Geologia Croatica
Journal of the Croatian Geological Survey and the Croatian Geological Society

2022 | 75/2 | 269–287 | 4 Figs. | 1 Tab. | 2 Appx. | www.geologia-croatica.hr

The geological potential of antimony, bauxite, fluorite, and magnesite of the Central Dinarides (Bosnia and Herzegovina): an exploration and exploitation perspective

Sibila Borojević Šoštarić[1], Anže Markelj[2], Eldar Jašarević[3] and Angelika Haindl[4]

[1] Faculty of Mining, Geology and Petroleum Engineering, Department of Mineralogy, Petrology and Mineral Resources, Pierottijeva 6, HR-10000 Zagreb, Croatia; (sibila.borojevic-sostaric@rgn.unizg.hr)
[2] Geology Survey of Slovenia, Department for Regional geology, Dimičeva ulica 14, 1000 Ljubljana, Slovenia; (anze.markelj@geo-zs.si)
[3] Mining Institute Tuzla, Scientific Research Center for Geology, Geotechnics and Civil Engineering, Rudarska 72, 75000 Tuzla, Bosnia & Herzegovina; (eldar.jasarevic@rudarskiinstituttuzla.ba)
[4] Chair of Mining Engineering and Mineral Economics, Department Mineral Resources Engineering, Montanuniversität Leoben, Franz-Josef-Straße 18, 8700 Leoben, Austria; (angelika.haindl@unileoben.ac.at)

doi: 10.4154/gc.2022.16

Article history:

Manuscript received November 18, 2021
Revised manuscript accepted February 23, 2022
Available online June 23, 2022

Keywords: CRM exploration, Mining potential, Bosnia and Herzegovina, Central Dinarides, Antimony, Bauxite, Fluorite, Magnesite

Abstract

This paper presents the critical raw materials (CRM) potential of antimony, bauxite, fluorite, and magnesite deposits in Bosnia and Herzegovina, discusses their metallogeny and joint geological features, and explains the methodology of the InvestRM application and evaluation criteria for the selected commodities in the following steps: (1) preparation of the geological data templates, (2) evaluation and verification of the geological data, (3) ranking of deposits according to the geological data relating to quality and quantity, and (4) identification of the 10+ perspective deposits. Existing geological datasets show the existence of significant potential in primary CRM such as bauxite (56 Mt), magnesite (4 Mt), and antimony (0.2 Mt) in Bosnia and Herzegovina (BiH). The geological settings of BiH provide favourable metallogenetic conditions primarily for bauxite and magnesite deposits but also for antimony within polymetallic deposits, while fluorspar is rather rare. Our methodology described herein led to the selection of the following fourteen deposits for further geological prospection and investment: the polymetallic antimony deposits Čemernica and Podhrusanj, antimony fields Srebrenica and Rupice; magnesite fields Kladanj, Banja Luka, Teslić and Novi Šeher and bauxite regions Vlasenica-Srebrenica, Grmeč Mountain deposits in Una-Sana region and South Bosnia regions from Posušje to Trebinje. A basic economic calculation based on the world producer ranking and a self-sustainability and economic contribution assessment shows that further investments in geological exploration and mining of antimony, magnesite, and bauxite CRM could place BiH on the list of important producers of these commodities in Europe.

1. INTRODUCTION

Since 2011, one of the major concerns of the European Commission has been a sustainable supply of the critical materials to maintain and develop the European industries (European Commission, 2011). The European Commission Communication listed 27 critical raw materials in 2017 (European Commission, 2017). The ADRIA region hosts significant primary geological potential for six of these critical materials, namely antimony, barite, bauxite, borate, lithium and Mg (magnesite). With the exception of borates and lithium, these primary commodities were exploited prior to the conflicts in the region during the 1990s when the ADRIA region generated 11% of the world's magnesite, 5% of the bauxite, 5% of the antimony, and 3% of world's barite production (REICHL & SCHATZ, 2021). Due to a complex geopolitical situation, geological data from the ADRIA region are outdated, segmented, and limited, and largely not included in the pan-European mineral deposits databases: Minerals4EU and ProMine. The EU commission review of the list of critical raw materials (European Commission, 2017) has not taken into consideration the CRM potential of the ADRIA region, even though non-EU ADRIA countries, including Bosnia and Herzegovina, are following the European path of Slovenia and Croatia, and initiating access negotiations with significant funding through the mechanism of pre-structural aid, and will join the European family in the future. Currently, China is the leading supplier of several important raw materials, including antimony (87%), magnesium (87%), and Rare Earth Elements commonly present in some bauxites (95%) (European Commission 2017). The dependence on China increases the risk of supply shortages and supply vulnerability along the value chain.

Bosnia and Herzegovina still have significant potential in primary critical raw materials (antimony, bauxite, magnesite), while the current production is negligible even though operating quarries, open pits, and mines represent important and strategic assets. Many large deposits, such as the Vareš, Srebrenica area, West Herzegovina, and the Jajce bauxite deposits, are known to European investors from past exploitation. A long mining tradition, existing geological potential, and the strategic position of the country close to the production centers of the major European industries still hasn't resulted in a significant rate of investment in the mining of the critical raw materials in Bosnia and Herzegovina. Some of the main issues preventing investments are the complexity of the internal organizational structure covering exploitation and exploration licensing in Bosnia and Herzegovina and the fragmentation, quality, and quantity of existing geological datasets.

In response to the aforementioned shortcomings, the aim of this paper is to:

1. Present the metallogeny and joint geological features of the selected 120+ antimony, bauxite, fluorite, and magnesite deposits in Bosnia and Herzegovina,
2. Present the developed InvestRM application and evaluation criteria for the deposits in Bosnia and Herzegovina (https://investrm.eu/app-tb/),
3. Implement evaluation criteria for the 120+ antimony, bauxite, fluorite, and magnesite deposits, and select the 10 highest-ranking deposits, and
4. Investigate and discuss the exploration and mining potential of the selected deposits.

2. GEOLOGICAL SETTING

The Dinarides are a folded, thrusted, and imbricated belt located between the Southern Alps in the northwest and the Hellenides in the south and southeast (PAMIĆ et al., 1998). The territory of BiH encompasses part of the Dinarides, consisting of several detachments of tectonostratigraphic and lithostratigraphic units of different origin and stratigraphic sequences related to the Alpine-Carpathian orogenic process of the Palaeozoic to Neogene age (PAMIĆ et al., 1998; SCHMID et al., 2008). The predominant structures are several thrusts with SW vergence, which, at a regional scale, resulted in knappes and local klippes thrust on top of one another in today's position. The Dinarides are divided into several tectonic units, which include external and internal sectors from the Adriatic Sea units towards the NE up to the adjoining Tisia mega-tectonic unit (zonation follows those reviews by PAMIĆ et al. (1998) and DIMITRIJEVIĆ (1982, 1997); Fig. 1):

1) The Adriatic Carbonate Platform hosting bauxite occurrences and deposits,
2) Palaeozoic basement units with surrounding Bosnian Flysch, hosting antimony, fluorspar, and bauxite deposits,
3) Dinaric Ophiolitic Zone hosting magnesite deposits, and
4) Sava-Vardar Zone hosting antimony deposits.

The Adriatic Carbonate Platform and its correlatives, together with the East Bosnian-Durmitor zone, constitute the External Dinarides, while the Dinaric Ophiolite zone and the Sava – Vardar zone represents units of the Internal Dinarides. The Adriatic Carbonate Platform comprises an Upper Palaeozoic basement, overlain by Upper Permian to Norian clastic sediments and platform carbonates with penecontemporaneous rift-related igneous rocks, the Norian-Lutethian carbonate platform, and Eocene overstep flysch sequences. The internal and external units of the Dinarides both contain exposed Palaeozoic basement units that have undergone various degrees of metamorphism (mainly up to greenschist, in some cases up to epidote-amphibolite facies conditions). The Palaeozoic basement units are composed of Ordovician to Carboniferous (Permian) metasediments (dominantly Carboniferous flysch and Permian molasse-type deposits) and metavolcanics mainly overlain by a Triassic carbonate-clastic cover. The degree of metamorphism increases from the northwest towards the southeast, whereas the age of metamorphism ranges from Variscan to Alpine. The Bosnian Flysch is a 4000-5000 m thick passive continental margin carbonate-clastic tectonostratigraphic unit of Jurassic to Late Cretaceous age. The Dinaric Ophiolite zone consists of Mesozoic radiolarite sequences with basalt, greywacke, and shale and an ophiolite mélange, ultramafic thrust sheets, and Late Jurassic–Early Cretaceous and Late Cretaceous overstep sequences. The Sava-Vardar zone contains Late Cretaceous to Palaeogene flysch sequences with volcanics, tectonized ophiolite mélange, regionally metamorphosed sequences originating from the surrounding Late Cretaceous–Palaeogene rocks and synkinematic granitoids.

The geodynamic evolution of the Dinarides began with the Early Permian rifting of the Palaeozoic basement rocks (BOROJEVIĆ ŠOŠTARIĆ et al., 2009; BOROJEVIĆ ŠOŠTARIĆ et al., 2012), followed by the opening of the Tethyan ocean in the Late Triassic and the Late Jurassic–Early Cretaceous subduction and emplacement of the Dinaric ophiolites (PAMIĆ et al., 1998). Parts of the Sava-Vardar zone remained open until the Early Palaeogene (SCHMID et al., 2008).

3. GEOLOGY AND METALLOGENY OF THE CRM DEPOSITS

3.1. Antimony

(a) Palaeozoic, continental rift-related polymetallic hydrothermal deposits

a. The quartz-Sb-polymetallic (Zn, Hg, As, Ag) hydrothermal deposits of the Mid-Bosnian Schists Mts. form a mineralizing zone of 3×0,3 km around Fojnička Banja, Gradina and **Čemernica** with numerous veins and tabular-ore bodies with a maximum thickness of 1,2 metres. The largest deposit in this ore field is Čemernica, hosted within Carboniferous-Permian quartz-muscovite schists, sandstones, and carbonates. Čemernica is a hydrothermal vein-type to tabular type of deposit containing, stibnite, stibarsene, cinabarite, sphalerite, tetrahedrite, boulangerite, arsenopyrite, pyrite, and marcasite within a quartz matrix. The metal content is highly variable (Sb= 0,2-15%; Zn = 2-10%; Ag=50-200ppm; Hg=0,01-0,1%; (JURKOVIĆ et al., 1999).
b. The barite-Pb-Zn-Sb vein-type hydrothermal mineralization with 0,1-0,4% of Sb (**Totinovac-Viduša**) located near Jajce, is hosted within a Carboniferous-Permian rift-related sequence in the vicinity of a Palaeozoic quartz-porphyry. Irregular veins, 0,1 – 0,5 m thick, and metasomatic bodies are composed of barite, galena, sphalerite, luzonite, stibnite, stibarsen and cinnabarite (RAMOVIĆ et al., 1979).
c. The quartz-Sb vein-type hydrothermal deposit **Podhrusanj** is hosted within Palaeozoic schists, sandstones, and carbonate rocks of the southeastern Bosnia Drina-Ivanjica unit and is considered to be related to the granitic and syenite intrusion near Čajniče (PAMIĆ, 1982; KUBAT, 1982; 1995). The mineralization is located at the contact zone between the impermeable schists and permeable limestones. Average amounts of antimony in the mineralized carbonates vary from 1,1% to 3,4% of Sb (KUBAT 1982; 1995).
d. The small-scale polymetallic (Pb, Zn, Sb) vein and metasomatic replacement type deposit of Podkozara belongs to a similar setting as the Podhrusanj deposit (Drina-Ivanjica unit; (RAMOVIĆ et al., 1979)).

(b) Triassic advanced rift-related hydrothermal antimony deposits

a. The barite-polymetallic (Pb, Zn, Hg, Sb) hydrothermal vein-type and metasomatic deposits at the **Rupice field** (Rupice, Rid, Veliki do, Križ, Veovača) are located within Upper Palaeozoic to Middle Triassic continental rift-related sandstone, limestone, and dolostone. The deposits are primarily mined for barite and Pb-Zn mineralization (Pb+Zn) = 2,3 – 6,5%, whereas the antimony-bearing minerals stibnite, tetrahedrite, and boulangerite on average contain Sb between 0,05 and 4,9%. The ore also contains Ag of 65 g/t; Au of 0,3 g/t; Cu of 0,1%, and Hg of 0,02% (OPERTA & HYSENI, 2016). Based on the superposition and sedimentary evidence, these deposits are considered to be related to a middle – upper Triassic advanced rift setting.

(c) Oligocene post-collisional deposits of the Sava-Vardar zone

The polymetallic (Pb, Zn, Sb, Ag) vein and metasomatic type hydrothermal deposits of the Srebrenice field (Lisac, Vitlovac, Čumavić) are related to the Oligocene dacite, andesite, and associated volcanoclastic formations that intruded into Palaeozoic schists. The typical mineralogy of galena, sphalerite, siderite, chalcopyrite, stibnite, and pyrrhotite is accompanied by various sulfosalts containing Pb, Sb, Cu, Bi, Ag (ZARIĆ et al., 2000). Small-scale greisen-type Sn-bearing mineralization developed at the magmatic-schists contact zone.

3.2. Bauxite

(a) External Dinaride bauxites

a. The South Bosnia region (Herzegovina; (BURIĆ & ŽIVALJEVIĆ, 1979))
   i. Around 80 Upper Jurassic deposits (Viduša) are embedded within the Upper Jurassic limestone and dolostone near Viduša Mt. in a 25 km long zone. The deposits are saddle-shape, of boehmite to gibbsite type, and contain 44-62% of Al_2O_3, 2-10% of SiO_2, and 11-19% of Fe_2O_3.
   ii. The most productive deposits are Upper Cretaceous – Palaeogene in age, embedded between Upper Cretaceous to Palaeogene carbonate rocks, with overlying Liburinan beds, alevoline-numulite limestones, flysch sediments or Promina beds (**Čitluk region**: Blatnica-Lokvice, Mamići-Rasno-Hamzići, Ošljari-

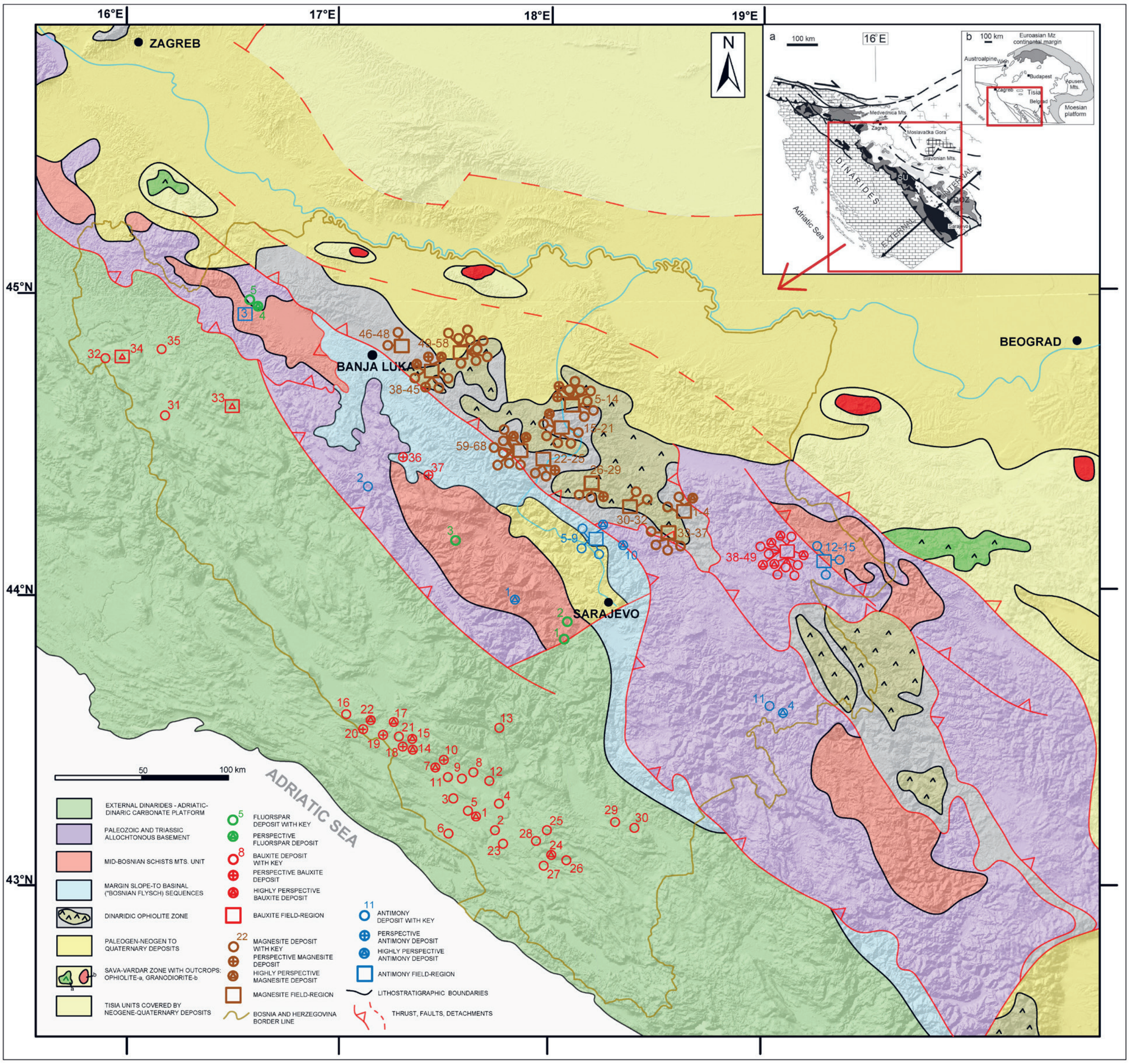

Figure 1. a. Geological scheme of studied area modified after PAMIĆ (1998), TOMLJENOVIĆ (2008) and PALINKAŠ (2008) with distribution of deposits and occurrences and corresponding keys-numbers linked to Appendix 2, Tables 1-4; **b.** Regional geological setting according to PAMIĆ (1998) with emplacement (red bounded) of studied area.

Krivodol, Služanj, Vitina-Lipno; **Lištica region**: Crne lokve-Kidačke njive, Resnica-Grabova draga, Uzarici-Knežpolje, Varda planina; **Mostar region**: Žovnica, Krstače-Cerovi doci; **Posušje region**: Mratnjača-Medine stanine, Podzavelin-Vinica, Studena Vrela, Trebistovo-Sobač, Vinjani, Volujak-Kadim, Vučipolje, Zagorje; **Stolac region**: Dabrica, Gornji Brštanik, Hrgud). The boehmite-type deposits occur as lensoid layers/pockets within palaeokarst depressions with a maximum thickness of 15 metres. In the majority of the deposits, the amount of Al_2O_3 is high (47-56%), with proportionally low SiO_2 (<10%). With an increase in SiO_2 of up to 18%, the amount of Al_2O_3 decreases to 42%.

Some stratigraphically slightly higher horizons, overlying alevoline-numulite limestones (**Čitluk region**: Krehin gradac-Blizanci, **Stolac region**: Bivolje brdo-Domanovići, Poplat) are smaller in size and of lower economic interest, containing 45-49% Al_2O_3 and variable amounts of SiO_2 (0,1-14%).

iii. The Upper Cretaceous – Neogene deposits (**Lištica region**: Trn-Sliškovića lokve) overlie Upper Cretaceous rudist limestones and are overlain by Neogene clayey marls. These deposits are of bauxite clay type, containing high SiO_2 (14-33%) and low variable amounts of Al_2O_3 (30-42%).

b. The Northwestern Bosnia region (Bosanska Krajina; (BURIĆ & ŽIVALJEVIĆ 1979))

i. The Middle Triassic deposits (Bjelaj, Veliki Skočaj) occur within palaeokarst surfaces of the Middle Triassic limestones as irregular layer-like lenses and pockets covered with Raibl Beds and Upper Triassic dolostone. The deposit thickness varies between 2 and 12 metres. Ooid to pisoid structures are common. The amount of Al_2O_3 (boehmite, rarely gibbsite) varies between 29 and 69%, whereas Fe_2O_3 varies between 2 and 20%, which affects the colour (white, pink, red bauxites). These deposits contain an average of 3% TiO_2, whereas the amount of SiO_2 is variable and high (2 – 40%).

ii. The Upper Jurassic deposits (Krnjeuša-Bravski vrh-Crni vrh) occur as irregular lenses and nests within the Lower Jurassic limestones and are covered with Upper Jurassic to Lower Cretaceous limestones. Bauxites are boehmite in origin, with high Al_2O_3 (58-69%), low SiO_2 (3-8%), and an average of 3% TiO_2.

iii. The Upper Cretaceous deposits (Pritoka-Tihotina-Trovrh, Suvaja-Šolaja) are embedded within rudist limestone of Upper Cretaceous age. These deposits are layered to lensoidal, boehmite-type, with an ooid to pisoid structure, containing the highest quality Al_2O_3-ore (55-75%), with very low SiO_2 (0-5%), and an average of 3% TiO_2.

(b) Internal Dinarides Cretaceous bauxites

a. Central Bosnia region (Jajce)

The largest Cretaceous karst bauxite deposits are located in the Jajce region (**Bešpelj-Crvene stijene, Poljana**, *Liskovica*) and cover an area of nearly 350 km^2. The formation of these deposits occurred during the 20 million-year terrestrial phase in the stratigraphic range from the Upper Albian to the Santonian-Campanian that resulted in tectonic-erosional discordance. The Jajce bauxite deposits are of boehmite-type and differ in shape and geometry: lenticular, canyon-like, graben type, sinkhole type, and tetanized. The hanging wall of the bauxites is rudist-coral-bryozoan limestones or carbonate breccias of Santonian-Campanian age (DRAGIČEVIĆ et al., 2019).

b. Vlasenica-Srebrenica region

The Cretaceous karst bauxite deposits of the Vlasenica-Srebrenica region (Palež, Podbraćan, Šumarnica, Štedra, **Crvene stijene,** Kosturi, Gerovi, Dragošnica, Žedanjsko, Pribojevići, Kutuzero) are similar to the other Internal Dinaride deposits of the Zlatibor and Poćuta area in Serbia and the Grebnik area in Kosovo. The bauxite deposits of the Vlasenica-Srebrenica region are located in a 30 × 4 km NW-SE trending zone in karst depressions in the Middle Triassic limestones and are covered by Upper Cretaceous limestones and/or a series of Neogene conglomerates, sands, and clays (DANGIĆ, 2015). The bauxites are brown-red, hard boehmite-haematite in composition (+anatas, brucite) with oolitic-pisolitic structure and appear in beds, lenses, and pocket fillings, sometimes over 40 m thick. The deposits vary in size from a few tens of thousands to over 10 million tons of bauxite (Braćan). Secondary kaolinitization is common, as well as the formation of diaspore.

3.3. Fluorite

(a) Early Palaeozoic continental rift-related deposits

i. As-polymetallic deposits with fluorite

The arsenic-polymetallic (As, Sb, Hg, Ba, F) hydrothermal deposit **Hrmza** is located near Kreševo in the Mid-Bosnian Schist Mts. The ore-bearing rocks are Permo-Carboniferous phyllites, sandstones, and breccias. The mineralized zone is 0,5 to 3,0 m wide and consists of veins, impregnations, and nests. The main minerals are realgar and orpiment, followed by accessory fluorite, pyrite, bravoite, barite, muscovite, sphalerite, tourmaline, rutile, and antimonite. The fluorite has a dark purple color, and forms hexahedron crystals up to 1 cm in size. The tourmaline occurs regularly in veins alongside rutile and less commonly with fluorite. The quartz is mostly idiomorphically developed. The mineralogy points to a transition from a pneumatolytic to a hydrothermal phase, with fluorite precipitating late (JELIĆ, 1979).

ii. Carbonate-hosted barite-fluorite deposits

The mineralized zone containing the barite-fluorite deposits of Mt. Meovršje is about 22 km long and 2 to 4 km wide and represents part of the Mid-Bosnian Schist Mountains (JELIĆ, 1979).

The Meovršje Mt. encompasses a 300 m thick Devonian carbonate complex, containing predominantly light-gray dolostone, followed by limestone and marble limestone. The underlying metamorphic complex contains chlorite and muscovite schists, phyllite, quartzite, and lydite. The carbonate complex hosts most of the barite deposits, which occur as impregnations, variously sized veins, or irregular bodies.

The barite deposits appear as almost monomineralic barite bodies, barite-quartz veins, **barite-fluorite** veins (**Meovršje**), and barite-tetrahedrite veins. In the barite-fluorite veins, the fluorite has an octahedral habit, and is colourless, violet, or transparent. The octahedral habit indicates that the formation of fluorite took place under temperatures >200°C.

The Meovršje deposit contains predominantly barite (90 - 99 % wt. $BaSO_4$ and about 6 % wt. $SrSO_4$), ferroan dolomite, calcite, Hg-Sb tetrahedrite, quartz, pyrite, fluorite, and enargite. The accessory minerals are chalcopyrite, sphalerite, antimonite, sericite, tourmaline, and rutile (JELIĆ, 1979).

The barite-fluorite deposit **Žune** in NW Bosnia lies within the Upper Palaeozoic dolostone close to the contact with Lower Triassic schists and sandstones. The structure and texture of the vein show some evidence of hydraulic fracturing, an important indicator of boiling of hydrothermal fluid, as recognized in the fluid inclusion studies (PALINKAŠ et al., 2016). The barite-fluorite vein is 3 to 9 m thick and vertically cuts the Upper Palaeozoic dolomites in an E–W direction. The contact zone consists of metasomatically recrystallized host dolomite with strings of tiny barite veins and impregnations. The central part of the vein consists of pure barite and some fluorite. The fluorite is mostly violet but can be blue to yellowish and has an octahedral habit. The accessories are calcite, quartz, sulfides and sulfosalts (tetrahedrite, cinnabarite, pyrite, realgar), and Au (JEREMIĆ, 1958).

iii. Carbonate-hosted barite-siderite-fluorite deposits

The **Vidrenjak-Ljubija** deposit in NW Bosnia has a similar setting within the Upper Palaeozoic carbonate complex. However, the mineralization is discordant and irregular and contains siderite, limonite, sandy barite, and fluorite.

(b) Oligocene post-collisional occurrences

Rare occurrences of fluorite are found within pneumatolytic-hydrothermal alterations of S-type granitoids in the Motajica Mts.

3.4. Magnesite deposits of the Central Dinaride ophiolitic zone

The Bosnian magnesite deposits and occurrences are genetically linked with serpentinized peridotite and dunite rocks of the Central Dinaric Ophiolite zone of Jurassic age (Appendix 2, Table 4). The quality and quantity of the magnesite increase from the northwestern Kozara-Pastirevo region towards the southeastern Krivaja-Konjuh region and the Zlatibor region. The Bosnian deposits are of the Kraubath-type and appear as several hundred-metre long veins, veinlets, and impregnations of various thicknesses, containing micro-crystalline magnesite with variable primary carbonates (dolomite, calcite), and quartz (ILIĆ & JELIĆ, 1979; JURKOVIĆ et al., 2012). The vein-type ore varies between massive, banded, and brecciate and is up to 7-8 metres thick. About 25% of the reviewed magnesite deposits contain more than 40% MgO (Appendix 2, Table 4). The previous exploitation was mainly underground. Brecciated fine-grained magnesite deposits are often cemented with coarse-grained neomagnesite or silica (quartz, opal, chalcedony), and contain remnants of the host-serpentinite, magnetite, or chromite. In the upper part of the deposits, silica veins and veinlets are very abundant, cross-cutting and prevailing over primary magnesite. Fe-hydroxide and Mn-oxide occur as a weak coating over the magnesite.

As a rule, the orientation of the majority of the micro-crystalline Bosnian magnesite veins follows the major Alpine tectonic structure oriented in a NW-SE direction. The oldest veins are of Early Cretaceous age, coeval with the onset of lateritization in the Dinarides. Their vicinity close to the Oligocene-Miocene volcanic/plutonic rocks (Moševac, and Vlasenica-Srebrenica fields), as well as the observed tectonic setting and textural sub-types (breccia-type) lead to the conclusion that their origin lies near the surface epithermal processes related to post-collisional magmatism in the Dinarides (ILIĆ & JELIĆ, 1979).

4. METHODOLOGY

4.1. InvestRM methodology

The development of the methodology within the InvestRM project is divided into several complementary phases (Fig. 2). Through constant feedback from project partners and from public presentations at project info days, the methodology was continuously improved, resulting in the selection of high-potential deposits for exploration or reinstating abandoned or ongoing mining activities.

1st phase: Geological data template

Geological templates gather available non-confidential geological data and tailor them to be aligned with:

– transferability to existing comparable international raw materials databases (*EGDI-European Geological Data Infrastructure: http://www.europe-geology.eu/*)

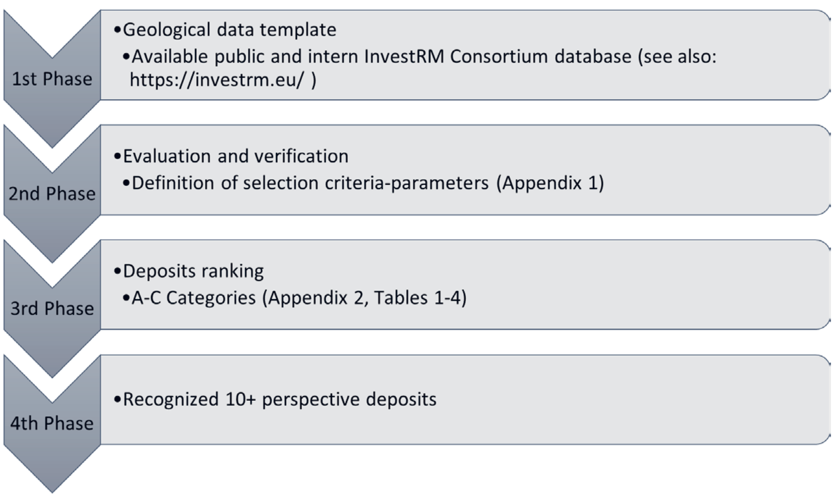

Figure 2. Invest RM methodology divided into complementing phases.

– InvestRM standardization for antimony, bauxite, fluorite, and magnesite occurrence types in the Dinarides
– Terminology aligned with INSPIRE
– Presenting essential data for evaluation of exploration and mining potential

The geological template contains information on the geological characteristics of each of the 126 deposits (basic deposit information, deposit characteristics), supplemented with information on raw materials, reserve, processing, waste/environmental characteristics, additional info and references, thus enabling data harvesting and linking to the existing international raw materials deposits databases such as EGDI (EuroGeoSurveys' European Geological Data Infrastructure; *http://www.europe-geology.eu)*, and comparison with deposits worldwide. This is essential considering that the addressed critical raw materials in Bosnia and Herzegovina are currently only partly presented in worldwide databases. Geological datasets have been extracted from available elaborates, technical documentation, reports, scientific papers, and geological maps. Between the 1960s and the late 1980s, a mapping campaign supported by the government of the former Yugoslavia responsible for the economic growth and planning resulted in geological maps at a scale of 1:100.000 for the entire territory of the former state. Following the mapping campaign, ČIČIĆ and co-authors (1979) provided a comprehensive overview of the targeted raw materials in a book covering ferrous, non-ferrous, and industrial commodities, as well as the energy generating materials in Bosnia and Herzegovina, which was used as a starting point for geological data extraction and supplemented with recent publications on the selected deposits.

2nd phase: Evaluation and verification of geological data.

For each of the 126 deposits/occurrences, the investment potential was estimated. The selection criteria were extracted from the World Risk Report (2017), whereas setting and adjusting the specific parameters for the selection criteria was done by the InvestRM consortia and consists of: (a) geological criteria (a level of current geological knowledge, i.e., data quality and quantity), and (b) non-geological criteria (social licensing, environmental management, project permits, skills availability). Specific parameters for the geological criteria were set up separately for individual raw materials and are described in **Appendix 1**. These include quality and quantity criteria summarizing reserves, exploration level, and favourable geological characteristics. Reserves are aligned with the law governing geological exploration (Official Gazette of the FBiH No. 9/10) and the rulebook on classification, categorization, and calculation of solid mineral raw material reserves and keeping records on them (Official Gazette of the FBiH No. 36/12).

Reserves encompass A, B and C_1 categories (proven and measured), whereas resources are used for C_2, D_1 and D_2 categories (indicated and inferred) in line with the Official Gazette of the FBiH No. 36/12. Used literature sources for Appendix 2 do not contain subdivided economical and non-economical reserves.

3rd phase: Deposit ranking

The principal parameters influencing ranking are the geological data quality (complete and relevant datasets from the geological data template) and data quantity (reserves, available past exploration data), as well as social licensing, environmental management, and project permits. Parameters were weighed and assigned to ranks A, B or C, respectively, whereby A denoted excellent data with defined and up to date characteristics, B encompasses good-sufficient geological data, and C means no or minimal geological data with poorly estimated reserves and resources. The deposits considered to be the most potentially viable among the A rank deposits, namely those meeting all established criteria, were defined as A+ deposits with highly lucrative investment opportunities. The evaluated deposits were ranked and presented in detail in **Appendix 2 (Tables 1-4).**

4th phase: Recognized 10+ perspective deposits

Deposits ranked A+ were described as highly lucrative investment opportunities, while A ranked deposits also present investment opportunities but do not meet all the predefined criteria. A number of A ranked deposits could be upgraded to A+ deposits by providing additional datasets as part of the geological prospection.

4.2. Indicators to evaluate exploration and mining potential

The exploration potential was estimated based on the geological setting of the wider area around an occurrence and the available data from previous exploration campaigns regarding the level of

Figure 3. Data sources and processes used to calculate indicators of mining potential (Copyright of original data used from World integrated Trade Solutions (WITS) belong to the World Trade Organization (WTO). Conclusions and analyzes based on this data are the responsibility of the authors and do not necessarily represent the opinion of the WTO. LOM = Life Of Mine)

uncertainty. The type of exploration method and targeted raw material (in polymetallic deposits) was also important in defining the exploration potential. Reserves are a further important indicator (aligned with a valid classification and categorization method – **Appendix 2 (Tables 1-4)**.

To calculate the mining potential based on the geological data and economic information using the InvestRM tool, three indicators - world producer ranking, self-sustainability, and economic contribution - are introduced (Fig. 3).

The first indicator, 'world producer ranking', compares the theoretically mineable tons to the world production and helps to position Bosnia-Herzegovina on the global ranking list. The second indicator, 'self-sustainability', relates produced and imported tons, thus showing the ratio of materials derived from within BiH and is thus an indicator of self-sustainability. The last indicator, 'economic contribution', evaluates the contribution of the country's mines to Bosnia-Herzegovina's economy in terms of taxed profits. A very simplified dynamic calculation method is applied to determine this value, as the input factors are based on assumptions. The calculation results based on current reserve tonnages are compared to numbers gained after upgrading C_1 and C_2 resources to A or B reserves.

5. RESULTS AND DISCUSSION

5.1. Exploration potential

The exploration potential of a specific mineral commodity depends on the geological potential, the number and distribution of occurrences and deposits in an area. Out of the total of 126 deposits of antimony, bauxite, fluorite, and magnesite in Bosnia and Herzegovina, 106 (or 84% of the investigated sites) are magnesite and bauxite deposits containing millions of tons of reserves and resources and showing high exploration potential (Table 1). When comparing all the reserves and resources, bauxites have the greatest exploration potential, followed by magnesite, antimony, and fluorspar (Table 1). The following results were obtained by applying the InvestRM methodology to the 126 investigated deposits:

1. Three out of five fluorspar deposits were evaluated as A+ deposits. A field reconnaissance investigating the three deposits indicated that only the Žune locality met each of the predefined criteria for the A+ rank.
2. Four of thirteen antimony deposits were evaluated as A+ deposits. The Čemernica and Podhrusanj deposits are abandoned deposits, while the Rupice and Veovača deposits are currently under development with an exploration license.
3. Six of fifty-seven magnesite deposits were evaluated as A+ deposits, including the magnesite field Kladanj with the most prospective operating deposit Miljevica and the poorly explored occurrences at Zeničica and Drinjača, all part of the Kladanj magnesite region. Furthermore, the abandoned deposit of Ošve, which is part of the Novi Šeher magnesite field, was recognized as a highly prospective deposit. The magnesite regions of Teslić, with several abandoned deposits, and Snjegotina, with nine deposits currently not operating, were also highly ranked (A+).
4. Fourteen out of fifty-one bauxite deposits were evaluated as A+ deposits. Of these, we highlight three perspective regions, namely the Krnjeuša-Bravski vrh-Crni vrh and Pritoka-Tihotina-Trovrh fields, with exploration licenses, and Vlasenica-Srebrenica, with several operational deposits.

Table 1. Reserve, resources and exploration potential of flourspar, antimony, magnesite and bauxite in BiH (data compiled after references used in verification and evaluation process: BODULIĆ et al., (2018); BURIĆ et al., (1979); CVIJIĆ et. al., (1979); CVIJIĆ (2004); ČIČIĆ (1979); DANGIĆ (1978, 1988, 2015); GRUBIĆ (1975); GRUBIĆ et al., (2016); JAŠAREVIĆ et al., (2013); JEJINA et. al., (1977); JURIĆ (1973); JURKOVIĆ (1961); KUBAT et. al. (1973); KUBAT (1995), MITROVIĆ (2011); OPERTA et al., (2018), PAVIČIĆ et al., (2018); RAMOVIĆ (1963) RAMOVIĆ et al. (1979); SUNARIĆ-PAMIĆ et al. (1988); TODOROVIĆ (2016).

Raw material	No. of deposits/ Occurrences	Total reserves (A+B+C1)	Total resources (C_2+D_1+D_2)	Exploration potential
	5			LOW
Antimony	13	100.000 t	115.000 t	
Magnesite	57	537.784 t	3.414.700 t	HIGH
Bauxite	51	35.067.305 t	20.852.000 t	

In the areas listed above, the geological potential indicates highly lucrative investment opportunities with some additional exploration required to prove the reserves and resources estimated during previous campaigns. The magnesite and bauxite areas show a high prospectivity for exploration – with regions evaluated as A+ or A representing several deposits/regions controlled by the regional geological setting. In cases of positively evaluated magnesite, only the operational deposits were studied in detail. The areas surrounding existing deposits can hold additional reserves and resources, but this study included only operational or abandoned sites. Abandoned deposits were categorized into the group of prospective sites when exploitation (or exploration) activities were undertaken there in the past, and the deposit was later abandoned for various reasons, such as feasibility, legislation, or environmental hazards resulting from inappropriate exploitation and processing techniques. Larger areas present huge investment opportunities especially for long-term projects.

Magnesite and bauxite occurrences are generally ranked based on the amount of available data on reserves and resources and the quality of the data because these two CRM represent the primary or sole RM mined in the chosen deposits. Antimony and fluorite usually occur as secondary minerals in economically more interesting, predominantly Pb-Zn-Fe, or barite deposits. Therefore, reserves and resources are usually estimated, and the geological settings of studied areas were used as a key criterion. Prospective fluorspar and antimony occurrences were studied in the InvestRM consortium to provide the possible geological potential for further exploration and feasibility studies.

5.1.1. Bauxite

Bauxite deposits and occurrences are related to the Adriatic Carbonate Platform and the internal Dinaride Cretaceous karst units. Several promising bauxite-bearing areas have a high exploration potential (Table 1):

(1) The Internal Dinarides Cretaceous karst deposit of the **Vlasenica- Srebrenica region** in eastern Bosnia hosts 12.950.000 t (MITROVIĆ, 2011) of reserves, representing 25% of the total bauxite reserves in BiH. Active exploitation is operated by the company Bauxite a.d. from Milići.

(2) Grmeč mountain in the Una-Sana region has potential reserves (resources), with the bauxite-bearing potential estimated to be about 20.000.000 t (ČIČIĆ, 1979), and has no active exploitation.

(3) The External Dinarides bauxite of the **South Bosnia region** (Posušje to Trebinje), based on the number of registered bauxite deposits and occurrences, is an area with

potential for further bauxite exploration (BURIĆ & ŽIVALJEVIĆ, 1979). Active exploitation is operated by the company Bauxite Mines d.o.o. from Posušje.

5.1.2. Magnesite

Magnesite deposits and occurrences in BiH are spatially and genetically related to the Ophiolite zone of the Dinarides. According to the degree of exploration, the most economically interesting magnesite regions are (as shown in Table 1):

(1) The **magnesite field of Kladanj** which is a highly explored area with proven reserves of 193.484 t and a potential of 67.100 t (HODŽIĆ & DJEDOVIĆ, 2014). Active exploitation is operated by the company Rudar d.o.o. from Tuzla.

(2) The **Banja Luka magnesite field,** with a low level of exploration and high-potential reserves exceeding 1.400.000 tons. It mainly belongs to the Snjegotina magnesite field (Jelovac = 420.000 t; Pločni = 437.757 t; (ILIĆ & JELIĆ, 1979). The Snjegotina field contains 25 magnesite occurrences investigated in detail, and more than 40 were partially investigated. Previous research (ILIĆ & JELIĆ, 1979) yielded a promising geological and economic assessment. Further research would likely result in additional discoveries.

(3) The **magnesite field of Teslić,** has three promising sites, namely Blatnica (260.000 t), Bukovački jarak (120.000 t) and Milošev jarak (377.000 t) (ILIĆ & JELIĆ, 1979). Magnesite bearing rocks include hornfels, amphibolite, and pyroxenite together with predominant serpentinized peridotite, whereby the magnesites have a high SiO_2 and CaO contents. Semi-industrial-scale tests were conducted to explore the possibility of magnesite enrichment by various methods, with two-stage flotation giving optimal results (ČIČIĆ, 1979). Further industrial-scale testing is necessary to determine the techno-economic factors and classify proven reserves.

(4) The **magnesite field of Novi Šeher** contains the Ošve deposit with 215.000 t of resources (150.000 t C_1 + 65.000 t C_2). Chemical analysis (ČIČIĆ, 1979) has shown that the raw material is largely suitable for the production of metallurgical sinter, but not for the production of high-refractory bricks due to the elevated SiO_2 and CaO contents. Semi-industrial flotation experiments (ČIČIĆ, 1979) yielded promising results, similar to those for Teslić, and should be complemented with industrial-scale testing.

5.1.3. Antimony

Economically interesting concentrations of antimony in BiH are spatially distributed across several areas, regions, or zones:

(1) Palaeozoic, continental rift-related polymetallic hydrothermal deposits

a. **The Central Bosnian Ore Mountains area (Čemernica and Fojnica deposits) contains** Ag, Hg and Zn. The mineralized zone of Čemernica is about 4.5 km long and about 120 m wide. Several ore veins were detected there, and the main ore vein was mined to the level of the Čemernica stream. Analyses show that the Čemernica ore is an Sb, Hg, Zn and Ag ore enriched in W and Au. Antimony ore reserves of the A + B + C_1 categories contain 299,235 t with contents of 3.3% Sb, 5.7% Zn, and 96 ppm Ag (JURKOVIĆ et al., 2012). Further exploration is needed to investigate the extent of mineralization and devise an extraction methodology.

b. **The southeastern Bosnia (Podhrusanj) deposit** was exploited for antimony ore from 1965 to 1975, during which time only high-grade ore with an antimony content of 4-5% was extracted. Reports from 1977 state that the A + B + C_1 reserves contain 74,651 t of ore with an average Sb content of 3.2% (KUBAT, 1982; 1995). Potential reserves of the C_2 category containing about 115,000 t with 1.1% of Sb were also reported. Based on the metallogenetic analysis, Kubat (KUBAT, 1982; 1995) reported that the Podhrusanj region is very interesting for further exploration. The Podhrusanj deposit has only been partially explored. Mineralized limestones of 0.5 - 1.5 m thickness appear in the wider area of the deposit containing 410,500 t of A + B + C_1 reserves with 3.4% Sb. Chemical analysis has shown that the ore does not contain As or Pb concentrations in heavy liquid analysis (classes -20 +2 mm), and the concentration by flow tables (classes -2 +0 mm) yielded a valuable antimony concentrate with a weight content of 13.9% and an Sb content of 43%, with a utilization degree of 81%.

(2) Oligocene post-collisional deposits of the Sava-Vardar zone

a. **The Srebrenica field in Eastern Bosnia (Čumavići)** consists of a 1m thick and several hundred-metre long main vein containing 7% Sb, 2.8% Zn, 0.3% Pb, 0.05% Cu, 0.1% WO_3, and 80 g/t Ag. Preliminary flotation extraction analyses have shown the possibility for concentrating Sb, Zn and Ag, while the Pb content is inadequate for economical extraction. The Čumavići deposit is only partially explored, showing D_2 reserves of 500,000 t (KUBAT, 1982; 1995). About 100 ha of terrain around the village of Čumavići is considered promising due to the identified outcrops of antimony ore.

(3) Triassic advanced rift-related hydrothermal antimony deposits

a. **The Borovica-Vareš-Čevljanovići-Srednje ore zone (the Rupice, and Veovača deposits)** consists of a complex polymetallic deposit of Ba-Zn-Pb ore with Sb and Hg. Significant geological research in combination with exploration drilling on the Rupice deposit was carried out in the second half of the 20^{th} century. Exploration results summarized by Kurtanović (KURTANOVIĆ, 1990) revealed reserves of 1,498,011 t with 3% Pb and 3,5% Zn. KUBAT (1982; 1995) estimated reserves of Sb in the host dolostone of up to tens of thousands of tons with an average antimony content of 4,8%. The Veovača deposit, in comparison with the Rupice deposit, is characterized by a lower Sb content and a slightly higher Hg content. Ore reserves and resources of all categories are over 6.000.000 t with an average $BaSO_4$ content of 16,3%, Zn of 1,6%, Pb of 0,8%, Hg of 0,1%, and Sb of 0,1% (KUBAT, 1982; 1995), and there is the possibility of discovering new ore resources in the northeast near the localities of Prijeljev and Orti. Although the Veovača location contains primarily Ba-Zn-Pb deposits, relatively low contents of Sb and Hg should

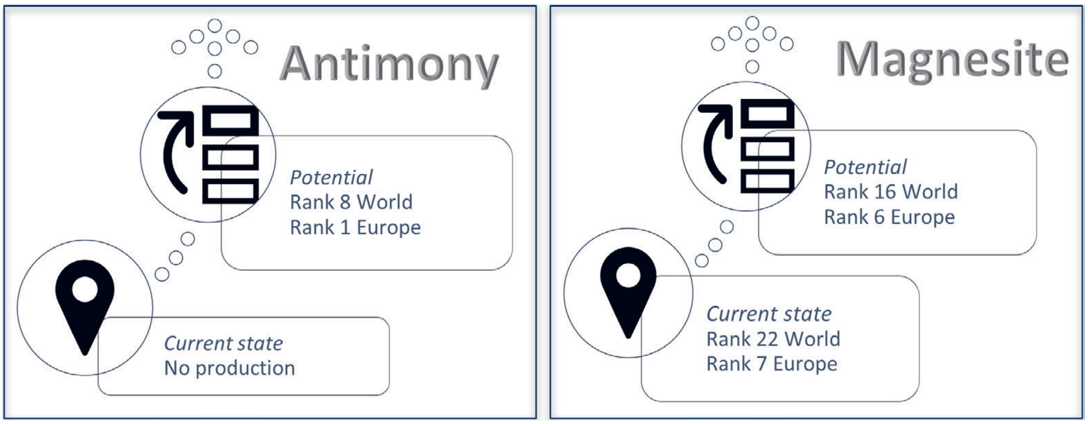

Figure 4a (left). Utilizing Bosnia-Herzegovina's potential for antimony production; **b** (right). Utilizing Bosnia-Herzegovina's potential for magnesite.

not be neglected in the extraction of useful components from ore. Within the Borovica-Vareš-Čevljanovići-Srednje ore zone, the Rupice and Veovača deposits are classified as prospective deposits containing economic ore reserves (KUBAT, 1982; 1995). Geological exploration is currently ongoing.

5.1.4. Fluorites

The occurrence of fluorite in BiH is small compared with the products of barite or arsenic mineralization. According to the scarce data, only five fluorite deposits were registered: Žune and Vidrenjak near Ljubija, Hrmza and Meovršje near Kreševo, and Pećine near Gornji Vakuf.

Based on the results of previous research (PALINKAŠ et al., 2016), as well as the conducted field research, the **Žune** deposit in the Ljubija ore area in the Republic of Srpska is the most promising. This deposit is Palaeozoic in age and hydrothermal in origin. It is represented by a single subvertical and partially depleted barite-fluorite vein that is several hundred metres long and has a maximum thickness of 10 m. The barite-fluorite vein is hosted by the Palaeozoic dolomites, near the contact with the Verfen shales and sandstones. The proportion of fluorite is usually about 20%, but it increases with depth, which presents an opportunity for further exploration. The inferred fluorite reserves in this deposit are estimated to be 1.500 t.

5.2. Mining potential

According to the World Mining Data (REICHL & SCHATZ, 2021), the contribution from Bosnia-Herzegovina to the mining of antimony, bauxite, fluorspar, and magnesite is comparatively low. Between 2015 and 2019, only bauxite (crude ore) and magnesite are listed, ranking Bosnia-Herzegovina in 18^{th} place out of the 28 bauxite producers and in 22^{nd} place of the 23 magnesite producers (REICHL & SCHATZ, 2021). Based on the geological potential identified for the four selected commodities, Bosnia-Herzegovina is capable of contributing much more. Following the methodology described in section 4.2, the three indicators for mining potential are discussed below, grouped by commodity.

5.2.1. Indicator 1: World Producer Ranking

Antimony

The world production of antimony was 125,478 metric tons in 2019, and at the same time, there was no production at the EU level. Looking at the two abandoned mines Čemernica and Podhursanj, a total of about 374 kt of reserves is estimated ($A+B+C_1$ reserves). Assuming a mining loss of 20% and a mine lifetime of 30 years, BiH could produce about 350 tons of Sb per year. This would make the country Europe's only producer of antimony and place it in 8th position in the world rankings (Fig. 4a).

Magnesite

A similar approach for magnesite shows a slightly different picture. The world production of magnesite in 2019 was 27 million metric tons, with about 11% being mined in Europe (EC) and Bosnia-Herzegovina contributing with 1400 tons. Looking at the deposits that have been identified as highly graded investment opportunities and only focusing on the abandoned and closed mines, Bosnia-Herzegovina is capable of producing an additional 36 kt of magnesite[1]. This would improve the country's position from 22^{nd} to 16^{th} in the rankings (Fig. 4b).

Similar thoughts would be applicable for the bauxite and fluorite deposits and occurrences, but these are not emphasized here as Bosnia-Herzegovina already mines more than 1 million metric tons of bauxite per year, and fluorite occurrences will not play a major role based on the currently available data.

5.2.2. Indicator 2: Self-sustainability

A vital topic is the importing of necessary commodities. Currently, Bosnia-Herzegovina does not import any antimony ores and concentrates but imports about 2 to 3 tons of antimony oxides per year. Assuming a working processing technique, the stibnite deposits could provide around 2 tons of antimony per year. Depending on the field of application, Bosnia-Herzegovina may reduce the required imports and could even start exporting antimony ores. The European Union imports roughly 4 kt of antimony ores and would benefit from a local provider (World Trade Organization, 2021).

Imports of magnesite vary, whereby it was 105 tons of sintered magnesite in 2019 (World Trade Organization, 2021). With the additional tonnage from the mines currently not operating, the magnesite mined in Bosnia-Herzegovina could reach self-sustainability and BiH could become an exporter.

Numbers on bauxite imports as crude ore are difficult to identify. Aluminum ore and concentrate imports amounted to 210

[1] Taking the available resources upgraded to reserves (amount reduced by 25%) and assuming again a lifetime of 30 years for the underground mine operation, the deposits at Blatnica, Bukovični jarak and Milošev jarak from the Teslić and Jelovac fields and Pločni (from the Snjegotina - Banja Luka field) could provide 29 kt. With the open pit mine in Ošve reopened, there is a total amount of 36 kt.

kt in 2019, whereas exports were in the range of 32 kt (World Trade Organization 2021). Both values have increased in recent years. It seems unlikely that additional bauxite deposits can dramatically change the import to export ratio but might be able to help maintain the balance.

Fluorspar imports into Bosnia-Herzegovina were in the range of 1.4 kt in 2019. The assigned value for this import is about 550.000 USD. Utilizing the country's own fluorite reserves would help to reduce these imports.

5.2.3. Indicator 3: Economic Contribution

This potential can also be expressed in monetary units. While the exact prices that could be obtained by selling the products cannot be forecast without proper feasibility studies, including market studies, the potential may be highlighted by simply assuming a perfect market and ideal conditions. Prices for antimony and raw magnesite are currently listed at 6586 USD/t and 89 USD/t, respectively (Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) 2021). All deposits examined here are underground mines, except the one in Ošve. To estimate the operating costs and capital costs for the mines, figures from an Estimator's Guide (InfoMine USA, Inc. 2016) are extrapolated to account for the estimated production tonnage and updated to current values by assuming an inflation factor of 8.5%. For all subsurface mines, a mechanized cut and fill operation with adit access is assumed. This seems feasible, as all deposits in question are irregular veins or of vein-type. The open pit mine is assumed to have a waste to ore stripping ratio of 8:1. When combining these estimates with the production tonnages from the previous paragraph, the theoretically achievable prices and the estimated costs and, thus, a potential net profit value can be calculated (Table 2). The calculation is based on currently stated reserves and compared to a theoretical tonnage after additional exploration. The reserves and resources upgraded to reserves are taken from the InvestRM reports are adjusted to account for mining losses. Costs are based on figures from InfoMine but adjusted to the production rates for an estimated lifetime of 30 years per deposit. Together with prices for antimony and magnesite, a simple NPV calculation is performed. Further assumptions: 12% discount rate and a LOM of 30 years, no price or cost increases over the years; re-occurring capital costs every 10 years (50%, 25%, 25%).

For Čemernica, a positive value can be achieved if additional metals (Zn and Ag) are mined and sold. The focus should be on processing to ensure the inclusion of Zn and Ag in the product portfolio. Looking at the overall economy of Bosnia and Herzegovina, mines could contribute ten percent of the profit as corporate income tax.

In Podhrusanj, the loss can be halved if additional exploration can prove 410 kt. Further engineering to reduce the capital costs and a market study on price development may produce a positive NPV.

The open pit mine in Ošve can achieve a significant improvement (factor 10) in the mineability if reserves can be upgraded from the C_1 and C_2 to the A and B categories. Additional improvements in mine design can reduce operating and capital costs.

For the Telić and Banja Luka fields, the calculation shows that currently calculated losses can be halved if the deposits per field could be combined. Using these synergies together with a reserve re-classification and a proper mine design, the operations may become very profitable. Additionally, attention should be paid to the inclusion of a refinement step to improve the final product and increase the achievable prices.

Comparing average prices for antimony and magnesite between 2016 to 2020 with values from June 2020 to May 2021, an increase of 2% (antimony) and 1.8% (Magnesite) can be seen (Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) 2021).

As described, antimony deposits also host Zn, Ag or, in the case of Rupice, $BaSO_4$. A closer analysis of the processability of the extracted ore could enhance the product portfolio of the mining sites in Rupice, Čemernica, and Srebenica and thus boost their profitability.

Fluorspar deposits currently do not provide enough data for a similar calculation, and most bauxite mines highlighted in the FIPA brochure are already operational. Therefore, both commodities are not included in this subsection.

All costs and price figures in this chapter are based on profound assumptions but would require further market studies (true prices, real demand) and costs (re-opening the abandoned mines, processing, employees, and energy). Furthermore, more detailed mine plans are necessary to estimate mining losses and production figures. In some cases, e.g. Podhrusanj, additional exploration could improve the inferred reserves (see section 5.1 for comparison) but will generate some costs. For all mines, feasibility studies would deliver more realistic estimations about the profitability and might provide better profit values.

For all deposits described here, two different courses of action can be taken: starting exploitation or continuing extraction by renewing existing mining permits. Either way, a more *profound financial calculation* on a micro-economic level is necessary, as the most critical parameter for the exploitation is the financial feasibility of a mining project. A major decision driver for a company to start or continue mining of a particular deposit is the ability of the mine to create a profit. It is no easy task to answer the question about the true mineability of a mine or deposit. The general process of evaluating mine investment opportunities usually includes the assessment of four main, interrelated factors: the ore reserves, the cut-off grade (or quality), the mine size, and the production costs (GENTRY & O'NEIL, 1984).

For mining financial calculations, investors require a sound and reliable data base. This data needs to cover all the main factors of production, including the deposit and relevant geological data. Especially for foreign investors, it can be a very time consuming and exhausting task to find consistent data on economic and social figures or deal with information about concessions or local political strategies. The InvestRM decision making tool offers a quick, user-friendly, and easy way to access and gather all the necessary information in a comprehensive report (HAINDL, 2020).

6. CONCLUSION

A total of 126 deposits and occurrences of antimony, bauxite, fluorspar, and magnesite occurrences in Bosnia and Herzegovina have been validated using the developed InvestRM methodology to determine their exploration and exploitation potential. The developed InvestRM methodology consists of the following steps:

(1) preparation of the geological data templates in line with international raw materials datasets (M4EU, EGDI) for 126 deposits/occurrences;

(2) evaluation and verification of the geological data in order to estimate the investment potential using criteria extracted from the World Risk Report (2017) and specific InvestRM parameters;

(3) ranking deposits according to the quality of the geological data (complete and relevant datasets from a geological data template) and data quantity (reserves, available past exploration data), as well as social licensing, environmental management, and project permitting, into ranks A, B or C, and

(4) identification of the 10+ perspective deposits (barite-fluorite vein-type deposit Žune; polymetallic antimony deposits Čemernica and Podhrusanj, antimony fields Srebrenica and Rupice; magnesite fields Kladanj, Banja Luka, Teslić and Novi Šeher and bauxite regions Vlasenica-Srebrenica, Grmeč Mountain deposits in Una-Sana region and South Bosnia regions from Posušje to Trebinje; Appendix 3, Table 1-4) meeting all predefined criteria and parameters.

Analysis shows that a significant potential in primary critical raw materials such as bauxite (56 Mt), magnesite (4 Mt), and antimony (0.2 Mt) exists in Bosnia and Hercegovina. However, current production places BiH in 18th position in the World for bauxite and 22nd for magnesite, with no production in antimony or fluorspar. Metallogenically, these commodities are associated with several large and distinctive tectonostratigraphic units within the Dinarides: (I) karst bauxites, predominantly hosted by the External Dinarides (Adriatic Carbonate Platform) and the Bosnian Flysch of the Internal Dinarides; (ii) magnesite deposits of Kraubath-type exclusively hosted by the Dinaric Ophiolitic Zone, and (iii) antimony within polymetallic deposits associated with Palaeozoic continental rifting, Triassic advanced rifting and Oligocene post-collisional events of the Sava-Vardar zone.

Three indicators: the world producer ranking, self-sustainability, and economic contribution, are included in the analysis of the country's mining potential. Bosnia-Herzegovina could play a major role in Europe's strategy to become self-sustaining in the supply of critical raw materials. The brief economic discussion shows that there is a need for investments in geological prospection and engineering to transform the abandoned mines into operational sites and prepare feasibility studies. Antimony and fluorspar occurrences are part of the polymetallic deposits and can add value to low-feasibilty deposits. Large magnesite and bauxite regions provide opportunities for additional exploration and improvements in the exploitation process. Considering all the facts, investments in exploration and mining could boost BiH's economy and create value not only for the country itself, as it could be self-sustaining in antimony and magnesite, but also as a supplier for Europe.

ACKNOWLEDGEMENT

This work has been financially supported by EIT RawMaterials project no. 17051 Invest RM: Multifactor model for investments in the raw material sector, a part of the Horizon 2020 program. We would like to thank the Invest RM team https://investrm.eu/ for continuous fieldwork support, helpful advice, and discussion. Proof reading by native English speaker, Isabella MERSCHDORF is highly appreciated.

REFERENCES

ANTON A., BURIĆ, P., DANGIĆ, A., ILIĆ, M., JELIĆ, M., JOVANOVIĆ, Č., JOVANOVIĆ, P., KAPELER, I., KARAMATA, S., KUBAT, I., MILADINOVIĆ, D., OLUJIĆ, J., PAMIĆ, J., PODUBSKY, V., RAMOVIĆ, M., SUNARIĆ-PAMIĆ, O., VAKANJAC, B., VARIĆAK, D., VASILJEVIĆ, R., VUJOVIĆ, M. & ŽIVANOVIĆ, D. (1979): Ležišta nemetala [*Non-metallic deposits - in Bosnian*]. – In: ČIČIĆ, S. (ed.): Mineralne sirovine Bosne i Hercegovine: Ležišta nemetala [*Mineral raw materials of Bosnia and Herzegovina*], Vol. 1/2, 2 volumes, 236–447.

BODULIĆ, G., JOVANOVIĆ, R., JOVANOVIĆ, P., JURIĆ, M., ĐURIĆ, S., KUBAT, I. & KULENOVIĆ, E. (1979): Ležišta crnih metala [*Ferrous metal deposits* – in Bosnian].– In: ČIČIĆ, S. (ed.): Mineralne sirovine Bosne i Hercegovine: Ležišta nemetala [*Mineral raw materials of Bosnia and Herzegovina: Non-metallic deposits* – in Bosnian], Vol. 2/4. 2 volumes, 215–414.

BOROJEVIĆ ŠOŠTARIĆ, S., NEUBAUER, F., HANDLER, R. & PALINKAŠ, L.A. (2012): Tectonothermal history of the basement rocks within the NW Dinarides: new40 Ar/39 Ar ages and synthesis.– Geologica Carpathica, 63/6, 441–452. doi: 10.2478/v10096-012-0034-2

BOROJEVIĆ ŠOŠTARIĆ, S., PALINKAŠ, L.A., STRMIĆ PALINKAŠ, S., BERMANEC, V., NEUBAUER, F., SPANGENBERG, J. & PROCHASKA, W. (2009): Origin of siderite mineralisation in Petrova and Trgovska Gora Mts., NW Dinarides.– Miner. Petrol., 97/1–2, 111–128. doi: 10.1007/s00710-009-0065-2

BUDEŠ, I., GALIĆ, I. & DRAGIČEVIĆ, I. (2018): Research of bauxite deposits from underground mining works.– MGPB, 33/3, 95–110. doi: 10.17794/rgn.2018.3.10

BUNDESANSTALT FÜR GEOWISSENSCHAFTEN UND ROHSTOFFE (2021): Preismonitor. Rohstoff-Preismonitor.– Edited by DEUTSCHE ROHSTOFFAGENTUR (DERA) in der BGR. Available online at https://www.deutsche-rohstoffagentur.de/DERA/DE/Produkte/Rohstoffpreise/Preismonitor/preismonitor_node.html, (checked on 8/27/2021)

BURIĆ, P. & ŽIVALJEVIĆ, T. (1979): Ležišta boksita [*Bauxite deposits* – in Bosnian].– In: ČIČIĆ, S. (ed.): Mineralne sirovine Bosne i Hercegovine: Ležišta obojenih metala [*Mineral raw materials of Bosnia and Herzegovina: Non-ferrous metals* – in Bosnian]. Geoinženjering, Sarajevo, Vol 2/3, 123–214.

ČIČIĆ, S. (ed.) (1979): Mineralne sirovine Bosne i Hercegovine: Ležišta nemetala [*Mineral raw materials of Bosnia and Herzegovina: Non-metallic deposits* – in Bosnian].– Geoinženjering Sarajevo. 2 volumes.

ČIČIĆ, S. (ed.) (1979): Mineralne sirovine Bosne i Hercegovine: Ležišta obojenih metala [*Mineral raw materials of Bosnia and Herzegovina: Non-ferrous metals* – in Bosnian].– Geoinženjering Sarajevo. 2 volumes. Sarajevo.

CVIJIĆ, R. (2004): Geomenadžment u funkciji korišćenja i razvoja mineralnih resursa Ljubijske metalogenetske oblasti [*Geo-management as production and development tool of mineral raw materials in Ljubija metallogeny area* – in Bosnian].– Rudarski Institut, Prijedor, 348 p.

DANGIĆ, A. (1978): Model evolucije hidrotermalne aktivnosti u rudonosnom području Srebrenice [*Model of evolution of hydrothermal activity in the ore – bearing area of Srebrenica* – in Bosnian].– In: IX. Kongres Geologa Jugoslavije. Sarajevo, 565–571.

DANGIĆ, A. (1988): Kaolinization of Bauxite: A Study of the Vlasenica Bauxite Area, Yugoslavia. II. Alteration of Oolites.– Clays and Clay Minerals, 36/5, 439–447. doi: 10.1346/CCMN.1988.0360509

DANGIĆ, A. (2015): Mineralogy, Geochemistry and Epigenesis of Bauxites in Inner Dinarides.– Herald Geological, 361–30.

DIMITRIJEVIĆ, M.D. (1982): Dinarides: an Outline of the Tectonics.– Earth Evol. Sci., 2/1, 4–23.

DIMITRIJEVIĆ, M.D. (1997): Geology of Yugoslavia.– Geol. Survey GEMINI Special Publication, Belgrade, 187 p.

DRAGIČEVIĆ, I., PAPEŠT, J. & PAVIČIĆ, I. (2019): Geological settings of the Jajce bauxite bearing-area (Bosnia and Herzegovina).– Journal of Maps, 15/2, 744–750. doi: 10.1080/17445647.2019.1664652

EUROPEAN COMMISSION (2011): Tackling the challenges in commodity markets and on raw materials. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. 25.– European Commission, Brussels.

EUROPEAN COMMISSION (2017): On the 2017 list of Critical Raw Materials for the EU. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions. 490.– European Commission, Brussels.

EUROPEAN COMMISSION (2020): Study on the EU's list of Critical Raw Materials – Final Report.– Publications Office of the European Union, Luxembourg. doi: 10.2873/11619

GENTRY, D.W. & O'NEIL, T.J. (1984): Mine investment analysis.– Society of Mining Engineers of American Institute of Mining, Metallurgical, and Petroleum Engineers Inc, New York.

GRUBIĆ, A. (1975): Geology of Yugoslavian bauxite.– In: Serbian Academy of Sciences and Arts. special edition, Book CDLXXXIII. Belgrade, 60–65.

GRUBIĆ, A., CVIJIĆ, R., MILOŠEVIĆ, A. & ČELEIĆ, M. (2016): Interpreters of the metalogenetic map of the Ljubjian ore region Acelor Mittal Prijedor.– Fund of technical documentation Mining institute Prijedor and ArcelorMittal Prijedor, 91 p.

HAINDL, A. (2020): InvestRM – Investieren in Rohstoffe am Balkan.– Berg Huettenmaenn. Monatsh., 165/4, 211–215. doi: 10.1007/s00501-020-00959-2.

HODŽIĆ, N. & DJEDOVIĆ, M. (2014): Elaborat o klasifikaciji, kategorizaciji i proračunu rezervi magnezita ležišta "Konjuh" sa stanjem [Study on the classification, categorization and calculation of magnesite reserves of the "Konjuh" deposit – in Bosnian].– Fund of the technical documentation, Rudar d.o.o. Tuzla.

ILIĆ, M. & JELIĆ, M. (1979): Magneziti [*Magnesites*– in Bosnian– In: ČIČIĆ, S. (ed.): Mineralne sirovine Bosne i Hercegovine: Ležišta nemetala [*Mineral raw materials of Bosnia and Herzegovina: Non-metallic deposits* – in Bosnian]. Geoinženjering, Sarajevo, Vol. 1/2, 273–309.

INFOMINE USA, Inc. (2016): Mine and Milll Equipment Costs: An Estimator's Guide.– InfoMine USA, Inc. CostMine Division.

INVESTRM-TEAM (2020): Investment Opportunities in Raw Materials in Bosnia and Herzegovina. Results of the project Invest RawMaterials – Multifactor model for investments in the raw material sector, case study Bosnia and Herzegovina. With assistance of FIPA, EIT Raw Materials. Council of Ministers of Bosnia and Herzegovina - Foreign Investment Promotion Agency of BiH. -Available online at: http://www.fipa.gov.ba/publikacije_materijali/brosure/FIPA%20brochure%20 23.11.2020.pdf (checked on 9/29/2021)

JANISCH, A. (2014): Ressourcenverfügbarkeit, Bergtechnische Charakterisierung und Bergbauplanungskonzepte ausgewählter Vorkommen EU-kritischer Rohstoffe in Österreich. Masterarbeit. Lehrstuhl für Bergbaukunde, Bergtechnik und Bergwirtschaft. Montanuniversität Leoben, Leoben.

JAŠAREVIĆ, E., DŽINDO, M., ŠABOVIĆ, A. & TALETOVIĆ, N. (2013): Projekat detaljnih geoloških istraživanja ležišta olova, cinka i barita u istražnom polju, Rupice-Juraševac-Brestić [*Design on detailed geological explorations of lead, zinc and barite deposits in the ,'Rupice-Juraševac-Brestić" exploration field* – in Bosnian].– Institute, Tuzla.

JEJINA, T. & CVIJIĆ, R. (1977): Preliminary design of mine and iron ore separation Vidernjak, mine Ljubija: Book I, geological part.– Fund of technical documentation, RŽR Ljubija Prijedor.

JELIĆ, M. (1979): Florit [*Fluorite – in Bosnian*].– In ČIČIĆ, S. (ed.): Mineralne sirovine Bosne i Hercegovine: Ležišta nemetala [*Mineral raw materials of Bosnia and Herzegovina: Non-metallic deposits* – in Bosnian], Vol. 1/2. 2 volumes, 243–244.

JEREMIĆ, M. (1958): Baritno-fluoritno ležište Žune kod Ljubije [Barite-fluorite deposit Žune-Dolinac near Ljubija – in Serbian].– Rudarsko-metalurški zbornik, 4.

JOVANOVIĆ, R. (1979): Ležišta željezne rude Centralne Bosne i Hercegovine, Mineralne sirovine Bosne i Hercegovine [*Iron ore deposits of Central Bosnia and Herzegovina, Mineral raw materials of Bosnia and Herzegovina* – in Bosnian].– Geoengineering Sarajevo.

JURIĆ M. (1973): Sanski paleozoik - sinteza poznavanja rudnih pojava [*Sana region Palaeozoic- synthesis of knowledge about ore phenomena* – in Bosnian].– Book I, II, III.- Fund of professional documentation, ArcelorMittal, Prijedor.

JURKOVIĆ, I. (1961): Zavod za geološka istraživanja i ispitivanja građevinskog materiala i tla [*Institute for Geological Research and Testing of Construction Materials and Soils* – in Bosnian].– Gelogical Herald, 5, 199–241.

JURKOVIĆ, I., PALINKAŠ, L.A., GARAŠIĆ, V. & STRMIĆ PALINKAŠ, S. (2012): Genesis of Vein-Stockwork Cryptocrystalline Magensite from the Dinaride Ophiolites.– Ofioliti, 37/1, 13–26. doi: 10.4454/ofioliti.v37i1.403.

JURKOVIĆ, I., RAMOVIĆ, M. & ZEC, F. (1999): Chemical and Geochemical Characteristics of the Čemernica Antimonite Deposit in the Mid-Bosnian Schist Mountains.– In: Rudarsko-geološko-naftni zbornik, 11/1, 1–16.

KUBAT, I. (1982): Metalogenija i prognoza čvrstih mineralnih sirovina u trijasu Bosne i Hercegovine [*Metallogeny and prognoses of the mineral raw minerals in Triassic of the Bosnia and Herzegovina* – in Bosnian].– In: Spec. Publ. Geol. Glasnik, 11, Sarajevo, 1–149.

KUBAT, I. (1995): Metalogenija antimona i žive u BiH i mogućnost proizvodnje i prerade [*Metallogeny of antimony and mercury in BiH and the possibility of production and processing* – in Bosnian].– Zavod za geologiju, Sarajevo.

KUBAT, I. & ĐORĐEVIĆ, D. (1973): Mineralizacija kalaja u okviru ležišta olova i cinka "Srebrenica" u Istočnoj Bosni [*Tin mineralization within the "Srebrenica" lead and zinc deposits in Eastern Bosnia* – in Bosnian].– Gelogical Herald, 17, 325–336.

KURTANOVIĆ, R. (1990): Godišnji izvještaj o regionalnim geološkim istraživanjima kompleksnih Zn i $BaSO_4$ mineralizacija na lokalitetu Rupice kod Vareša za 1989 godinu [*Annual report on regional geological research of complex Zn and $BaSO_4$ mineralizations at the Rupica site near Vareš for 1989* – in Bosnian].– Fund of technical documentation, Federal geological survey, Sarajevo.

MARJORIBANKS, R.W. (1997): Geological methods in mineral exploration and mining.– Chapman & Hall, London.

Minerals4EU http://minerals4eu.brgm-rec.fr/minerals4EU/ (checked on 8/27/2021)

MITROVIĆ, D. (ed.) (2011): Mineralne sirovine Republike Srpske [*Mineral raw materials of the Republic of Srpska* – in Bosnian].– Ministry of Industry, Energy and Mining; Republic Geological Survey, Zvornik.

NEUKIRCHEN, F. & RIES, G. (2014): Die Welt der Rohstoffe. [*World of Raw Materials* – in German].– Springer Spektrum, Berlin [u.a.].

OPERTA, M. & BUŠATLIĆ, N. (2018): Contribution to the Knowlede of the Magnesite Deposits in Bosnia and Herzegovina.– Geografski pregled, 39, 107–122.

OPERTA, M. & HYSENI, S. (2016): Mineral raw materials Metallogenic Zone Borovica-Vares-Cevljanovici (BiH).– International journal of technology enhancements and emerging engineering research, 4/2, 16–20.

PALINKAŠ, L., BOROJEVIĆ ŠOŠTARIĆ, S., STRMIĆ PALINKAŠ, S., PROCHASKA, W., PÉCSKAY, Z., NEUBAUER, F. & SPANGENBERG, J.E. (2016): The Ljubija geothermal field: A herald of the Pangea break-up (NW Bosnia and Herzegovina).– Geologia Croatica, 69/1, 3–30. doi: 10.4154/GC.2016.02

PALINKAŠ, L. & JURKOVIĆ, I. (1994): Lanthanide Geochemistry and Fluid Inclusion Peculiarities of the Fluorite from the Barite Deposits South of Kreševo.– Geologia Croatica, 47/1, 103–115.

STRMIĆ PALINKAŠ, S., SPANGENBERG, J.E. & PALINKAŠ, L.A. (2009): Organic and inorganic geochemistry of Ljubija siderite deposits, NW Bosnia and Herzegovina.– Miner. Deposita, 44/8, 893–913. doi: 10.1007/s00126-009-0249-z

PAMIĆ, J. (1982): Some geological problems of the Dinaridic ophiolites and their associations.– Earth Evol. Sci., 2, 30–35.

PAMIĆ, J., GUŠIĆ, I. & JELASKA, V. (1998): Geodynamic evolution of the Central Dinarides.– Tectonophysics, 297, 251–268.

PAVIČIĆ, I., DRAGIČEVIĆ, I. & IVKIĆ, I. (2018): High-resolution 3D geological model of the bauxite-bearing area Crvene Stijene (Jajce, Bosnia and Herzegovina) and its application in ongoing research and mining.– Geological Quarterly, 62/1, doi: 10.7306/gq.1396

ProMine http://www.europe-geology.eu/promine/ (checked on 8/27/2021)

RAMOVIĆ, M. (1963): Rudne parageneze u oblasti Srebrenice (istočna Bosna) [*Ore paragenesis in the Srebrenica area (eastern Bosnia)* – in Bosnian].– Spec. Publ. Geol. Glasnik, 1, 1–96.

RAMOVIĆ, M., KUBAT, I., VELJKOVIĆ, D., KULENOVIĆ, E. & ĐURIĆ, S. (1979): Cink, olovo i srebro [*Zinc, Lead and Silver* – in Bosian].– In: ČIČIĆ, S. (ed.): Mineralne sirovine Bosne i Hercegovine: Ležišta obojenih metala [*Mineral raw materials of Bosnia and Herzegovina: Non-ferrous metals* – in Bosnian].– Geoinženjering, Sarajevo, Vol 2/3, 9–97.

REICHL, C. & SCHATZ, M. (2021): World Mining Data 2021. Iron and Ferro-Alloy Metals, Non-Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels. – Federal Ministry of Agriculture, Regions and Tourism, Republic of Austria, Vienna. Minerals Production, 36, checked on 5/25/2021.

RULEBOOK on classification, categorization, and calculation of solid mineral raw material reserves and keeping records on them (Official Gazette of the FBiH No. 36/12).

SCHMID, S.M., BERNOULLI, D., FÜGENSCHUH, B., MATENCO, L., SCHEFER, S. & SCHUSTER, R. (2008): The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units.– Swiss J. Geosci., 101/1, 139–183. doi: 10.1007/s00015-008-1247-3.

SUNARIĆ-PAMIĆ, O. & PAMIĆ, J. (1988): Žični magneziti ofiolitske zone Dinarida u Bosni i njihova geneza [*Magnesites from the Dinaride ophiolite zone in Bosnia and their genesis* – in Bosnian].– Spec. Publ. Geol. Glasnik, 22, 1–173.

TOMLJENOVIĆ, B., CSONTOS, L., MÁRTON, E. & MÁRTON, P. (2008): Tectonic evolution of the northwestern Internal Dinarides as constrained by structures and rotation of Medvednica Mountains, North Croatia.– Geological Society Special Publications, 298, 145–167.

TODOROVIĆ, M. (2016): Geološko petrološke i mineraloške karakteristike rudnog polja Srebrenica-Milići [*Geological-petrological and mineralogical characteristics of the Srebrenica-Milići ore field* – in Bosnian].– Fund of technical documentation, Boksit Milići d.o.o.

WAHL, S. VON (1990-1991): Bergwirtschaft. [*Mining Economics* – in German].– Verl. Glückauf, Essen.

WORLD TRADE ORGANIZATION (2021): World Integrated Trade Solution (WITS). Available online at https://wits.worldbank.org/Default.aspx?lang=en (checked on 8/27/2021)

ZARIĆ, P., JANKOVIĆ, S., RADOSAVLJEVIĆ, S. & ĐORĆEVIĆ, D. (2000): Tin Minerals and Tin Mineralization of the Pb-Zn-Sb-Ag Ore Deposits of the Srebrenica Orefield.– In: Proc. of the International Symposium Geology and Metallogeny of the Dinarides and the Vardar Zone, Vol. 1. Banja Luka, 425–434.

Appendix 1

Table 1. Selection criteria parameters – Geological criteria.

		RANK (defined by InvestRM consortium)		
Selection criteria 1 (according to Word Risk Report)	**Parameters (defined by InvestRM consortium)**	**A**	**B**	**C**
Geological criteria	Level of current geological knowledge - data quality	Excellent geological data with defined and up to date CRM reserves and deposit characteristics. Data are based on references that describe the specific deposit (Elaborates, Technical documentation, Reports, Scientific papers, Geological maps). Moreover, the benchmark for assessing this level is at least ¾ of essential characteristics delivered in the deposit template. Exploration and sampling data avaliable for individual deposit.	Good-sufficient geological data for CRM reserves estimation based on deposit characteristics. Data are based on references that describes the deposit's wider area (Publications, Scientific papers, Geological maps), with similar geological characteristics. The second benchmark for assessing this level is at least ½ of essential characteristics delivered in the deposit template. Only partial exploration and sampling data for targeted CRM avaliable (e.g.: Polimetal deposits with estimation of total reserves for several RM, targeted CRM not or poorly individually described. Bauxite and Magnesite deposts with reserves estimation and deposits characteristics based on Bauxite or Magnesite region data with some exploration and sampling data for the individual deposit avaliable.).	No or minimum geological data for individual deposit, based on regional scale geological data, CRM reserves not defined or poorly estimated. Data are based on references that describe the deposit's wider area on regional scale (Publications, Scientific papers, Geological maps). In this group less than ½ of essential characteristics are delivered in the deposit template. No data about exploration and sampling for individual deposit avaliable. Reserves are estimated only on basic regional data.
	Level of current geological knowledge - quantity[1]	Fluorit deposits: Level A or B data quality, poorly estimated mineral resources, expert judgement-short explanations based on area geological characteristics and historical data. Antimony deposits: Level A data quality, more than 10.000 t of reserves (A+B+C category) and expert judgement. Magnesite deposits: Level A data quality, more than 100.000 t of reserves (A+B+C category). Bauxite deposits: Level A data quality, more than 1.000.000 t of reserves (A+B+C1 category) or more than 500.000 t of A+B category reserves.	Fluorit deposits: Level A or B data quality, poorly estimated mineral resources or inaccessible documentation, expert judgement, historical data. Antimony deposits: Level A or B data quality, reserves are estimated only for all present raw materials in polymetallic deposit considering expert judgement. Magnesite deposits: Level A or B data quality, more than 10.000 t and less than 100.000 t of reserves (A+B+C category). Bauxite deposits: Level A or B data quality, more than 10.000 t and less than 1.000.000 of reserves (A+B+C) category.	Fluorit deposits: Any level of data quality, inaccessible documentation, expert judgement-short explanations based on area geological characteristics and historical data. Antimony deposits: Level C of data quality with inaccessible reserves documentation considering expert judgement. Magnesite deposits: Any level of data quality, less than 10.000 t of reserves of any category. Bauxite deposits: Any level of data quality, less than 10.000 t of reserves A+B category or inaccessible reserves data.

Table 2. Selection criteria parameters – Social licencing, Environmental management, Project permitting, Skills availability.

Selection criteria 2 (according to Word Risk Report)	**Parameters (defined by InvestRM consortium)**	**A**	**B**	**C**
Social licencing	Acceptance by Local community	Excellent, local community is aware of need for economical prosperity that industry brings along, local mines operate without conflict, supported by local community, location of the deposit is within poor rural area in the vicinity of urban area	Sufficient, local community is aware of need for economical prosperity that industry brings along, however several incidents have been recently reported from local mines operate, local community is partly supportive but worried from the aspects of health and safety	Insufficient or problematic based on current state of mining activities; local community does not accept industry due to focus on other area (agriculture, tourism), usually urban area. Local mines experience various problems related to social acceptance.
Environmental management	Legal requirements: Master plan, EIA, Environemental permit	Excellent - Enviromental permit issued	Good - EIA prepared	Insufficient - exploitation filed NOT included in the Master plan
Project permitting	Legal requirements: Preliminary investigation work, Mining project, Concession permit	Excellent - Concession permit issued	Good - mining project approved	Insufficient - no research approved and/or no reserves determined
Skills availability	Labour cost, skills, task force defined in a WP2 Social and Economics data	4 - 5 unique rank for B&H; in general 15% higher than average salaries		

Appendix 2. CRM Deposits in Bosnia and Herzegovina

Table 1. Antimony deposits in Bosnia and Herzegovina (data complied after references used in verification and evaluation phase: CVIJIĆ (2004); ČIČIĆ (1979); DANGIĆ (1978); GRUBIĆ et al., (2016); JAŠAREVIĆ et al., (2013); JURIĆ (1973); KUBAT et al. (1973); KUBAT (1995); MITROVIĆ (2011); PALINKAŠ et al., (2009; 2016); RAMOVIĆ (1963); TODOROVIĆ (2016).

	Area	Deposit	Key to Figure 1	Age	Shape	Mineral	Commodity	Sb (%)	Pb+Zn (%)	Reserves (t)	Resourses (t)	Reserves + Resourses	Data level	Quantity-perspec-tivity	Social licencing	Environmental management	Project permitting
										$(A+B+C_1)$	(C_2+D)	$(A+B+C_1+C_2+D)$					
Internal Dinarides	Central Bosnia Canton	Čemernica	1	Carboniferous, Permian	irregular, vein	Antimony-Stibnite	Sb-Zn-Hg-As-Ag	4.0		11,935		299,234	A	A+	B	B	B
		Totinovac-Viduša	2	Paleozoic			Sb-Zn-Hg-As						B	C	B	C	C
	Republic of Srpaska (Field Ljubija)	Field Ljubija	3	Paleozoic+Triassic	irregular, vein	Antimony-Stibnite	Pb-Zn-Sb-Hg			1,100,000	2,000,000	3,100,000	B	B			
		Podhrusanj	4	Paleozoic-Middle Triassic			Sb	1.1–3.2		74,651	115,000		A	A+	B	C	C
	Zenica-Doboj Canton	Field Rupice	5	Paleozoic-Middle Triassic	layer, vein	Antimony-Stibnite	Ba-Pb-Zn-Ag-Au-Sb-Hg			>10,000		3,000,000	A				
		Rupice	6	Middle Triassic	irregular, vein			4.8		>10,000			A	A+	A	A	A
		Rid	7		layer				7			1,000,000	A	B	A	B	B
		Veliki do	8		layer, vein				4.5–7			500,000	A	B	A	B	B
		Križ	9		layer, irregular				4.0–8			1,500,000	A	B	A	B	B
		Veovača	10		vein		Ba-Pb-Zn-Sb-Hg	0.1	2.3			6,000,000	A	A	A	A	A
	Republic of Srpska	Podkozara	11	Middle Triassic	irregular, vein	Antimony-Stibnite	Sb-Pb-Zn-As-Au-Hg						B	B	A	A	A
		Field Srebrenica	12	Oligocene	irregular, vein	Antimony-Stibnite	Pb-Zn-Sb-Ag-Au		23,000,000	A/B							
		Lisac	13						20,000,000	A/B	B	A	A	A			
		Vitlovac	14				Pb-Zn-Sb-Ag-Au-As		2,000,000	A/B	B	A	A	A			
		Čumavić	15						1,000,000	A/B	B	A	A	A			

Table 2. Bauxite deposits in Bosnia and Herzegovina (data complied after references used in verification and evaluation phase: BUDEŠ et al., (2018); ČIČIĆ (1979); DANGIĆ (1988); DANGIĆ (2015); GRUBIĆ, A., (1975); MITROVIĆ (2011); PAVIČIĆ et al., (2018)).

	Area	Deposit	Key to Figure 1	Enbeded between	Shape	Mineral	Chemical composition				Reserves	Resourses	Data level	Quantity-perspectivity	Social licencing	Environmental management	Project permitting
							Al_2O_3 (%)	SiO_2 (%)	Fe_2O_3 (%)	TiO_2 (%)	$A+B+C_1$	C_2					
External Dinaride bauxites	South Bosnia region (Hercegovina)																
	Herzegovina-Neretva Canton (Čitluk region)	Blatnica-Lokvice	1	Upper Cretaceous-Paleogene	lensoidal, layer	Boehmite	53.4	5.4			1,070,958		A	A+	B	C	C
		Krehin gradac-Blizanci	2				49.2	6.0			159,653		A	B	B	C	C
		Mamići-Rasno-Hamzići	3				50.2	9.7			4,765		A	C	B	C	C
		Ošljari-Krivodol	4				46.3	11.3			94,630		A	B	B	C	C
		Služanj	5								no data		C	C	B	C	C
		Vitina-Lipno	6	Upper Cretaceous	lensoidal		41.7	18.3			427,275		A	B	B	C	C
	West Herzegovina Canton (Lištica region)	Crne lokve-Kidačke njive	7	Upper Cretaceous-Paleogene	lensoidal, layer	Boehmite	51.0	5.3			1,545,322		A	A+	B	C	C
		Resnica-Grabova draga	8				55.5	8.1			25,180		A	B	B	C	C
		Uzarici-Knežpolje	9				56.3	3.8			157,020		A	B	B	C	C
		Varda planina	10				54.4	3.4			816,301		A	A	B	C	C
		Trn-Sliškovića lokve	11	Upper Cretaceous-Neogene			30-45	14-33			197,000		A	B	B	C	C
	Herzegovina-Neretva Canton (Mostar region)	Žovnica	12	Upper Cretaceous	lensoidal, layer	Boehmite	41.7	18.1			no data		C	C	B	C	C
		Jasenjani	13	Upper Cretaceous-Eocene		Gibbsite, Boehmite	46.5	4.2			35,700		A	B	B	C	C
	West Herzegovina Canton (Posušje region)	Krstače-Cerovi doci	14	Upper Cretaceous-Paleogene	lensoidal, layer	Boehmite	55.6	3.7			1,459,507		A	A+	B	C	C
		Mratnjača-Medine stanine	15				56.5	3.5			1,648,427		A	A+	B	C	C
		Podzavelin-Vinica	16				51.4	7.5			23,150		A	B	B	C	C
		Studena Vrila	17								111,130		A	A+	A	B	B
		Trebistovo-Sobač	18				52.0	5.7			901,880		A	A	B	C	C
		Vinjani	19				52.0	5.7			558,679		A	A	B	C	C
		Volujak-Kadim	20				43.0	13.1			487,260		A	A	B	C	C
		Vučipolje	21				53.8	1.7			252,740		A	B	B	C	C
		Field Studena Vrila-Zagorje	22				50.2	6.5			111,130		A	A+	A	B	B
	Herzegovina-Neretva Canton (Stolac region)	Bivolje brdo-Domanovići	23	Upper Cretaceous-Paleogene	lensoidal, layer	Boehmite	45.1	13.7			62,600		A	B	B	C	C
		Dabrica	24				47.7	13.1			1,065,695		A	A+	B	C	C
		Gornji Brštanik	25				47.6	10.9			286,443		A	B	B	C	C
		Hrgud	26				39–45	6–37			20,000		A	B	B	C	C
		Poplat	27				49.4	0.1			25,420		A	B	B	C	C
		Hodovo	28	Upper Cretaceous-Eocene			50.1	2.2				42,500	A	B	B	C	C
	Republic of Srpska	Udrežnje	29	Upper Cretaceous-Eocene	lensoidal, layer	Gibbsite, Boehmite	47.7	13.3			421,000		A	B	A	A	A
		Viduša	30	Upper Jurassic	saddle-shaped		44–62	2–10	11-19		165,062		A	B	A	A	A
	Northwestern Bosnia region (Bosanska Krajina)																
	Una-Sana Canton	Bjelaj	31	Middle Triassic	lensoidal, layer	Gibbsite, Boehmite	29.4–57.2	7.5–40.2	7.3–15.5	2.6–3.0	60,000		A	B	B	C	C
		Veliki Skočaj	32				45.3–69.2	7.6–24.0	2.3–19.5	0.4–2.9	no data		B	C	B	C	C
		Krnjeuša-Bravski vrh-Crni vrh	33	Upper Jurassic	irregular lenses, irregular nests	Boehmite	57.75–68.8	2.9–7.7	9.9–11.6	2.8–3.2		10,500,000	A	A+	B	C	A
		Pritoka -Tihotina-Trovrh	34	Upper Cretaceous	lensoidal, layer		62–74.5	1–5	6.9–15.8	3.0		10,000,000	A	A+	B	C	C
		Suvaja-Šolaja	35			Gibbsite, Boehmite	55–60	0–5			275,000	1,499,100	A	B	B	C	C
	Central Bosnia region (Jajce)																

Table 2. Continued.

Internal Dinaride bauxite	Central Bosnia Canton	Bešpelj-Crvene stijene	36	Upper - Lower Cretaceous	saddle-shaped	Boehmite	55.0–60.0	1.0–4.0	<21.0	3.0	116,375	305,000	A	A	A	A	A
		Poljana	37	Upper - Lower Cretaceous	irregular and lensoidal		53.0–62.0	0.5–4.0	<21.0–30.0	2–3	300,000		A	A	A	A	A
	East Bosnia region (Vlasenica-Srebrenica) (38-49)																
	Republic of Srpska	Palež	38	Middle Triassic	tabular	Boehmite	42.0–55.0	1.0–20.0	17.0–30.0	2.0–3.5	no data		B	C	A	A	A
		Štedra	39		irregular		41–55	5–20	20–34		no data		B	C	A	C	A
		Žedanjsko	40	Middle Triassic- Upper Cretaceous	irregular		34–53	2–37				60,000	B	B	A	C	A
		Kutuzero	41				44–56	2–12			no data		C	C	A	C	A
		Pribojevići	42				37.8–64.6					250,000	B	B	A	C	A
		Crvene stijene-Vlasenica	43				50.0	28.0	8.0		4,827,809		A	A+	A	A	A
		Dragošnica	44				52.1	7.0	26.0		122,680		B	B	A	C	A
		Gerovi	45							n.a.	no data		C	C	A	C	A
		Kosturi	46				53.1	6.3	26.3	2.6	5,813,644		A	A+	A	A	A
		Podbraćan	47		tabular/ lensoidal					n.a.	2,300,000	500,000	A	A+	A	A	A
		Šumarnica	48	Middle Triassic - Neogene	tabular/ lensoidal		50.9	6.3	29.0	2.8	5,000,000		A	A+	A	A	A
		Palež II-Braćan	49	Lower Cretaceous-Neo-gene	lenses		51.8	10.3	20-34		415,330		A	A+	A	A	A

Table 3. Fluorite deposits in Bosnia and Herzegovina (data complied after references used in verification and evaluation phase: CVIJIĆ (2004); ČIČIĆ (1979); GRUBIĆ et al., (2016); JEJINA et al., (1977); JURIĆ (1973); JURKOVIĆ (1961); KUBAT (1995); MITROVIĆ (2011); PALINKAŠ et al., (2009; 2016)). Itallic stands for C_1+C_2 resourses.

	Area	Deposit	Key to Figure 1	Age	Shape	Mineral	Chemical composition				Reserves	Resourses	Data level	Quantity-perspectivity	Social licencing	Environmental management	Project permit-ting
							MgO(%)	SiO_2 (%)	CaO(%)	R_2O_3(%)	A+B+C_1	C_2 or C_1+C_2					
Internal Dinarides	Tuzla Canton (Field Kladanj)	Magnesite Field Kladanj	1	Paleocene	Irregular, vein-type	Magnesite					200,784	59,800	A				
		Miljevica	2					193,484 A			A+	A	A	A			
		Zeničica	3	Paleocene			19.8–47.8	0.4–3.56	0.3–2.4		7,300	55,000	A	B	A	B	B
		Drinjača	4				19.8–47.8	1.81–4.01	1.3–5.3			4,800	A	C	A	B	B
	Zenica-Doboj Canton (Field Moševac)	Magnesite Field Moševac	5	Paleocene	Irregular, vein-type	Magnesite	28.5–45.1	0.4–36.9	0.4–11.6	0.6–3.3		464,900	A/B				
		Borik	6					12.5				194,000	B	A	B	C	C
		Moševac	7					3.11–27.0			116,000 2,900 43,000 45,000 24,000 10,000 10,000 20,000	B	A	B	C	C	
		Paklenica	8					36.9				B	C	B	C	C	
		Šahmanska Bašća	9					10.1				B	B	B	C	C	
		Divan 1	10					13.2				B	B	B	C	C	
		Divan 2	11									B	B	B	C	C	
		Daska	12					0.4				B	B/C	B	C	C	
		Beša Potok	13					0.8				B	B/C	B	C	C	
		Drum	14									B	B	B	C	C	
	Zenica-Doboj Canton (Field Novi Šeher)	Magnesite Field Novi Šeher	15	Paleocene-Eocene	Irregular, vein-type	Magnesite					150,000	105,000	A				
		Ošve	16	Eocene			40.5	2.5	3.8		150,000	65,000	A	A+	B	C	C
		Bijeli Klanci	17				34.5	0.4				10,000	A	B	B	C	C
		Samar	18				36.4–45.4	0.2–13.5	0.2–9.4	0.1–11.1		6,500	A	C	B	C	C
		Veliki Križ	19				36.6	2.4			3,000 500	20,000	A	B	B	C	C
		Sač	20				30.4	2.2				A	C	B	C	C	
		Muratovac	21				45.6	1.9				A	C	B	C	C	
	Zenica-Doboj Canton (Field Žepče)	Magnesite Field Žepče	22	Paleocene	Irregular, vein-type	Magnesite	21.2–45.0	0.3–23.6	0.7–25.6	0.5–6.4		282,000	A				
		Loznikovac	23				32.99	10.3				76,000	A	B	B	C	C
		Selište	24	Eocene			34.1	5.3			87,000 119,000	A	B	B	C	C	
		Čubrino brdo	25				41.9	1.6–19.7				A	A	B	C	C	
	Zenica-Doboj Canton (Field Bajvat)	Magnesite Field Bajvat	26		Irregular, vein-type	Magnesite	29.0–51.7	0.1–21.7	1.3–40.2	0.7–7.7		256,500	A/B				
		Polića njive	27					1.3–13.9				191,000	B	A	B	C	C
		Velike ravni	28					0.1–9.5			43,500 22,000	B	B	B	C	C	
		Krčevina	29					0.2–21.7				B	B	B	C	C	
	Zenica-Doboj Canton (Field Dištica)	Magnesite region Dištica	30	Paleocene	Irregular, vein-type	Magnesite	39.5–46.2	0.9–6.9	1.6–4.6	0.7–1.6		32,000	B				
		Maoča	31									7,000	B	C	B	C	C
		Dištica	32					7.0				25,000	B	B	B	C	C
	Zenica-Doboj Canton (Field Olovo)	Magnesite Field Olovo	33	Paleocene	Irregular, vein-type	Magnesite	45.1–46.5	0.1–0.8	1.1–3.0	0.4–0.7		8,500	B				
		Donje Lanište	34					0.5				6,000	B	C	B	C	C
		Mladoševac	35									500	B	C	B	C	C
		Tovarnica	36									1,000	B	C	B	C	C
		Berina	37									1,000	B	C	B	C	C

Table 3. Continued.

Republic of Srpska (Field Banja Luka-Snjegotina)	Magnesite Field Banja Luka-Snjegotina	38	Jurassic	Irregular, vein-type	Magnesite					1,231,900	A				
	Jelovac	39				41.3–45.0	1.2–4.1	1.5–4.6		419,992	A	A+	A	C	C
	Mednjak	40								113,100	A	A	A		C
	Pločni	41				44.5–45.0	3.0–4.3	1.3–1.7		437,757	A	A+	A	C	C
	Snjegotina	42								42,050	A	B	A	C	C
	Četnja	43								164,937	A	A	A	C	C
	Stanikova 2	44								39,584	A	B	A	C	C
	Čađavica 2	45								14,500	A	B	A	C	C
Republic of Srpska (Field Banja Luka-Vrbanja)	Magnesite Field Banja Luka-Vrbanja	46	Jurassic	Irregular, vein-type	Magnesite				9,497	14,500	A				
	Jazavići 1	47				44.3	1.4	1.0	9,497		A	C	A	C	C
	Repište	48				45.7	1.3	1.3		14,500	A	B	A	C	C
Republic of Srpska (Field Prnjavor)	Magnesite Field Prnjavor	49	Jurassic	Irregular, vein-type	Magnesite					176,926	A				
	Raulića potok	50				45.1	1.6	1.0		39,926	A	B	A	C	C
	Sigovac	51				45.4	1.8	2.3		7,000	A	C	A	C	C
	Tanasića potok	52				45.9	1.4	1.7		10,000	A	C	A	C	C
	Brezna	53				40.1	3.7	3.3		43,000	A	B	A	C	C
	Stražbenica	54					4.4	4.2		35,000	A	B	A	C	C
	Ravno brdo	55				46.1	1.4	1.1		12,000	A	B	A	C	C
	Domaćevac	56				46.1	0.4	1.2		20,000	A	B	A	C	C
	Dugovac	57				46.4	0.3	1.2		10,000	A	C	A	C	C
	Mala Ukrina	58				18.3–33.8	6.0–27.4	0.4–26.4			C	C	A	C	C
Republic of Srpska (Field Teslić)	Magnesite Field Teslić	59	Jurassic	Irregular, vein-type	Magnesite					881,000	A				
	Blatnica	60				32.7	5.8	7.1		261,475	A	A+	A	C	C
	Bukovički jarak	61				40.8	5.6	3.7		119,990	A	A	A	C	C
	Milošev jarak	62				41.0	8.6	1.5		377,456	A	A+	A	C	C
	Proleterov do	63				42.6	2.1	3.3		69,065	A	B	A	C	C
	Skok	64				29.7	5.5	14.1		25,000	A	B	A	C	C
	Vranilovići	65				41.6	3.8	2.2		9,000	A	C	A	C	C
	Maksimova kosa	66				27.3	18.5	10.0		10,000	A	B	A	C	C
	Paradnjak	67				42.5	5.0	1.6			C	C	A	C	C
	Goveđa luka	68					29.2	1.0		10,000	A	B	A	C	C

Table 4. Magnesite deposits in Bosnia and Herzegovina (data complied after references used in verification and evaluation phase: ČIČIĆ (1979); HODŽIĆ et al., (2014); OPERTA et al., (2018); MITROVIĆ (2011); SUNARIĆ-PAMIĆ et al. (1988)).

	Area	Deposit	Key to Figure 1	Age	Shape	Mineral	Commodity	Flourspar (%)	Reserves ($A+B+C_1$)		Reserves + Resourses ($A+B+C_1+C_2+D$)	Quantity-per-spectivity	Data level	Social licencing	Environmental management	Project permitting
									Flourspar (t)	All RM (t)						
Internal Dinarides	Centra Bosnia Canton	Meovršje	1	Paleozoic-Triassic	vein, irregular	Fluorspar	Ba-F					A/B	A/B	B	C	C
		Hrmza	2				As-Sb-Hg-Ba-F					A/B	A/B	B	C	C
		Pećine	3	Triassic			Fe-Mn-F				514,000	B	B	B	C	C
	Republic of Srpska	Žune-Ljubija	4	Paleozoic-Triassic	vein, irregular	Fluorspar	Ba-F	20	1,500	1,100,000	3,100,000	A+	A	B	C	C
		Vidrenjak-Ljubija	5							1,100,000	2,100,000	B	B	B	C	C