović I. (2017). Report on macropaleontological and micropaleontological researches of core samples from boreholes K-40, K-58 i K-45 from revir Kotezi in the Bugojno coal basin. FSD RGGF-a University of Tuzla, Tuzla. *[Bosnian language]*

[9] Vrabac, S., Đulović I. (2018). Report on macropaleontological andi micropaleontological researches of core samples from borehole K-80 from revir Kotezi in the Bugojno coal basin. FSD RGGF-a University of Tuzla. Tuzla. *[Bosnian language]*

[10] Aiglstorfer, M. (2020). Ruminantia from the middle Miocene of the Gračanica coalmine (Bugojno Basin, Bosnia-Herzegovina). Palaeobiodiversity and Palaeoenvironments.

[11] Vasilyan, D. (2020). Fish, amphibian and reptilian assemblage from the middle Miocene locality Gračanica—Bugojno palaeolake, Bosnia and Herzegovina. Palaeobiodiversity and Palaeoenvironments.

[12] Andrić, N., Sant, K., Matenco, L., Mandic, O., Pavelić, D., Tomljenović, B., Demir, V., & Hrvatović, H. (2017). The link between tectonics and sedimentation in asymmetric extensional basins: inferences from the study of the Sarajevo-Zenica Basin. Marine and Petroleum Geology.

[13] Forčaković, Dž. (2014-2018). Final report on detailed geological researches of coal in the northwestern part of Bugojno basin. JP EP BiH d.d. Sarajevo, ZD Coal mine Gračanica d.o.o.,Gornji Vakuf-Uskoplje. *[Bosnian language]*

[14] Forčaković, Dž., Operta M. (2013). Geological and qualitative-quantitative characteristics of the coal deposit Dimnjače, Municipality Gornji Vakuf-Uskoplje. Proceedings of the V conference of geologists of the Bosnia and Herzegovina with international participation. Pale – Jahorina. *[Bosnian language]*

[15] Hajdarević, M., Rožnjaković N. (2018). Elaborate on classification, categorisation and calculation of coal reserves in the main coal layer of the deposit Kotezi, municipalities Bugojno and Donji Vakuf. Geoservice Živinice. *[Bosnian language]*

[16] Zaimović, M., Hodžić N. (2018). Study on the quality of coal from the Kotezi exploration area. RGH-Inspekt. Sarajevo. *[Bosnian language]*

[17] Butorac, Đ. (1986). Study on ore reserves at the Odžak-Zanesovići deposit. Geoinstitut - Sarajevo. *[Bosnian language]*

[18] Redžepović, R. (2003). The key to the classification of reserves/resources of mineral resources. Geological journal 35. Sarajevo. [*Bosnian language]*

[19] United Nations International Classification for Reserves/Resources: Solid Fuels and Mineral Commodities, (2009). Available at: https: //www.- unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/un fc2009 / UNFC2009_ES39_e.pdf.