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The primary and secondary mineral resources of Montenegro and their mapping into the European data model

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Abstract

Primary and secondary mineral resources are of strategic importance to the EU economy. Montenegro, as a country candidate for membership in the EU, is required to follow (and later to implement) European policies, strategies as well as initiatives, including those related to mineral resources and the mining sector. The importance of providing access to mineral raw materials in the future is recognized by the EU, as well as meeting the needs of European industry, maintaining employment and ensuring further development. Considering the overall economic situation in Montenegro, it is important to encourge the mining sector and other industries based on the use of mineral resources in making a greater contribution to the development and sustainability of society as a whole and also increase the share of national GDP.

The potential for discovery and utilization of primary and secondary mineral resources in Montenegro is demonstrated. The most important metallic mineral resources are bauxite, lead and zinc, while conventional energy resources include coal (oil and gas potential has yet to be proven). In addition, there are abundant non-metallic mineral raw materials - industrial minerals and construction materials.

Secondary mineral resources, especially aluminous red mud (bauxite residue), are also significant and have been the subject of research in recent years. Tailings from flotation processes at operating and abandoned lead and zinc mines might also be of interest for metal recovery. Bottom and flay ash from thermal power plants, slag from steel production, as well as marlstone and limestone from the hanging wall of coal deposits may also have potential. Waste rocks could be used particularly for secondary aggregate production.

A database was developed and the most important deposits of primary and secondary mineral resources in Montenegro were mapped during the RESEERVE project. Mineral data were harmonised so as to be INSPIRE compliant. In addition, some novel geochemical exploration results of secondary mineral resources are presented.

Keywords: Primary and secondary mineral resources; Montenegro; rESEErve project; European geological data platform (EGDI); INSPIRE

1. INTRODUCTION

The importance of ensuring reliable and unobstructed access to minerals in the future has been recognized by the European Union, in considering the current needs and future development of European industry, as well as retaining high employment levels. The European Commission's commitment in this area is reflected in the adoption of The Raw Materials Initiative (2008) which aims to ensure: a fair and sustainable supply of mineral raw materials from global markets; a sustainable and increasingly efficient supply of mineral raw materials within the EU, leading to more rational use of resources through the supply of recycled secondary raw materials. The strategy includes all mineral raw materials which are used in European industry, excluding materials from agricultural production, as well as materials used as fuels (energy raw materials).

The European Commission regularly publishes a list of Critical Raw Materials (CRM) in the European Union. The latest published CRM list contains 30 different mineral raw materials (EC, 2020). Some commodities, such as: bauxite, barite, titanium, rare earth elements (light and heavy), vanadium, scandium and gallium are found either in primary mineral deposits in Montenegro and/or within secondary resources, which are referred to (in national classification nomenclature) as technogenic mineral raw materials. The list of critical mineral raw materials is based upon two main criteria and includes mineral raw materials of great importance for the EU economy as well as mineral raw materials for which the global market supply has a potentially high risk.

Apart from the objectives mentioned above, following adoption of the 17 Sustainable Development Goals defined by the United Nations (2015), the European Commission has committed itself to apply these principles to all policies and initiatives of the European Union. That mining can contribute to achieving sustainable development goals was shown by the Report on Mining and Sustainable Development Goals (2016).

In accordance with the Europe 2020 Strategy, the European Innovation Partnership (EIP) on mineral raw materials aims to increase the share of the industry to 20% of GDP. Primarily, this will be achieved by reducing dependence on imports of mineral raw materials. In addition to this, the European Commission is financing a number of projects related to mineral raw materials through Horizon 2020.

In the light of the above objectives, Montenegro, as a candidate for EU membership, ought to harmonize its policy in the field of sustainable use and management of mineral resources with the policies at the European level.

From 2018 to 2021 the Geological Survey of Montenegro (GSM) has been a participant in the RIS RESEERVE project, which had as its main objective the inclusion of existing data from Montenegro into the West Balkan Mineral Register for primary and secondary mineral resources. During this three-year period, in cooperation with the Geological Survey of Slovenia (GeoZS) as the lead partner of the RIS RESEERVE project, the GSM team have firstly identified 57 of the most important primary and secondary mineral deposits and occurrences, with priority given to metals and industrial primary minerals deposits, as well as mining, processing and metallurgical waste sites. Subsequently, data have been updated for each mineral deposit and occurrence (the geological data - geological reserves, lithology, mineral and chemical composition, content of major and minor elements in the deposits; exploration activity, as well as spatial data) and mapped in accordance with the INSPIRE directive.

2. METALLOGENIC SETTINGS

In geotectonic terms, the territory of Montenegro belongs to the Dinarides, while in the metallogenic sense it belongs to the Dinaric metallogenic province, that is to say to the sector of the northeastern Mediterranean which is a part of the Tethys Eurasian belt (JANKOVIĆ, 1974, 1977; JANKOVIĆ & JELENKOVIĆ, 2000; JANKOVIĆ et al., 2003). Bordered by the Southern Alps in the northwest, the Hellenides in the southeast, the Adriatic Sea in the southwest and the Vardar zone in the northeast, the Dinaric metallogenic province is characterized by numerous deposits and occurrences of mineral raw materials. The metallogeny of the Dinarides and its features are presented in detail in JANKOVIĆ & JELENKOVIĆ (2000) and references therein. In general the Dinaric metallogenic province is considered to have a rather modest mineral endowment, characterized by relatively small scale ore deposits, some metallic commodities are significant, notably bauxite, lead and zinc, iron and mercury. The oldest iron and manganese deposits originated in the Caledonian metallogenic epoch, whereas siderite-barite-tetrahedrite deposits occur in rocks of Carboniferous age and are characteristic of the Hercynian metallogenetic epoch. The formation of numerous economically important deposits of iron, lead and zinc, mercury, barium, and antimony, mostly occurring as hydrothermal-vein systems are related to the Late Permian-Middle Triassic period. Karstic bauxite deposits are a distinctive feature of the Dinaric province. PAJOVIĆ (2000a), states that the karstic bauxite formations in the Dinarides were formed during fourteen terrestrial phases, eight of which are significant, namely those formed during the Triassic, Jurassic, Lower and Upper Cretaceous, Paleocene, Eocene, Oligocene and Neogene.

A more detailed metallogenic zonation of Montenegro was performed by PAJOVIĆ (1999), who defined the following zones: Durmitor metallogenetic zone, High Karst zone (which is subdivided into Kuči and Old Montenegrin metallogenetic subzone), the Budva zone and the Adriatic zone (Fig. 1). Within these metallogenetic units, he identified a further 17 ore regions, including a list of all known deposits and occurrences of mineral raw materials in the territory of Montenegro. According to age, geological units in Montenegro are classified into: Caledonian-Hercynian, Palaeoalpine, Mesoalpine and Neoalpine. Within the Palaeoalpine Middle Triassic volcanic-sedimentary succession, nine lithological members have been recognized as they are especially important for defining the formation of polymetallic (Pb, Zn, Cu) mineralization in NE Montenegro. All types of mineral raw materials in Montenegro are shown on the map by special graphic marks, while according to genetic criteria they are classified into seven environments and processes of ore formation. According to the time of their origin, they are classified into metallogenic epochs/periods. Twenty-eight types of mineral raw materials have been identified so far in Montenegro, fifteen of which have been exploited.

3. PRIMARY MINERAL RESOURCES

Of the 28 types of raw materials mentioned above, 23 were identified as having significant geological reserves, following intensive geological exploration after the Second World War, especially in the period from 1946 to 1986. The exploitation and processing of these natural resources have so far made an exceptional contribution to the economic development of Montenegro and continue to represent a reliable basis for further economic development. The following review of mineral raw materials of Montenegro is based on data from various publications: GOMILANOVIĆ et al. (1999; 2003), PAJOVIĆ & RADUSINOVIĆ (2010), GOM (2021) and references therein.

Mineral resources of Montenegro can be classified into different types of metallic, non-metallic minerals and energy raw materials, which also (according to national legislation) include groundwater, thermal and mineral waters.

During the implementation of the RESEERVE project, special emphasis was placed on significant primary deposits of metallic mineral raw materials (Figs. 1 and 2), their characteristics and geological features, as well as data relating to reserves and quality, all with the aim of forming a comprehensive database. The basic characteristics of the most important types and deposits of primary mineral raw materials in Montenegro are presented here; non-metallic and energy raw materials are also included.

3.1. Metallic mineral raw materials

Deposits of karstic red bauxites and deposits of lead and zinc ore have the greatest economic importance when considering the metallic mineral raw materials of Montenegro. It is estimated that new reserves and economically significant copper ore deposits could be proven by additional exploration at Varine, near Pljevlja. In contrast, the known occurrences of mercury, manganese, iron, titanium and chromium ores are currently assessed as economically uninteresting.

Deposits (with proven geological reserves) and occurrences of *red bauxites* are widely distributed in the central part, and to a lesser extent in the southern part of Montenegro and represent the most important metallic mineral raw material. Thirty deposits and many occurrences of red bauxites have been identified so far (PAJOVIĆ, 2000b). They were formed in three geological periods: the Triassic, Jurassic and Early Paleogene, with the Jurassic bauxites having the greatest economic importance. They were discovered in the following regions: Nikšićka Župa, Bjelopavlićke planine, Banjani, Bijele Rudine and in the Cuce-Čevo area. However, the most important reserves of red bauxites are located in the Nikšićka Župa district, where the largest karst deposits of red bauxites have been discovered: Liverovići I and II, Zagrad (Fig. 3), Kutsko Brdo, Đurakov Do, Biočki Stan and Štitovo I and II (PAJOVIĆ et al., 2017). Of the Triassic bauxite deposits, the Gornjopoljski Vir deposit has been partially explored, while previous exploration in the Palaeogene bauxites of the Ulcinj area and in the Luštica-Grbalj terrain, did not provide a conclusive assessment of their economic potential.

Proven geological reserves of different quality in bauxite deposits amount to about 35 Mt in Montenegro while estimates suggest resources of about 60 Mt. Bauxite production from high-quality deposits in the region of Nikšićka župa which amounted

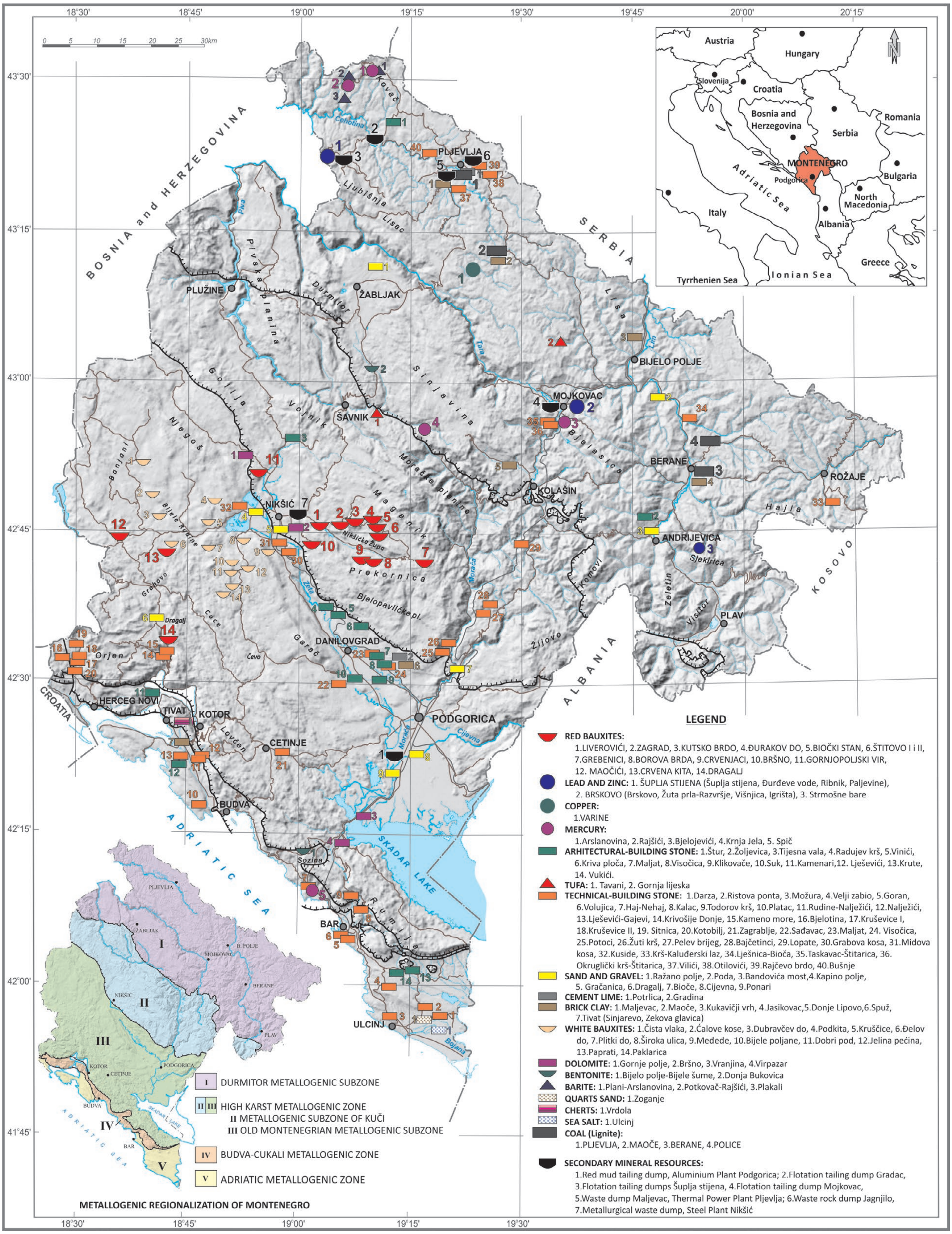

Figure 1. Map of the most significant mineral deposits and secondary mineral resources in Montenegro (according to PAJOVIĆ & RADUSINOVIĆ, 2010, modified and updated) with metallogenic regionalization (PAJOVIĆ, 1999).

to about 500,000 to 990,000 t/year in the last five years. The entire bauxite production is currently exported, due to the closure of the alumina plant at Podgorica in 2009.

The presence of *rare earth elements (REE)* in significant concentrations in bauxite formations of different ages in Montenegro was confirmed by recent exploration (RADUSINOVIĆ,

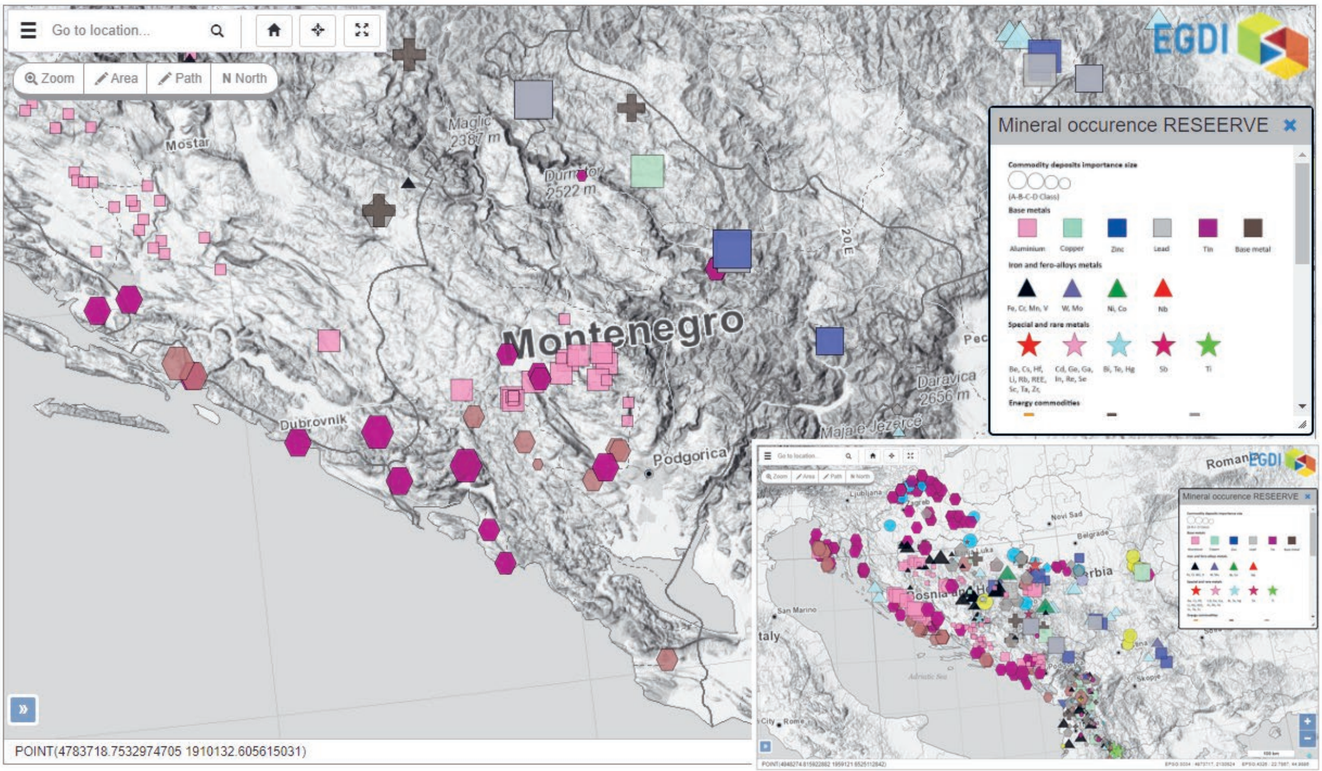

Figure 2. EGDI map viewer, Montenegro Mineral Register - the part of the West Balkan Mineral Register, RESEERVE Project (EGDI - WBMR, RESEERVE, 2021), http://www.europe-geology.eu/mineral-resources/mineral-resources-map/reseerve/.

2017; RADUSINOVIĆ et al., 2017; RADUSINOVIĆ & PAPADOPOULOS, 2021), especially in the deposits and occurrences investigated in Jurassic bauxites in the Vojnik-Maganik and Prekornica ore regions. This has opened new possibilities for more detailed exploration for new mineral resource in Montenegro, where the mineral and economic potential and importance have yet to be determined.

Deposits and occurrences of *lead and zinc* in Montenegro are related to the metallogenetic area of NE Montenegro. Economic ore concentrations of these metals have been proven in

Figure 3. The "Zagrad", Nikšić bauxite mine.

the mountainous terrain of Ljubišnja - "Šuplja Stijena Mine" and Bjelasica - "Brskovo Mine" (JANKOVIĆ et al., 2002). Extensive detailed geological exploration has been carried out in the Brskovo, Žuta Prla-Razvršje and Višnjica deposits in recent years, which have resulted in a significant increase in the total proven geological reserves and more reliable determination of the quality of the ores. The exploitation of lead and zinc ore, as well as the production of concentrates of these metals, and probably additional concentrates of copper and accompanying precious metals, are expected to begin in the following years. The areas of the Visitor and Sjekirica Mountains, where several economically interesting ore occurrences have been found, have also been assessed as highly prospective. The ore occurs in volcanic and volcanogenic-sedimentary rocks of Middle Triassic age with which it is invariably genetically and paragenetically associated. Other occurrences of lead and zinc mineralization in clastic rocks of Early Triassic and Palaeozoic age in NE Montenegro have not yet been studied in detail, although some of them deserve attention. Apart from the pyrite, sphalerite and galena in the Triassic polymetallic sulfide mineralization, chalcopyrite - the main copper mineral in these ores ("Šuplja Stijena" and "Brskovo" Mines) is regularly present as an accompanying mineral.

Geological reserves of lead and zinc ore amount to about 50 Mt in Montenegro. The estimated prospective resources are about 40 Mt in all the above mentioned ore regions. The production capacity of lead and zinc ore in the "Šuplja Stijena" Mine (Fig. 4), has stabilized in the last five years and amounts to between 540,000 to 590,000 t/year. An average of 18,500 t/year of lead concentrate and 4,700 t/year of zinc concentrate were produced in the same period. According to the mine operator´s plans, the production capacities of ore and concentrate at the "Brskovo" Mine will be significantly higher.

The most significant concentrations of *copper ore* in Montenegro were discovered at Varine (near Pljevlja). Mineralization occurs in Jurassic diabases and pyroclastics, in the form of hydrothermally altered ore zones, with ore veins (pyrite, chalcopyrite, quartz), layered-lenticular thin ore bodies (pyrite and chalcopyrite) and impregnations of pyrite with accompanying chalcopyrite. In addition to the above, rare, narrow veins of chalcopyrite ore have been discovered in clasts in Lower Triassic sediments in the Šćepan Polje district, as well as in Palaeozoic sediments in Kukića Bor (near Plav). These copper mineralizations have been assessed as economically insignificant.

Mercury ore (mineral cinnabar) has been observed in Middle Triassic volcanic rocks in the Krnja Jela area near Boan, in Middle Triassic volcanogenic-sedimentary rocks in Bjelojevići and Brskovo near Mojkovac, in Lower Triassic sediments in Spič near Sutomore and in the Kovač Mountain area near Pljevlja. Mineralization occurs as three types: as monomineral (followed by pyrite), in paragenesis with barite and together with polymetallic sulfides. The economic reserves of mercury have not been proven.

Over 20 occurrences of *iron* have been discovered in Montenegro, of which the most important are in Sozina (Sutomore), Klini (Konjusi near Andrijevica) and Kozica (Pljevlja).

Manganese occurrences have been discovered in the coastal part of Montenegro as well as on Sinjajevina Mountain but are considered to have no economic value.

Occurrences of *titanium and chromium minerals* were discovered in coastal sands at Ulcinj, in the area between the shoreline, the river Bojana and Štoj. These sands contain: chromite, ilmenite, zircon, magnetite, apatite and other minerals. The possibility of titanium and chromium valorisation from the sands of Ulcinj has not yet been investigated.

Figure 4. The lead and zinc mine at "Šuplja stijena", Pljevlja. Open pit, waste rock dump and flotation tailings.

3.2. Non-metallic mineral raw materials

Non-metallic mineral raw materials, both industrial minerals and construction materials, are becoming increasingly important in the mineral economy of many developed countries.

Twelve types of non-metallic mineral raw materials of economic importance have been identified in Montenegro, as follows: architectural-building (natural) stone, technical-building stone (crushed rock- aggregates), gravel and sand, brick clays, cement marl, white bauxite, dolomite, barite, bentonite, quartz sand, chert and sea salt. Nine of them have been utilised to date, while the dolomites, quartz sand and chert are unexploited.

Natural stone for architectural building and ornamentation is one of the most important non-metallic mineral raw materials in Montenegro. All deposits of architectural-building stone are within carbonate rocks (limestones, dolomitic limestones, limestone breccias, etc.) which comprise about 70% of the territory of Montenegro. Also, there is significant potential for using volcanic rocks for decorative purposes. The carbonate rocks in which more than 20 natural stone deposits have been identified so far are of Triassic, Jurassic, Cretaceous and Neogene ages. The most important deposits occur in Late Cretaceous carbonate formations in the Bjelopavlići ore region (BOŽOVIĆ et al., 2018). According to test results, natural stones from Montenegran deposits are mainly suited to the production of slabs for interior and exterior cladding of horizontal and vertical surfaces, as well as for the production of stone accessories, kerbstones and other elements in construction.

Proven natural stone resources in Montenegro amount to about 20.5 Mm^3. Production currently occurs in six quarries, with average amounts about 10,000 m^3 of commercial natural stones being extracted annually.

Tufa is a specific type of natural stone that forms in proximity to waterfalls and cascades. Due to its extremely favourable physical, technical and decorative characteristics, tufa has been used as a building material since ancient times. Medieval churches and other sacred buildings, monuments and buildings of national importance in Montenegro were mainly built from this type of natural stone. The most important deposits in Montenegro are located at Tavani (Šavnik), Gornja Lijeska (Tomaševo) and in Zbljevo (Pljevlja).

The *technical-building stone* in Montenegro is mainly produced from carbonate rocks - limestones, dolomitic limestones and dolomites, with only one deposit in which volcanic rocks are exploited (Štitarica near Mojkovac). More than 40 deposits have been defined so far. The largest number of technical-building stone deposits are located in the coastal part of Montenegro, which is also the area with the fastest development and the most intensive construction activity, and consequent demand for resources.

Proven geological reserves of technical-building stone in Montenegro amount to about 90 Mm^3. The average annual production of stone aggregates used for the production of concrete, asphalt and other purposes, from 23 active quarries is about 0,6 Mm^3.

A further specialized possibility for valorization of technical and architectural building stone resources, providing that they are of carbonate composition, is in the production of *carbonate fillers,* which have various industrial applications (BOŽOVIĆ et al., 2016).

Gravel and sand are exploited from alluvial sediments in riverbeds as well as, to a lesser extent, from glaciofluvial deposits in karst fields.

The most important deposits of *brick clays* in Montenegro are located in Neogene lake sediments with coal, in the areas of Pljevlja, Maoče and Berane. Significant reserves of this mineral raw material have been proven by exploration in the localities of Maljevac and Maoče near Pljevlja, and also in Budimlja near Berane (DROBNJAK et al., 2003). Alluvial deposits represent the second genetic type of clay deposits in Montenegro. They have been explored throughout almost the entire area of Montenegro, while estimates of the reserves of this mineral raw material have been determined in the following places: Kukavički vrh near Bijelo Polje, Donje Lipovo near Kolašin, Moromiš and Stanjevića Rupa near Danilovgrad, Sinjarevo and Zekova Glavica near Tivat and finally in Ćurke near Ulcinj. Exploitation and processing of clay into brick products in the second half of the 20^{th} century was occasionally carried out at Pljevlja, Berane, Tivat, Spuž, Kolašin, Bijelo Polje, Virpazar, Šavnik, amongst others. There have been no active clay mining operations in Montenegro in recent years, nor production of brick building materials and the value of annual imports of non-refractory ceramic bricks is about 25 MEur (MONSTAT, 2021).

The production of *cement* in Montenegro took place in Pljevlja during the period 1976-1988, when the cement factory closed. During the 13 years of operation 1,66 million tons of cement was produced. The marl from the hanging wall of the Potrlica coal deposit was the main material supplying this factory and this still represents an assured, high-quality resource for the long-term development of the cement industry. Deposits of cement marl with more heterogeneous composition have also been proven in the vicinity of Gradina near Danilovgrad as well as at Donja Klezna near Ulcinj.

White bauxites are a rare mineral raw material in which clay minerals (mostly kaolinite) are mixed with aluminium hydroxides (boehmite, rarely hydrargillite) and iron oxides (haematite, goethite). More than 100 deposits and occurrences of this mineral raw material have been discovered in Montenegro, more precisely in Western Montenegro, within an area of about 1,000 km^2 - between Nikšić, Čevo, Dragalj, the River Trebišnjica and the Golija Mountain.

Dolomite, like limestone, is a mineral resource with great potential in Montenegro. Unfortunately, the issue of industrial use of dolomite has not yet been resolved and so far, only four dolomite deposits have been proven by exploration: Virpazar, Vranjina, Šume near Gornje Polje and Bršno near Nikšić.

Barite deposits are concentrated in the ore region of Kovač Mountain, in the far northwest of Montenegro, in the vicinity of Potkovač, Plakalo, Plana and Arslanovina. Exploitation of barite from Potkovač was carried out in the period 1948-1956.

The most important *bentonite* deposits have been found in the coastal part of Montenegro, Bijelo Polje and Bijele Šume above Petrovac and in the central part of Montenegro, at Donja Bukovica near Šavnik. However, bentonite has only been exploited from the Bijelo polje deposit, where detailed geological and technical investigations have been renewed in recent years, with the aim of determining the possibilities for use in various industrial applications.

Deposits of *quartz sands* in Montenegro have only been found in the Miocene sediments around Ulcinj (localities: Zoganje, Škaret and Zekova šuma). Quartz sand from these deposits has not yet been exploited.

The Vrdola *chert* deposit is situated on the northern slope of Vrmac hill, about 3 km northeast of Tivat. It consists of platy and

Figure 5. The coal mine at "Potrlica", Pljevlja.

thinly laminated Jurassic-Cretaceous cherts, clays, silicified limestones and calcarenites. Silicate sand, obtained by processing the cherts, can be used in the glass and refractory industries, for obtaining abrasives, in construction and the chemical industry.

Salt has been prodcued from sea water in Montenegro at the "Bajo Sekulić" saltworks in Ulcinj, by natural (solar) and industrial (thermocompression) evaporation.

3.3. Energy raw materials

Economically interesting *coal (lignite)* deposits in Montenegro occur in the Neogene lacustrine Pljevlja and Berane coal basins. In the strictest sense, the Pljevlja Basin includes the Potrlica deposit as well as Kalušići, Komini, Grevo and Rabitlje. The Pljevlja area also contains coal-bearing basins: Ljuće-Šumani, Mataruge, Otilovići and Bakrenjače, Glisnica and Maoče. Coal is being exploited from the Potrlica deposit (Fig. 5) and used for the needs of the Pljevlja Thermal Power Plant.

Coal reserves in the Pljevlja basin are about 50 Mt, while the Maoče basin is estimated to contain about 110 Mt; other smaller basins contain a total of about 11 Mt. The production of coal from the Potrlica open pit is designed to meet the requirements of the Pljevlja Thermal Power Plant (TPP), which during the last five years has been about 1.6 Mt annually .

There are several coal deposits in the Berane Basin: Budimlja, Petnjik, Zagorje and Berane. The Police coal basin can also be considered to be part of the Berne basin. Coal from the Petnjik deposit is exploited as an underground mine but its complex tectonic structure significantly complicates the possibility of applying mass excavation methods. The geological reserves of coal in the Berane Basin are about 25 Mt, while in the Police Basin they are about 12 Mt. The average annual production of the Petnjik underground mine is only about 150,000 t.

Oil and gas exploration on the mainland of Montenegro began in 1949. while offshore exploration began in 1970. Seventeen exploration holes have been drilled on the mainland, while 4 deep exploration boreholes have so far been drilled offshore. In addition, extensive geophysical exploration has been carried out offshore. The results of previous exploration show that in this area, conditions were favourable for the formation of hydrocarbon deposits. Preliminary exploratory drilling under new exploration programs is underway, and the first results are expected this year.

4. SECONDARY MINERAL RESOURCES

Mining, minerals and metals production has left a significant legacy in the landscape of Montenegro. The mining and metals processing industries represented some of the most important economic activity in Montenegro, from 1950 to 1990. (GOMILANOVIĆ et al., 1999; 2003). The most important mining areas are Nikšić, where the exploitation of bauxite is taking place, Pljevlja with significant production of lead and zinc concentrates and coal, and Mojkovac, where lead and zinc concentrates were produced from 1976 to 1991. In addition, there has been production of steel and iron based on secondary resources in the Nikšić Steel Plant and the Podgorica Aluminum Plant produces aluminium (Fig. 6).

LOTTERMOSER (2007) classifies mine waste as: mining waste, processing waste, metallurgical wastes and mine waters. Mining wastes include: waste rocks, overburden and spoils from the process of exploitation of mineral deposits. This group in Montenegro includes: cement marlstone and limestone from the hanging wall of the "Potrlica" coal deposit; carbonate rocks from bauxite open pits in the wider area of Nikšićka župa; carbonate and volcanic rocks from the «Šuplja stijena» lead and zinc opencast mine. Flotation residue material from the «Šuplja stijena» and «Brskovo» lead and zinc mines as well as bauxite residue (red mud) from Alumina Plant Podgorica belong to processing wastes. Metallurgical waste includes rocky sand and slag fom the

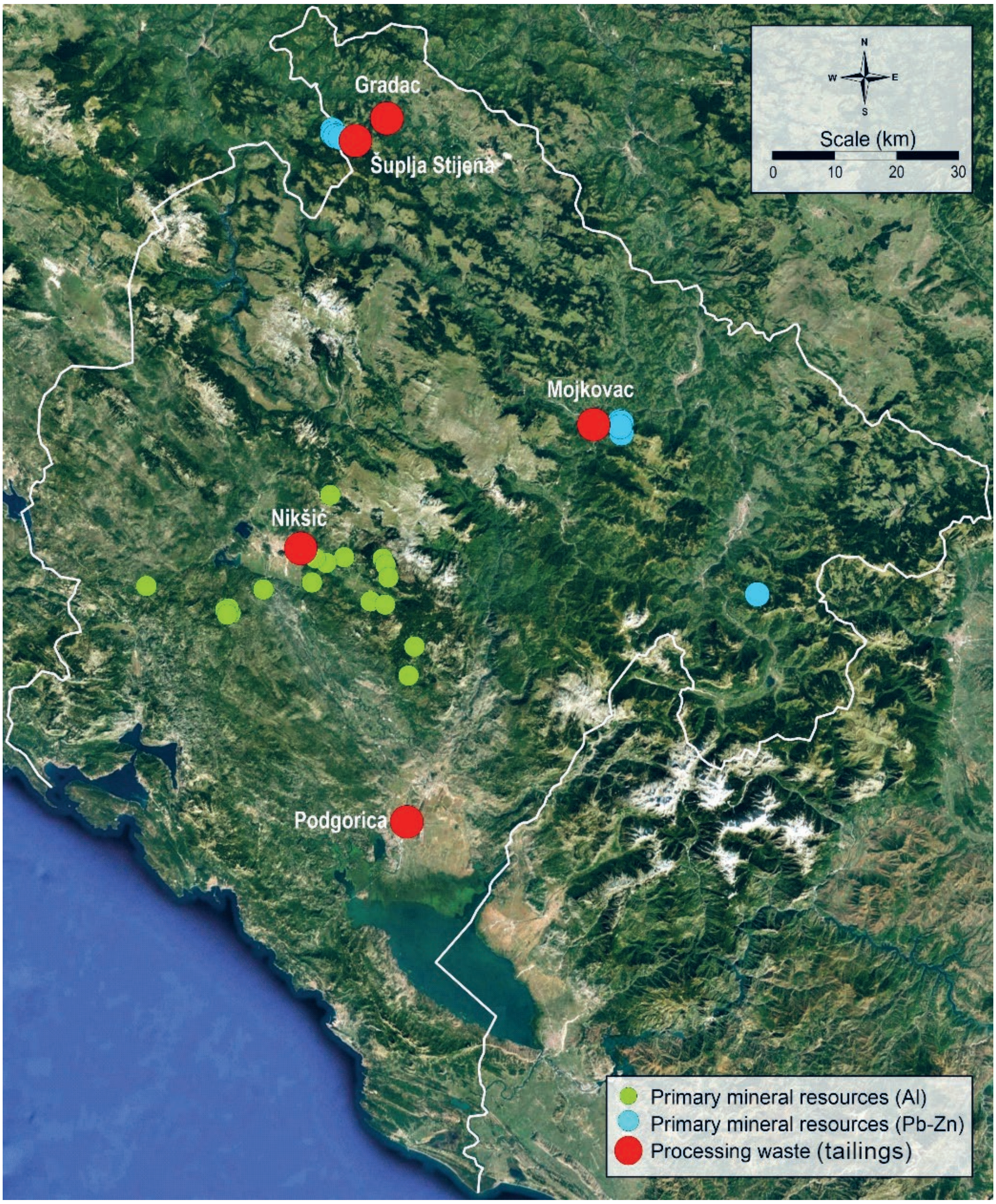

Figure 6. Location map of Primary Mineral Resources (PRM) (bauxite and Pb-Zn deposits) and Secondary Mineral Resources (SRM) in Montenegro.

Nikšić Steel Plant. The bottom and fly ash from the Thermo Power Plant Pljevlja are classified in the TPP waste group.

It is obvious that care of the environment has not always been a matter of priority. However, Montenegro took steps to address environmental issues by declaring itself as an "ecological state" in 1991. Based on the previously mentioned objectives and in accordance with legal regulations, the remediation of so-called "black ecological points" was initiated by tackling the Flotation tailings dam in Mojkovac and Gradac near Pljevlja; the Red mud tailings dam in Podgorica; TPP waste dump Maljevac near Pljevlja as well as the metallurgical waste dump from the Nikšić Steel Plant (EPA, 2014). The Flotation tailings dam remediation in Mojkovac has already been completed, while the rehabilitation and remediation of the TPP waste dump Maljevac and the Gradac Flotation tailings dam is in progress.

Although the previously mentioned environmental objectives and national regulations in Montenegro require remediation of mining wastes, they are also regarded as so-called "technogenic mineral raw materials", i.e. secondary mineral resources (GOMILANOVIĆ et al., 1999; 2003).

4.1. Processing wastes – Red mud (bauxite residue) tailings, Aluminum plant Podgorica

Bauxites in Montenegro have been used for the production of alumina and aluminium from 1972 to 2009. During this period, 16.6 Mt of bauxite was processed in the Podgorica Aluminium Plant, while 6.8 Mt of alumina and 3.1 Mt of aluminum were produced (RADUSINOVIĆ &PAPADOPOULOS, 2021). After bauxite processing, the main by-product is red mud - bauxite residue, which was disposed of in two large open tailings dams next to

Figure 7. Red mud - bauxite residue tailings dams, Podgorica.

the factory (Fig. 7). The total quantity of bauxite residue is about 7,5 Mt. This material is characterized by high alkalinity and a high iron content. Red mud is classified as a hazardous waste and it presents a potential threat to the environment, especially to groundwater, according to data relating to hazard elements and pollutants.

Apart from the significant abundances of major elements: Fe, Al, Si, and sometimes Ca and Na, red mud contains increased concentrations of trace elements, especially Rare Earth Elements (REE). An average REE content of 1535 ppm was determined for red mud in basin A at Podgorica, while the average content determined in basin B was 1646 ppm, according to TOMAŠIĆ et al. (2020). The total average content of rare earth elements (∑Sc, Y, La-Lu) in the bauxite residue in basins A and B is 1.4 times higher than the average content in bauxites. The largest increase in average content is shown by Sc, La and Ce (RADUSINOVIĆ & PAPADOPOULOS, 2021).

Based on some of the criteria developed within the framework of the RESEERVE project, sampling in the field and laboratory testing, these tailings sites have been characterized as potential sources for trace element extraction and recovery.

The concentrations of 65 elements in tailings samples have been analysed by ICP-MS in Bureau Veritas Commodities Canada Ltd. (accredited under ISO 9001:2015) after aqua regia digestion (at 95 °C, using the 1DX method) and total 4-acid digestion following international standards (ISO 14869-1:2001, 2001).

In the area of the red mud landfill at Podgorica, concentrations of REE exceeding 1200 mg/kg REE (mostly ∑Sc, Y, La-Lu) were discovered. Deviations from these observed concentrations are attributable to different sampling techniques, sample preparation and analytical methods used. The Podgorica red mud tailings dam could warrant further investigations, and above all, the application of REE extraction methods might be commercially interesting (Tab. 1).

Table 1. Average concentration of some elements in SRM deposits – Montenegro.

	Digestion	Unit	Podgorica	Gradac	Šuplja stijena	Nikšić
Ag	Total	mg/kg	0.25	3.2	2.9	3.1
Au	AR	µg/kg	0.20	80	62	1.2
Cr	Total	mg/kg	720	42	43	4200
Cu	Total	mg/kg	110	320	140	460
Mo	Total	mg/kg	2.5	0.46	0.43	93
Ni	Total	mg/kg	260	24	28	290
Pb	Total	mg/kg	230	1900	1400	850
Zn	Total	mg/kg	350	4100	4700	1500
REE	Total	mg/kg	1200	55	52	42

In addition, bauxite residue can also be used in the cement and concrete industries, as inorganic polymers as well as in other novel applications, as catalysts, polymer composites, or adsorbents.

4.2. Processing wastes – Tailings at Gradac and “Šuplja Stijena Mine”, lead and zinc flotation residue material

The Šuplja stijena underground mine produced more than 4 million tons of ore and about 76,000 t of lead concentrate and 300,000 t of zinc concentrate, between 1954 and 1987.

About 3.5 million tons of residue materials after flotation have been accumulated at the Gradac tailings dam over many years (Fig. 8). Recent results of the solid phase analysis showed that metals, such as lead and zinc, are present at concentrations below 1%, which is currently considered insufficient for cost-effective re-processing of this material.

The material from the Gradac tailings has been tested several times, and potential opportunities for its use occur in the cement industry, the production of plaster and the production of

Figure 8. Flotation tailings dam at "Gradac".

silicate bricks (GOMILANOVIĆ et al., 1999). However, there have been no commericial attempts to use the tailings for any of these purposes so far.

After recommencement of production in 2010, more flotation tailings dams were constructed near the Šuplja stijena mine, completed by applying several layers of materials of appropriate characteristics.

Surface samples of material from the abandoned Gradac and the active Šuplja Stijena tailings deposits were also collected and analysed. Slightly elevated concentrations of Ag (3.2 mg/kg - Gradac and 2.9 mg/kg - Šuplja Stijena) and relatively high concentrations of Zn (0.41% - Gradac and 4.7 mg/kg - Šuplja Stijena) could possibly warrant further investigations (Tab. 1). Nevertheless, these values are much lower in comparison with many other areas that were studied in the project. Thus, the tailings do not appear to be promising from the commercial perspective.

4.3. TPP wastes – Waste dam Maljevac – bottom and fly ash from TPP Pljevlja

The Thermal Power Plant Pljevlja produces about 350,000 t of bottom and fly ash annually. About 10 million tonnes of this material have been disposed of as a TPP waste dam at Maljevac during the last 35 years (Fig. 9). There are many positive benefits of using ash, the first being that removing the ash from the waste dam contributes to environmental remediation as well as providing financial gain.

Fly ash is already widely used by the global cement and concrete industry. By conducting more tests and investment, a significant environmental issue in Montenegro could be solved while also exploiting these resources for the production of building materials.

However, current information indicates that the Maljevac TPP waste dam will be closed soon and due to the lack of capacity, site remediation has already begun. The new TPP waste dam will be in the area of the former open-cast coal mine at Ljuce-Šumani.

4.4. Mining wastes – Waste rocks dump Jagnjilo, Pljevlja – Cement marlstone and limestone from the "Potrlica Coal Mine"

Natural cement marlstone and limestone, up to 130 m thick, overlies coal layers in the Potrlica deposit (Fig. 5). More than 80 Mt of these rocks have been excavated and redeposited at the Jagnilo mining waste rocks dump in the vicinity of the Potrlica open pit, and represents a significant secondary resource (Fig. 10).

There is no doubt that there are exceptional natural conditions for long-term cement production and development of the construction industry based on this and other mineral raw materials in the Pljevlja basin. Technological advances in cement production, quality basic mineral raw material, energy fuel and additives all offer significant potential for the development of this important industry for Montenegro, which currently annually imports Portland cement worth about 40 MEur (MONSTAT, 2021).

4.5. Metallurgical waste dump, Nikšić Steel Plant

The Steel Plant Nikšić was founded in 1956. The metallurgical waste dump is situated 2,5 km from the factory and has also been in use since 1956. It consists of two parts with more than 3 Mm^3 of materials (based on estimation), described as a mixture of rocky sand with ash and slag, as well as other waste material, which has been deposited without any regulatory supervision (Fig. 11).

The largest proportion of material from the steel factory consists of ash from the thermoelectric furnace and sludge from the water treatment plant, as well as ash and slag from foundry sand. These materials contain potentially toxic metals, as well as other contaminants but after appropriate treatment, they could be successfully used as an aggregate component in asphalt production.

The analytical results of surface samples of metallurgical slag collected from the waste dump are merely indicative because of the very coarse-grained texture of the sampled material. Analyses yielded 3.1 mg/kg Ag and 0.42% Cr (Tab. 1). From the commercial perspective, this waste dump is not attractive for further metal extraction.

Figure 9. The TPP Pljevlja waste dump "Maljevac".

4.6. Mining wastes – Waste rocks at Nikšićka Župa and "Šuplja Stijena Mine"

With respect to secondary aggregates comprising waste rocks of carbonate composition, the largest volumes originate from bauxite open pits in the wider area of Nikšićka župa. The total excavated quantity (limestone, dolomite limestone and glacial gravel and sand) of waste rocks dumps deposited in the past 60 years at several locations are about 50 Mt. Some of the material is used for infilling of the abandoned open pits from exhausted deposits of bauxite. A significant part of this material could be used for the production of aggregates. Formerly, there was an attempt at such aggregate production on a small scale at a location near Nikšić but there is no production at present.

Exploitation of about 5 Mm^3 of overburden of carbonate composition in the active lead and zinc open pit "Šuplja Stijena Mine" was also planned. Mining waste of carbonate composition is disposed of separately and can potentially be used for aggregate production (Fig. 4). Other uses, such as carbonate fillers, lime and the cement industry are also possible.

5. MAPPING – METHODOLOGY AND RESULTS

The aim of this work was to integrate the national data of Montenegro into the already existing European platform EGDI and present them on the web portal. This represents the starting point for following the INSPIRE directive and obtaining a strong decision-making tool for the management of mineral resources in Montenegro.

Figure 10. The waste rock dump "Jagnjilo".

Figure 11. Metallurgical waste dump, Nikšić Steel Plant.

As the overall EU strategy is to reduce dependency on raw materials from "abroad", it is necessary to standardize the data between the individual countries at EU level. That goal was instigated by the Directive of the European Parliament and of the Council on the establishment of an infrastructure for spatial information in the European Community, known as the INSPIRE (INfrastructure for SPatial Information in Europe) directive, which became valid from 15th May 2007. INSPIRE regulates the baseline for the establishment of a European infrastructure for spatial and environmental data in the Member States. Such infrastructure enables the institutions and stakeholders to share information and knowledge, and to find, view and acquire, standardized and harmonized geo-referenced and related data, including data on mineral resources. It integrates the best available mineral expertise and information based on the geological knowledge, in support of public policy making, industry, society, communication and education purposes at an international level (INSPIRE, 2007).

The work was mostly focused on workflows for harmonizing the data and dissemination of Information Technology (IT) knowledge for mapping the national primary and secondary minerals data of Montenegro to the already existing European data model and developing a national relational database, that fits within the European common database structure. Data harmonization was performed through two national training workshops, designed to make the first step toward INSPIRE directive implementation.

For reaching the final harmonization of data the following methodology has been used:

Engineering of end users' requirements

The first step was the analysis of end user needs. The end users are different,and they have different requirements. This phase was realized through questionnaires.

Qualitative and quantitative research of data

To achieve this purpose, an Excel summary table was designed for the collection of national data on primary and secondary mineral raw materials, relevant for potential investors. A table with common attributes, using a top-down approach (from general to detailed information) has been completed. The table includes attributes such as basic geographical and ownership information about each site, geometry, volume, mining data such status, mining methods and reserves, geological data such as stratigraphy and lithology, mineral composition and rock types, stability, chemical composition and environmental impacts .

Overview of existing EU data model and harmonizing the basic Excel table fields with the INSPIRE database fields

National data have been harmonized with the INSPIRE data model and online services for data on mineral raw materials have been established. To accomplish this, we examined the INSPIRE directive in detail, identified the fields that coincide with the directive, and adapted them accordingly to the requirements.

Mapping the basic Excel table to INSPIRE customized Excel tables/ harmonization of existing data to INSPIRE-compliant data

At this stage, it was necessary to consider the specific rules required by the common data model. The data must be entered in an exact sequence, for this purpose the instructions for inserting data were also compiled. It is necessary to follow the provided INSPIRE code lists for interoperability with the existing EGDI platform, use the specific record identifiers and correctly track the relationships between the data.

This stage of work has been carried out in two national workshops/training courses with technical support to acheive harmonization of data sets into INSPIRE compliant data and working with relational databases.

Mapping INSPIRE customized Excel tables to the Access relational database

This phase was relatively simple since the pre-existing Excel tables have been organized in the same way as a relational database and the data were only copied to the tables one by one. Because the Access database is already a relational database and all the errors, made in the Excel table appear, it also provides good control of the data entry itself. National workshops have also been carried out for this purpose.

Mapping Access database into PostgreSQL

The next step was the migration of national Access databases to open-source Solutions (PostgreSQL database, used by the project).

Harvesting national databases to the common EU database

To create a system with updated data, the project adopted a distributed architecture based on a central harvesting database synchronized with a central database. Data harvesting is the process of automatically extracting large amounts of data from web services. GeoZS implemented a harvesting system to collect and validate INSPIRE compliant spatial European data of mineral resources (Fig. 12). At an individual country level the national provider distributes their data as a Web Feature Service (WFS), so that the GeoZS harvesting system retrieves this data, performs data transformation and quality control, and finally stores validated data in the central database (Minerals4EU, 2014).

Presentation of data on the EGDI web portal

In addition to the map service displaying mineral deposits and mines on the EGDI portal, the portal also provides occurrence-specific documents related to mineral materials, enabling users to make their own analyses from a huge amount of data (Fig.2). It represents a new knowledge base of regional primary and secondary resources which is also interoperable with national databases. The purpose of this, is to encourage industry to invest in the West Balkan mineral sector (EGDI, 2021).

Data for a total of 53 Primary mineral resources (PRM), including 35 mines and 4 secondary mineral resources (SRM) were collected and harmonized in Montenegro.

The register allows information related to primary and secondary mineral resources to be combined easily and for delivery of all the available information to the end users. The data platform represents a first step towards future effective and sustainable information systems for the region. The technical solutions also facilitate data update and maintenance and gives a full access to information related to the entire life cycle and value chain of mineral resource.

6. CONCLUSIONS

What is the economic and social importance of mineral production in Montenegro? Statistics show that in recent years the mining industry has contributed less than 2% to national GDP and employs less than 2,000 workers. It should be noted that coal is mostly used for electricity production - approximately half of Montenegro's production, while bauxite, aluminum and lead and zinc concentrates are the most important export products of Montenegro.

It is evident that Montenegro, in relation to its size, possesses significant primary and secondary mineral resources, primarily bauxite, lead and zinc ores and coal, as well as raw materials for the production of cement, bricks and ceramics and other construction materials and industrial minerals. The potential for the enhanced usage of raw materials such as brick clays, cement marl, dolomite, barite, bentonite, quartz sand, chert, sea salt, undoubtedly exists, as demonstrated by the documentation of numerous deposits and proven reserves, as well as the historical evidence that most of these raw materials have been previously exploited or processed industrially . The basic question is one of economic justification and investor interest in commencing production of some of the listed mineral raw materials. At present, the most significant and most promising are the reserves of cement marls in Potrlica and Jagnjilo (secondary mineral raw materials), as well as bentonite in the deposits of Bijelo polje and Bijele šume on Paštrovačka gora and barite in the area of Kovač.

Nevertheless, in recent years, Montenegro has been importing various mineral commodities with an annual worth on aver-

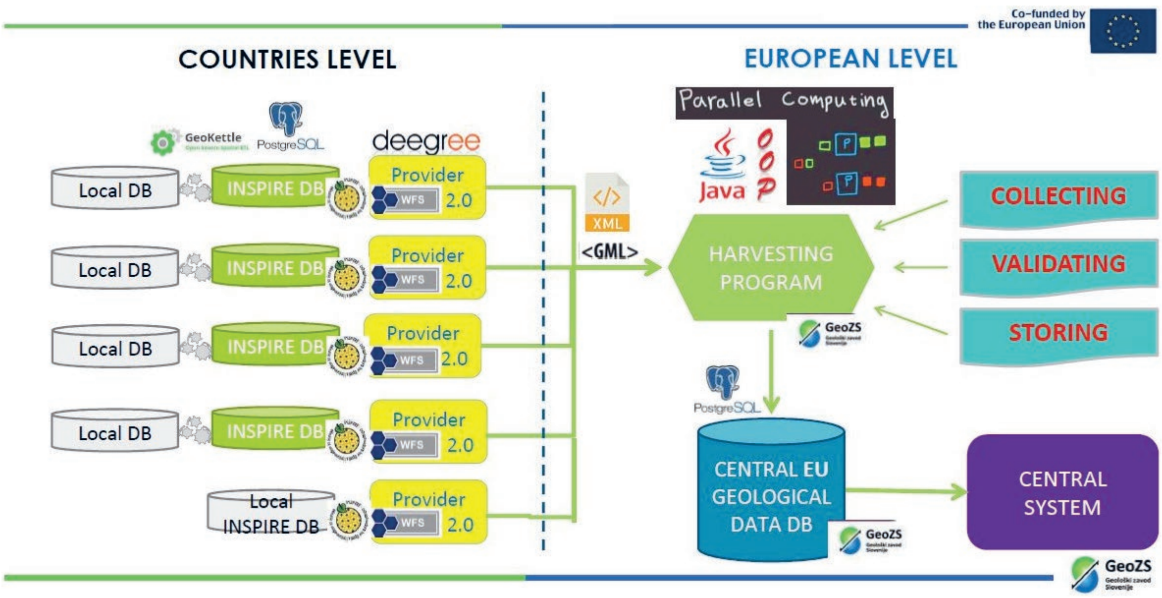

Figure 12. Architecture of the harvesting system.

age of around 335 million euros per year, which is a significant burden for a small economy, otherwise mainly reliant on tourism and services.

Long-term planning and management of the mineral sector in accordance with the principles of sustainable development could significantly contribute to the diversification of the Montenegran economy as well as increase the economic stability. We believe that one of the ways to draw attention to this potential is to include data on the mineral resources of Montenegro in the European database, as has been done through the RIS RESEERVE project. In addition, it is necessary to promote investment possibilities in exploration and exploitation of mineral resources and processing capacities, with respect to both metal production and industrial minerals and construction materials from primary and secondary deposits.

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