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PALEOZOIC QUARTZITE OF THE SMRČEVICE IN THE CENTRAL BOSNIA

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SUMMARY

The paper presents results of detailed geological research of quartzite in the wider area of Smrčevice, southeastern of Gornji Vakuf-Uskoplje. Based on the defined boundaries of surface distribution and research results, geological reserves of about 12 million tons have been determined in the wider area of Smrcevica. The quartzite reserves that have been so far determined in this area are at a low level of geological research.

The paper contains an overview of the geological characteristics of the area, qualitative and quantitative characteristics of quartzite, and the mineral raw material potential of quartzite in the Smrčevice area according to the PERC standard.

The results of the conducted research indicate that the general geological and technical-exploitation factors are relatively favorable and indicate a possible profitable exploitation of the deposit. Taking into account the significant raw material potential, and the possibility of expanding the existing raw material base, this area has special importance for the perspective development of quartzite exploitation and its use in the production of ferrosilicon and silico-metals.

Key words: *quartzite, Paleozoic, Smrčevice potentiality, PERC standard*

INTRODUCTION

The wider area of Smrčevice, where a large number of deposits and the occurrences of quartzite have been discovered, is located in the Central Bosnian mountain belt, 32 km southeastern of Gornji Vakuf-Uskoplje. The area belongs to the high mountain region where the peaks Gradac (1800 m above sea level), Vitreuša (1911 m above sea level), Štit (1950 m above sea level) and others, which belong to the mountain Vranica, stand out. The relief is characterized by prominent ridges, conical forms of well-marked peaks and canyon shapes conditioned by geological structure, tectonic structure and various erosion-denudation processes [1,2]. Surface of the Smrčevice exploration area is about 150 ha, while the total area of exploitation fields is about 90 ha (Figures 1 and 4). The most economically interesting deposits are Gradac I and III (primary deposit) and Obodski potok-Gromilica (secondary deposit). At the Gradac I and III deposits, quartzite reserves have been accurately researched, verified, but also checked in the process of exploitation and technological processing, while at the Obodski potok-Gromilica deposit, reserves have been precisely researched, verified and occasionally exploited [3,4,5].

Regional geological research in the area of Smrčevica was realized in the period from 1979 to the end of 1982 (RO Geoinženjering OOUR Institute of Geology Ilidža). Detailed geological research on the

Gradac I and III deposits was performed from 1982 to 1983 (RO Geoinženjering OOUR Institute of Geology Ilidža) [3,4]. Exploitation geological researchs at the surface mine Gradac I and III were performed in 1998, 2004, and 2018 (Faculty of Mining, Geology and Civil Engineering in Tuzla and Geotehnos d.o.o. Sarajevo). Detailed research on the Obodski potok-Gromilica deposit was carried out from 2003 to the end of 2004 (NT-IGM d.o.o. Novi Travnik) [3].

At the Gradac deposit quartzite was exploited from 1984 to 1992 (with the cessation of production from 1992 to 1997), exploitation from 1997-2005. year (cessation from 2005 to 2017); exploitation from 2017 to the end of 2018 [5].

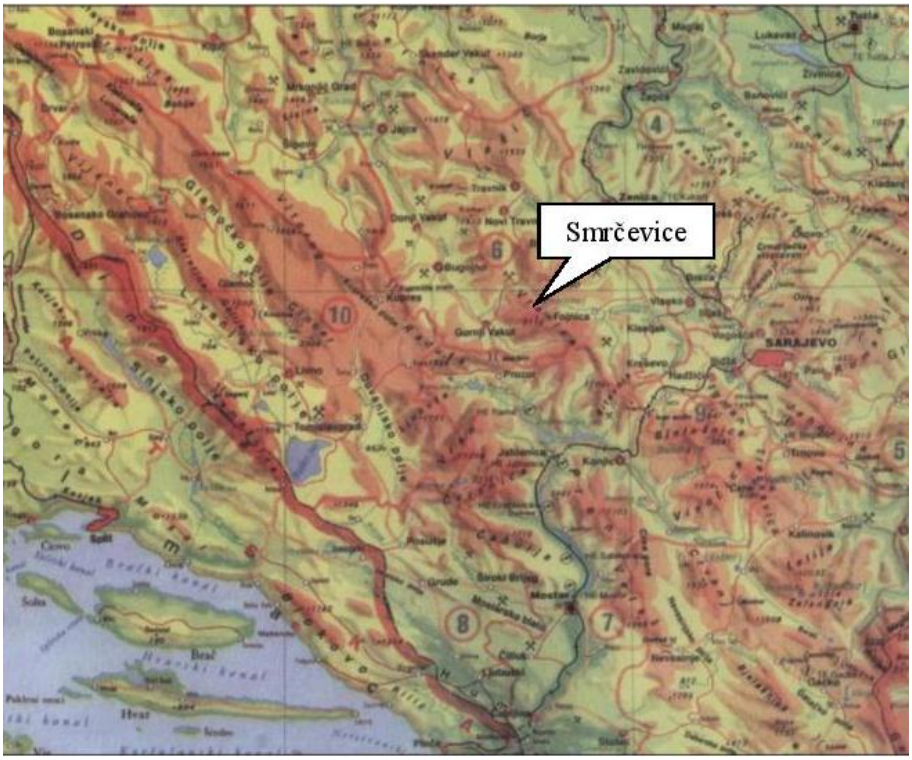

Figure 1. Geographical position of the wider Smrčevice area

Based on geological research results, the potentiality of the deposits and the occurrences of quartzite in the wider area of Smrčevice were analyzed [3,4]. In the area of Smrčevice, there is a quality quartzite of whitish-gray, yellowish-white or white color, in which yellow iron laminae and scrams are often visible.

The wider exploration area contains significant but insufficiently explored quartzite reserves. It should be borne in mind that only two deposits have been investigated in detail, so it is justified to predict significantly larger quartzite reserves in the wider area of Smrčevice [3,4,5].

GEOLOGICAL CHARACTERISTICS OF THE QUARTZITE DEPOSIT SMRČEVICE

Quartzite, quartz sandstones and quartz-sericite shales participate in the geological structure of the Smrčevice area [1,2] Silurian-Devonian age? (Figures 2 and 3). In the bottom and roof of the ore body there are gray and dark gray quartz-sericite shales, which are the most common rocks, and white to gray-white sandstones, with a clear border to light gray or reddish bank, massive or layered quartzite. Contact is usually tectonic. Cracks intersecting quartzite are often filled with milky white quartz.

The Gradac quartzite deposit consists of two separate ore bodies, both of the primary type: Gradac I (deposit dimensions 350x150 m) and northeast of it, another ore body marked as Gradac III (deposit dimensions 200x100 m) formed in Paleozoic shale clasts [3,4]. Ore bodies have the shape of lenses

and layers, varying in thickness from a few to several tens of meters. At the Smrčevice site, two quartzite deposits were investigated: Gradac I and III and Obodski potok-Gromilica [3,4,5].

Quartzite deposit Obodski potok-Gromilica is a secondary deposit formed by the destruction of the primary deposit during intense glacial activity and deposited on steep slopes [3]. In the vicinity, occurrences with potential reserves of the C_2 category were identified, on which there were no more specific researches (Zapade, Gromilica, Marina rocks, Vagan, Kljun i Lazine) [3,4,6,7].

Figure 2. Contact of shale and quartzite in the deposit Gradac I (Forčaković Dž. 2021)

AGE	GRAPHIC LABEL	THICKNESS (m)	LITHOLOGICAL COMPOSITION
Silurian, devonian?		8	Gray and dark gray quartz-sericite schist
		7	White massive quartzite
		16,5	Gray, gray-greenish quartz-sericite-chlorite schist with layers of quartzite
		10	Gray-yellow and white massive quartzite with a layer of quartz-sericite schist 0,5 m thick
		5	Dark gray graphite quartz-sericite schist and meta sandstone

Figure 3. Synthesized geological column of the Gradac deposit I and III (Forčaković Dž. 2021)

GENERAL CHARACTERISTICS OF QUARTZITE

The analysis of productive areas in the wider area of Smrčevice identified deposits and occurrences in which reserves of about $12x10^6$ tons of quartzite were calculated (Tables 1 and 2). Quartzites are metamorphic rocks that in most cases are formed from quartz sandstones or quartz sands.

Occurrences and deposits of quartzite are most often caused by processes of regional metamorphosis or by the action of hydrothermal solutions from felsic magma, due to which they are spatially localized in older crystalline terrains [3,4].

Table 1. Basic parameters of quartzite deposits in the Smrčevice area

Deposit	Quartzite thickness [m]	Bulk density [t/m^3]	Ore-bearing capacity [t/m^2]	Economic significance
Gradac I and III	3,0	2,6	7,8	Yes

Table 2. Total quartzite reserves in the Smrčevice area according to the FBiH Rulebook 36/12 and classification of potentialities

QUARTZITE OF THE SMRČEVICE				
Type of row material	Locality	Character of the resurce	Ore reserves	Potentiality classes
Quartzite	Gradac I and III	Deposit	$A+B+C_1 = 1x10^6$ t	First
			$C_2 = 9x10^6$ t	Second
	Obodski potok-Gromilica	Deposit	$A+B+C_1 = 350x10^3$ t	First
			$C_2 = 62x10^3$ t	Second
	Gromilica	Occurrance	$C_2 = 325x10^3$ t	Second
	Zapade	Occurrance	$C_2 = 170x10^3$ t	Second
	Lazine	Occurrance	$C_2 = 700x10^3$ t	Second
	Vagan	Occurrance	Opened outcrops	Third
	Kljun	Occurrance	Opened outcrops	Third
	Marina rocks	Occurrance	Opened outcrops	Third

In the study area, quartzites are banked, massive or layered with occasional alternations with quartz-sericite shales, and show less schistosity [8,9]. They are most often found in the form of elongated lenses whose thickness reaches up to ten meters. There are thinner layers of other silicon rocks around the edges of these lenses.

Quartzites are cracked and disintegrated at the surface, white, grayish-white, and sometimes yellowish-white in color. Other varieties have local type of color which depends on the content of dispersed organic matter and impregnation of Fe-hydroxide They are crystalline in structure, with granoblastic texture, medium to large grained. Relics of psammitic texture were discovered in some parts of the deposit, which indicates that they were formed by the metamorphosis of quartz sandstones.

RESEARCH METHODOLOGY

For a more detailed definition of the area of Smrčevice, and in order to expand the reserves and quality, the following field research and laboratory tests were conducted.

Field research included:

- detailed geological mapping of the wider area
- exploratory drilling with continious coreing
- exploartion-exploitation floors
- exploratory open pits
- mapping of research works with testing of characteristic intervals
- taking samples for laboratory tests: mineralogical-petrographic, chemical, thermal and determination of specific and bulk density.

Laboratory tests were performed in accredited laboratories for the following analyzes that give the characteristics of quartzite:

- Partial chemical tests included the analysis of the following elements SiO_2, Fe_2O_3, Al_2O_3, CaO and MgO. These tests were performed on 26 samples, of which 16 partial analyzes were performed.

- Complete chemical tests included analysis of the following elements: SiO_2, Fe_2O_3, Al_2O_3, CaO and MgO, TiO_2, S, P, Mn and LOI. These tests were performed on 38 samples, of which 14 composite samples were obtained.
- Silicate-chemical tests included the analysis of the following elements: SiO_2, Fe_2O_3, Al_2O_3, CaO and MgO, K_2O, Na_2O, P, H_2O, TiO_2. These tests were performed in the scope of 7 analyzes.
- Mineralogical-petrographic tests were performed on 8 samples.
- Thermal tests, in which differential-thermal and thermo-gravimetric tests were performed, conducted are on 10 samples.
- Specific and bulk density was determined on 10 rock samples.

These studies and tests had aim to prove the quality of quartzite that meets the criteria for obtaining in an electric arc furnace FeSi75%.

RESEARCH RESULTS

Data on the quality of individual deposits represent the average of perennial laboratory and technological tests and show that in the investigated deposits it is possible to selectively isolate quartzite that meets the quality criteria for the production of FeSi75. According to the technical conditions, quartzites intended for the production of FeSi75 in Steelmin BH d.o.o. from Jajce, have to meet the following criteria: SiO_2 – min. 97,0%, Al_2O_3 - max. 1,2% i CaO - max. 0,5%, granulation 25-120 mm [3,4,10,11,12].

Long-term exploitation and delivery of quartzite from the Smrcevica deposit has proven the average chemical quality of quartzite (Table 3), which meets the criteria for obtaining FeSi75% in an electric arc furnace [12].

Chemical composition of quartzite was determined by tests conducted in several relevant institutions, as well as chemical analyzes of quartzite performed in the laboratory of Steelmin BH d.o.o. from Jajce, which used quartzite from this deposit for more than 15 years to produce 75% ferrosilicon [3,4,10,11].

Table 3. Quartzite quality in the Smrčevice area

DEPOSITS	COMPONENT CONTENT %										
	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	CaO	MgO	K_2O	Na_2O	Cr_2O_3	P_2O_5
Gradac I and III	97,53	0,02	1,12	0,45	0,022	0,19	0,04	0,07	0,11	0,02	0,008
Obodski potok - Gromilica	96,54	-	0,83	1,22	-	0,21	0,03	-	-	-	-
Gromilica	97,75	-	0,82	0,47	-	0,23	0,04	-	-	-	-
Zapade	97,76	-	1,15	0,48	-	0,15	0,02	-	-	-	-
Lazine	97,42	-	1,31	0,39	-	0,15	0,08	-	-	-	-

Tables 2 and 4 provide an overview of ore reserves and occurrences, and the classification of mineral potential of quartzite in the Smrčevica area according to the PERC standard [13,14,15,16,17].
Based on the achieved degree of geological exploration of quartzite in the area of Smrčevice (Table 2 and Figure 4), three classes of potentiality are separated.

Quartzite deposits with established economic reserves of quartzite (deposits prepared for exploitation or are being exploited) have been determined as areas of the first potential class.

Areas of the second potentiality class represent partially explored areas of quartzite (tested outcrops and determined chemical composition) with potentially economic reserves of quartzite. Areas of the third potential class represent areas where the occurrences of quartzite at the level of prospecting has been determined (they have been separated on the basis of lithological characteristics and on the basis of comparison with already known deposits and occurrences of quartzite in the wider area). Within the

area of the third class of potentiality, no tests of the quality of the mineral raw material were performed. All areas with deposits and occurrences are perspective for surface exploitation.

The large amount of potential reserves in total reserves indicates that quartzite reserves have a very low level of exploration. In the structure of total reserves of quartzite deposits, balance reserves participate with only 13.5% and potential reserves with 86.5%. Quartzite reserves are also characterized by an uneven level of research. Based on the determined boundaries of surface distribution, results of research in the area of Smrčevice, and the achieved level of research, several million tons of quartzite reserves have been proven and assumed (Tables 2 and 4).

Table 4. Mineral potential of quartzite in the Smrčevice area according to the PERC standard

QUARTZITE OF SMRČEVICA				
Mineral resource	Locality	Resource character	Type of deposit/occurrence	Ore reserves
Quartzite	Gradac I and III	Deposit	Primary	Proven $1x10^6$ t Assumed $9x10^6$ t
	Obodski potok-Gromilica	Deposit	Secundary	Proven $350x10^3$ t Assumed $62x10^3$ t
	Gromilica	Occurrence	Primary	Assumed $325x10^3$ t
	Zapade	Occurrence	Primary	Assumed $170x10^3$ t
	Lazine	Occurrence	Primary	Assumed $700x10^3$ t
	Vagan	Occurrence	Primary	
	Kljun	Occurrence	Primary	
	Marina rocks	Occurrence	Primary	

Reserves of quality quartzite in the area of Smrčevice are significant and can serve as a reliable basis for further development of mining as well as construction of factory for ferrosilicon production [18].

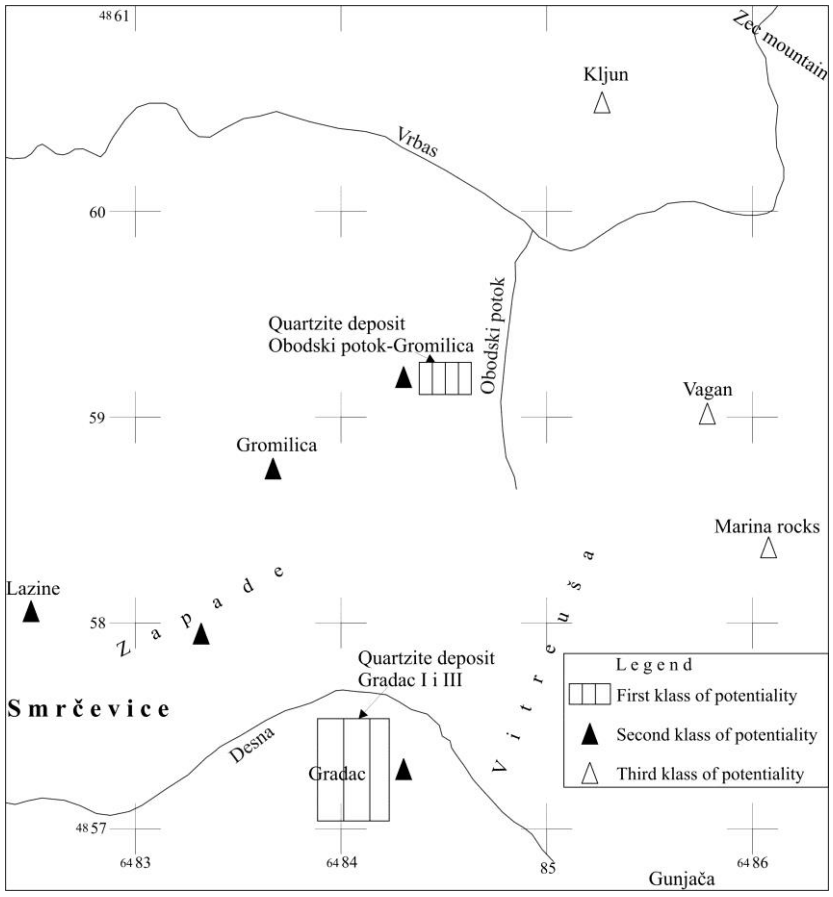

Figure 4. Spatial classification of quartzite potentials in the Smrčevice area (Forčaković Dž. 2021)

DISCUSSION

Comparing the results of the basic parameters of the quartzite deposits in the Smrčevice area, and taking into account the scope of performed work, it was proved that the quartzite of the Obodski potok-Gromilica deposit have the highest ore potential. The quartzite deposits Gradac I and III and Obodski potok-Gromilica have a significant distribution, are exploitable and have great economic significance. Gradac I and III quartzite deposit has a significantly higher economic significance in relation to the Obodski potok-Gromilica deposit. The Gradac I and III deposit is the most important deposit in the area of Smrčevice, which is very important due to the continued continuity of quartzite exploitation (balance reserves of about one million tons have been proven in the deposit). In the area of the Obodski potok-Gromilica deposit, balance reserves of about 0.35 million tons have been proven. Occurrences of quartzite in the wider area of Smrčevice determined by prospection are also important.

The quality of quartzite in the deposits of the Smrčevica area is very variable, both vertically and laterally. The quartzite of the Gradac I and III deposits has a better chemical composition compared to the Obodski potok-Gromilica deposit. In the vertical profile, the highest quality quartzite masses are located in the upper part where white, massive quartzites are represented. Slightly lower quality are gray-yellowish and white, massive quartzites with a layer of quartz-sericite shale, 0.5 m thick, which are located in the middle and lower part of the profile. The analysis of the ore-bearing capacity of the Smrčevica area identified parts with a distinct potential in which it is possible to realize surface exploitation of quartzite. Proven economic and potentially exploitation reserves of quartzite presuppose the possibility of exploitation and opening of new mining plants, but also the construction of a factory for the production of ferrosilicon in the area of Gornji Vakuf-Uskoplje [18].

The presented quartzite reserves in the Smrčevice area are at a low level of geological research. The deposits of the Smrčevica area have a raw material potential and perspective that represents the basis for the economic exploitation of quartzite and the selection of priority localities for exploitation. Exploitation of potential deposits is allowed by the spatial plan [19]. Based on the performed analysis and evaluation, 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 [20,21,22,23].

Previous research on the application of Smrcevice quartzite has been performed only for the production of ferrosilicon, but their most significant application is in metallurgy. Namely, in addition to chemical resistance, quartzites are also resistant to high temperatures. Therefore, they are widely used in various branches of industry, such as in the refractory industry for the production of dinas bricks for cladding "blast furnaces" of different sizes and shapes. For this purpose quartzites with content SiO_2 - 95% are used, where maximal participation of Al_2O_3 can be 2,0% and CaO - 1,5%.

Quartzite is used as solvent, especially in the smelting of nickel and copper concentrate to convert iron into slag. For this purpose, quartzite with 90-95% SiO_2 with the lowest possible content of harmful components (Al_2O_3+Fe_2O_3+Cao+MgO) is used. In the chemical industry, quartzite with a SiO2 content above 90% is used in the production of various acid-resistant materials, and in construction as a technical-building stone, as well as for the production of abrasives.

CONCLUSION

The paper presents the results of research and testing of quartzite in the Smrčevice area. The chemical composition of quartzite was determined by tests during many years of exploitation and delivery of quartzite for the production of ferrosilicon. Considering fact that significant quantities of quality quartzite for many years of exploitation have been proven on the deposit, it is important to underline that next to the deposit Gradac I and III (but also in the wider area of Smrcevice) there are significant potential reserves of quartzite of secondary and primary type which need to be investigated in detail, classified and thus could extend the life of the mine.

Taking into account the fact that the exploitation of potential deposits is allowed by the spatial plan, all future research in the coming period should be carried out exclusively by programs and projects in accordance with current regulations in the field of geology, mining, spatial planning and environmental protection.

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LITERATURE

[1] Sofilj, J., Živanović M. (1965-1971). BGM sheet Prozor 1 : 100 000, Geoinžinjering – Institute for geological research - Sarajevo. *[Serbian language]*

[2] Sofilj, J., Živanović M., i Pamić J. (1971). Interpreter BGM sheet Prozor, Geoinžinjering - Institute for geological research-Sarajevo. 1-49. *[Serbian language]*

[3] Đuzdanović, Z. (2004). Elaborate on classification, categorization and calculation of reserves in the deposit Obodski potok-Gromilica, Gornji Vakuf-Uskoplje. NT-IGM d.o.o. Novi Travnik. 1-44. *[Bosnian language]*

[4] Forčaković, Dž., Selimović, E. (2018). Elaborate on classification, categorization and calculation of reserves in the quartzite deposit Gradac I and III, Gornji Vakuf-Uskoplje. Geotehnos d.o.o. Sarajevo-lidža. 1-54. *[Bosnian language]*

[5] Forčaković, Dž. (2018). Annual geological report on researcf of quartzite in the deposit Gradac I, III (2019). PTD Smrčevice d.o.o. Gornji Vakuf Uskoplje. 1-16. *[Bosnian language]*

[6] Kurtanović, R. (2000). Deposits of non-metallic mineral row materials. University of Sarajevo. Faculty for metallurgy and materials Zenica. 1-218. *[Bosnian language]*

[7] Kulenović, E. (2006). Non-metallic mineral row materials of Bosnia and Herzegovina. Chamber of Commerce of the Fedration of Bosnia and Herzegovina. Sarajevo. 1-179. *[Bosnian language]*

[8] Salihović, S. (1998). Report on mineralogical-petrographic examinations of quartzite from Gradac near Gornji Vakuf. University of Tuzla. Faculty of Geology and Mining. Tuzla. 1-4. *[Bosnian language]*

[9] Salihović, S., Salkić, Z. (2004). Report on mineralogical-petrographic examinations of quartzite from the deposit Obodski potok-Gromilica near Gornji Vakuf. University of Tuzla. Faculty of Geology and Mining. Tuzla. 1-1. *[Bosnian language]*

[10] Pašalić, A., Hasanica, N. (2018). Report on chemical analysis of quartzite from teh deposit Gradac I. University of Zenica. Institute Kemal Kapetanović. Zenica. 1-1. *[Bosnian language]*

[11] Linder, K. (2018). Report analysis of Quartz Gradac I. Sintef Molab. Mo i Rana. Norway. pp.1-1.

[12] Ohran, B., Kasumović, S., Kasumović, K., Čehić, M. (2018). Quartzite mine PTD Smrčevice d.o.o. Gornji Vakuf-Uskoplje, general mine informations. 1-27. *[Bosnian language]*

[13] Rulebook on cassification, categorization and calculation of reserves of solid mineral row materials and keeping records on them FBiH (Off. newspapers of FBiH 36/12). 1-131. *[Bosnian language]*

[14] Pan-European Standard for Reporting of Exploration Results, Mineral Resources and Reserves (PERC Standard), 2013. Available at: http://www.crirsco.com/perc_reporting_standard_2013.pdf. 1-29.

[15] Spasojević, LJ., Kačunković, V. (2014). Necessity of application of UN classification of mineral resources reserves. Mining Gazette 1-2 (CXI). Beograd. 20-26. *[Serbian language]*

[16] Ilić, M. (2017). Application of geological research results of solid mineral row materials in mining. Technics - mining, geology and metallurgy 71. Beograd. 204-211. *[Serbian language]*

[17] Forčaković, Dž., Dervišević, R. (2021). Potentiality of the Bugojno coal basin, Bosnia and Herzegovina. Archives for Tehnical Sciences. Bijeljina, pp. 39-49. *[Bosnian language]*

[18] Ministry of Economy of Middle Bosnia Canton -Travnik (2013). Construction of factory for production of ferrosilicon in Gornji Vakuf-Uskoplje. 1-24. *[Bosnian language]*

[19] Jevtić, G., Knežević M. (2015). Spatial plan of municipality Gornji Vakuf-Uskoplje from 2015 to 2020. Institute for constructions IG. Banja Luka. 1-130. *[Serbian language]*

[20] Krstić, S., Ljubojev, M., Bugarin M. (2017). Possibility of use the Kaona quartzite (east Serbia). Mining and Metallurgy Institute Bor. pp. 1-14. *[Serbian language]*

[21] Mashkovtsev, G.A., Bakanova, T.V. (2019). On Mineral Resources for Ferroalloy Production. KnE Materials Science/Theoretical and practical conference with international participation and School for young scientists. pp.29-45.

[22] Kopeć, G., Przeliorz, R. (2015). Usefulness of Quartzites for the Production of Ferrosilicon. Faculty of Material Engineering and Metallurgy-Computer Science in Engineering. Solid State Phenomena, 226. pp.111-114.

[23] Legemza, J., Findorák, R., Bul'ko, B., Brian, J. (2021). New Approach in Research of Quartzes and Quartzites for Ferroalloys and Silicon Production. Metals, 11, 670. pp.1-23.