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Economic Geology of the Eastern and South-eastern European (ESEE) Region

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Abstract: Europe's metal supply is dependent on imports to a very large extent. More than 20% of the European production of Cr, Ni, W, bauxite, Pb, and Au is mined from the ESEE region, and some of the critical elements as defined by the EU Commission are known to occur in elevated concentrations in the Variscan metallogenic province and in the Alpine-Balkan-Carpathian-Dinaride region. The geology of the ESEE region is very complex. It is an amalgamation of various terranes that collided during distinct phases in Earth history, producing orogenic belts and mountain chains through a long period of time. Each terrane is characterized by a distinct metallogenic history. Especially in Bulgaria, Slovakia, Serbia, Bosnia and Herzegovina, and Romania, mining of base and precious metals from collision-related metallogenic provinces is well advanced and metallurgical plants are in operation providing significant raw materials to the European industry. Macedonia is a major producer of Zn, Pb, and Ag. Greece, Bosnia-Herzegovina, Hungary, and Montenegro produce more than 30% of the European bauxite. A significant potential for Pb-Zn and associated critical metals exist in Triassic carbonate platforms, such as in Austria, Slovenia, Serbia, and Kosovo. During collision, granitic magmatism produced rare-element pegmatites that carry Li, Be, Nb, Ta, Sn, Cs, REE, and other valuable by-products. Greece, Kosovo, and Albania have a potential for Ni and Cr ores with some associated PGE in ophiolite sequences representing old oceanic mantle and crustal sequences. Greece, Czech Republic, Slovakia, Austria and Bulgaria are important producers of industrial minerals such as bentonite, perlite, magnesite, kaolin, fluorspar, and salt.

Keywords: Economic geology, Metal raw materials, Industrial minerals, Alpine-Balkan-Carpathian-Dinaride region, Variscan metallogenic province

Rohstoffgeologie von Ost- und Südost-Europa (ESEE Region)

Zusammenfassung: Der Bedarf an metallischen Rohstoffen wird in Europa großteils durch Importe gedeckt. Mehr als 20 % der europäischen Eigenproduktion von Cr, Ni, W, Bauxit, Pb und Au stammen jedoch aus der „ESEE"-Region (Ost- und Südost-Europa). Zudem sind die variszische metallogenetische Provinz und die Alpen-Balkan-Karpaten-Dinariden-Region für einige der von der EU Kommission als kritisch bewerteten Rohstoffe interessant. Die Geologie der ESEE Region ist komplex: im Laufe der Erdgeschichte bildeten sich zahlreiche orogene Gürtel und Gebirgsketten durch die Kollision verschiedener geologischer Platten und Terranes. Jede dieser Einheiten zeigt eine eigene metallogenetische Geschichte. In Bulgarien, Serbien, Bosnien-Herzegowina, Rumänien und der Slowakei spielt der Bergbau auf Bunt- und Edelmetalle nach wie vor eine große Rolle. Metallurgische Industrien versorgen die europäische Industrie mit notwendigen Rohstoffen. Viele dieser Lagerstätten sind in einem kompressiven tektonischen Umfeld während einer Subduktionsphase entstanden. Mazedonien ist ein wichtiger Produzent von Zn, Pb und Ag. Griechenland, Bosnien-Herzegowina, Ungarn und Montenegro liefern mehr als 30 % der europäischen Bauxitproduktion. Bedeutende Potenziale für Pb-Zn und assoziierte kritische Metalle sind aus den triassischen Karbonatplattformen in Österreich, Slowenien, Serbien und dem Kosovo bekannt. Im Zuge von Kontinent-Kontinent-Kollisionen entstanden Selten-Element-Pegmatite und assoziierte granitische Gesteine, die mit Li, Be, Nb, Ta, Sn, Cs, Seltenen Erdelementen und anderen wertvollen Nebenprodukten assoziiert sein können. Die ehemaligen ozeanischen Erdmantelgesteine in den Ophiolithabfolgen Griechenlands, des Kosovo und Albaniens haben Potential für Ni und Cr-Erze, teilweise verbunden mit Platingruppenmetallen. Griechenland, die

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Tschechische Republik, Slowakei, Österreich und Bulgarien sind bedeutende Bergbauproduzenten von Industrieminералen wie Bentonit, Perlit, Magnesit, Kaolin, Flussspat und Steinsalz.

Schlüsselwörter: Rohstoffgeologie, Metallische Rohstoffe, Industrieminerale, Alpen-Balkan-Karpaten-Dinariden Region, Variszische metallogenetische Provinz

1. Introduction

Europe's metal supply is dependent on imports to a very large extent. In 2015, members of the European Union provided about five percent of the world mining production of copper (4.5%), zinc (5.4%), and lead (3.8%), whereas very little critical raw materials have been produced (tungsten, 2.7%; palladium, 0.4%; platinum, 0.6%; cobalt, 1.5%; germanium, 16.3%) [1]. Some of these elements are recovered from imported residues, e. g. germanium from metallurgical residues and, until 2014, gallium from red mud residues from Bayer-type bauxite leaching, and thus are not from domestic mine production.

More than 20% of the European production (including the European part of Russia) of chromium, nickel, tungsten, bauxite, lead, and gold is mined in the ESEE region ("Eastern and South-eastern Europe"). This region is defined here as the states that have emerged from former Yugoslavia and Czechoslovakia and some of their neighbours, including Austria, Hungary, Romania, Bulgaria, Greece and Albania. The ESEE region comprises about 10% of the size of Europe and is host to about 100 million people (13% of the European population). Significant mine production is recorded for iron, manganese, bauxite, chromium, nickel, tungsten, copper, zinc, lead, silver and gold. Compared to the world production, however, it is only chromium, nickel, aluminum, cadmium, lead, and tungsten that exceed the 1% level.

2. Raw Material Production in the ESEE Region

The ESEE region was and still is a major producer of metal ores, industrial minerals, and energy raw materials in Europe. However, the situation has changed dramatically from the 1980ies until today. This section summarizes production statistics of important commodities from 1984 until 2015. The dataset is based on the World Mining Data collected and published by the Austrian Federal Ministry of Science, Research and Economy in Vienna [1].

2.1 Iron and Steel Alloys

Iron ore production has dropped from about 5 Mt (million metric tons) Fe content in 1984, mined in seven countries, to 2.0 Mt in 2015 (Fig. 1), with Bosnia-Herzegovina and Austria as the only remaining producers in the region. This constitutes only 1.8% of the European iron ore production and just 0.13% of the world production. Manganese production in the ESEE region is close to 36,000 tons Mn content, mainly from Hungary, Bulgaria, and Bosnia-Herzegovina. Chromium dropped from >400,000 tons in 1986 to almost nil in the 1990s but recovered to 185,000 tons Cr_2O_3 content in 2015, mainly from Albania. In contrast, current nickel production is higher than in the 1980s, peaking at annually >50,000 tons Ni content from 2010 to 2013, delivered by Greece, Macedonia, Kosovo, and Albania. The Macedonian nickel ore production shut down in 2014 as the company bought a nickel deposit in Guatemala and ore now is shipped to the Macedonian refinery site. There is no cobalt, molybdenum, niobium, tantalum, titanium, and vanadium production in the ESEE region, and tungsten is solely produced in Austria but with annually 700–1000 tons W content.

2.2 Base Metals

Next to the European part of Russia, the ESEE region is the most important supplier of bauxite in Europe (31% of the

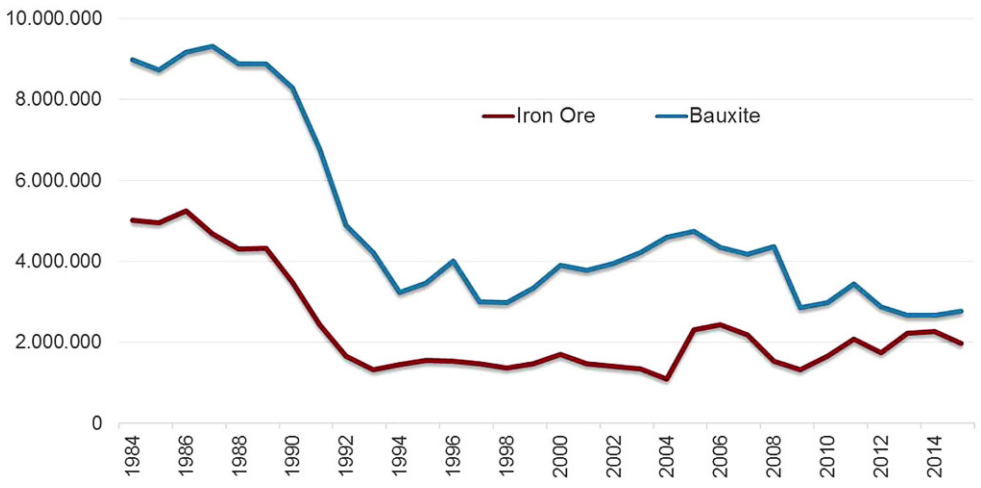

Fig. 1: Historic production (1984–2015) of iron ore (Fe content) and bauxite in the ESEE region (in metric tons)

European production), producing 2.8 Mt from 5 countries, which is down from 9.3 Mt in 1987 (Fig. 1). Today, the largest producer of bauxite is Greece (1.83 Mt), followed by Bosnia and Herzegovina. Copper production peaked in 1986 with 241,000 tons, and has been reduced to 163,000 tons in 2015; Bulgaria is the major producer followed by Serbia. Likewise, zinc and lead production has decreased over the years, totalling to 82,500 tons Pb and almost 90,000 tons Zn in 2015, which represents 31 and 37% of the maximum production numbers in 1985, respectively. The major producers are Macedonia, Greece, and Bulgaria. In refineries, some cadmium, gallium, and selenium are produced.

2.3 Precious Metals

Gold production in the ESEE region totalled to 11.8 tons in 2015, which is 77% of the maximum production recorded in 1990 and 25% of the European gold production including the European part of Russia. Bulgaria accounts for 67%, followed by Greece and Serbia. Silver, on the other hand, has decreased from a maximum of 370 tons in 1986 to 95 tons in 2015. Some platinum and palladium production is recorded from Serbia as by-product of copper refining at RTB Bor.

2.4 Industrial Minerals

Industrial minerals are mined in many ESEE countries. Very prominent are the production numbers for bentonite (10% of the world and 55% of the European production), fluorspar (2 and 30%, respectively), kaolin (11 and 33%), magnesite (7.5 and 53%), and perlite (38 and 95%). On a global scale, production of barite, feldspar, graphite, gypsum, salt, sulphur, and talc is less important. Bentonite is mined in nine ESEE countries with Greece dominating, followed by the Czech Republic, Slovakia, and Bulgaria. The Czech Republic is the largest producer of diatomite and kaolin in the region. Bulgaria accounts for the largest production of fluorspar and salt, whereas Romania takes the lead with gypsum, but also produces significant salt. Austria is the main producer of talc and a significant producer of magnesite, gypsum, and salt. Currently, the largest production of magnesite is recorded from Slovakia, which is also the only producer of barite in the ESEE region. The development of production numbers shows increasing trends for salt and quite stable situations for gypsum, magnesite, and kaolin within the past 10 years (Fig. 2).

2.5 Critical Metals

The Ad hoc Working Group on defining critical raw materials has, in its report from May 2014, identified 20 raw materials as critical [2]. Among them, only seven are currently mined in the ESEE region. These are, in decreasing order of their share on the world market, magnesite (7.4%), fluorite (2.1%), and tungsten (1.0%), followed by small volumes of coking coal, graphite, platinum, and palladium. In the past, the ESEE region did produce some of the remaining critical raw materials but stopped in the 1990s. Therefore, a proven potential exists for the following materials: cobalt (Albania, production stopped in 1992), antimony (Slovakia and several other countries, last production recorded from Romania, Czechoslovakia and Yugoslavia in 1992), germanium (Austrian production until 1990), gallium (past production in Hungary), and phosphates (last production from Albania in 1992). No production has been recorded for beryllium, borates, indium, magnesium, niobium, and the REE in the ESEE region from 1984 to 2015.

2.6 Development of Mineral Production in Selected Countries

The political changes affecting the ESEE region from the 1990s until the early 2000s did have an enormous impact on mineral production. The transformation of former Czechoslovakia into the Czech Republic and Slovakia illustrates a comparably smooth transition: Czechoslovakia produced between 5 and 8 Mt raw materials (only metals and industrial minerals), a similar number as the sum produced by the follower states. Major positive outliers are caused by a four-fold increase of kaolin production in 1990

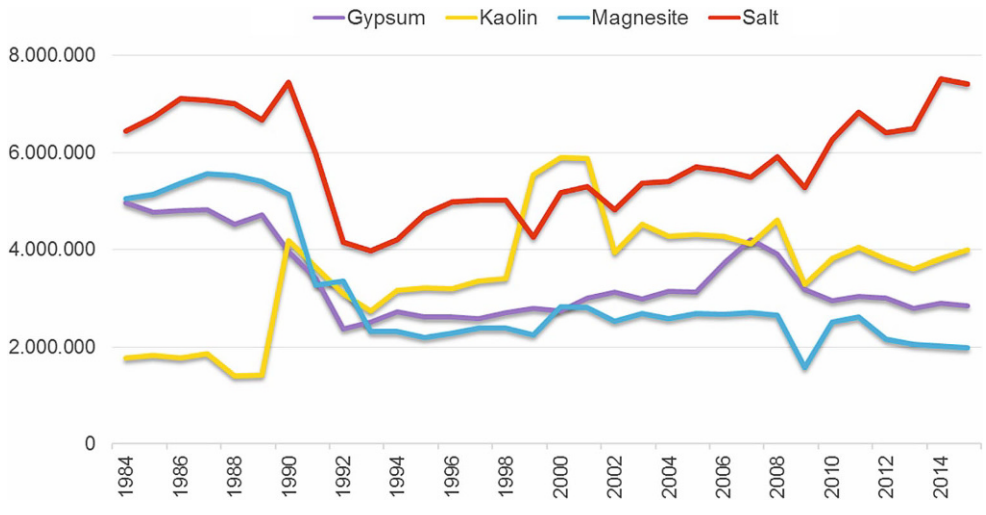

Fig. 2: Historic production (1984–2015) of selected industrial minerals in the ESEE region (in metr. tons)

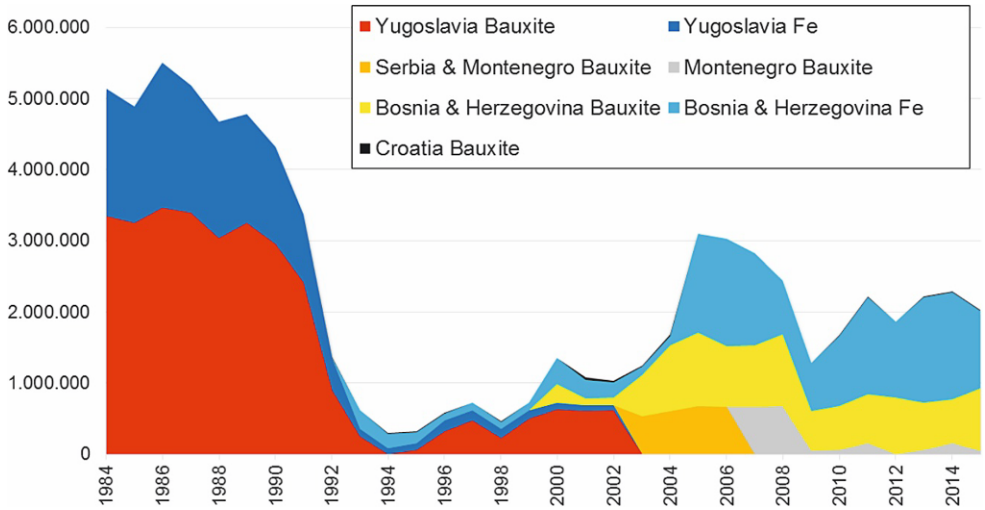

Fig. 3: Changes in iron ore and bauxite production in countries of former Yugoslavia (in metr. tons)

and by a doubling of kaolin production in the Czech Republic from 1999 to 2001. On the contrary, mineral production in former Yugoslavia decreased from a high of nearly 9 Mt in 1986 to just 1.1 Mt in 1994. Yugoslavia mined a total of 28 different commodities, most importantly bauxite (up to 3.5 Mt) and iron ore (up to 2 Mt Fe content). Among the subsequently formed states, it is only Bosnia and Herzegovina that has developed a significant quantity of mineral production, thanks to a revival of iron ore mining starting in 2005 and bauxite mining in 2003 (Fig. 3).

3. Metallogeny of the ESEE Region

The ESEE region is divided into the Alpine-Balkan-Carpathian-Dinaride region (ABCD) and the smaller area of the Variscan belt north of the Alps and the Carpathians, mainly exposed in the Czech Republic. The geology of the ESEE region is very complex. It is an amalgamation of various terranes (areas that share a common geological history through some time in the past) that collided during distinct phases in Earth history, producing orogenic belts and mountain chains through a long period of time, e. g. from the Precambrian to the Cenozoic (from 550 million years ago to today). Each terrane is characterized by a distinct metallogenic history, and a collision of two or more terranes produces an additional metallogenic province, thus resulting in a multitude of metallogenic signatures.

It is beyond the scope of this contribution to present a synopsis on the metallogeny of the ESEE region. Several publications cover parts of the area (e. g. [3–8]), and a summary following the metallogenic provinces used in [3] is given here.

Most of the ESEE region is underlain by rocks of the ABCD Chain (Fig. 4), a mountain belt that formed during the Alpine orogeny starting in the Cretaceous and resulting from the collision of the European plate with various terranes and microplates at the northern margin of Africa. The system is characterised by inherited metallogenic structures (mainly from the Variscan metallogenic event) in the Internal zones (Eastern Alps, Carpathians), by metamorphogenic deposits (mineral deposits that formed during metamorphism and deformation, e. g. talc), and by ore deposits related to magmatic activity during the Cretaceous (Banat, Panagyurishte) and Paleogene (Carpathians, Rhodopes) subduction processes.

Obducted ophiolitic melange zones represent suture zones in which former oceans have disappeared; these zones form ophiolite belts with chromite, magnesite, and Cyprus-type massive sulfide deposits. Carbonate-hosted Pb-Zn-Ba deposits are developed in the Triassic shelf carbonates affected by extensional tectonics. During the subduction stage, acid to intermediate magmatic rocks intruded in the Carpathians, forming world-class porphyry deposits (Cu, Au, Mo, Bi) associated with Au-rich epithermal veins systems (Banatite belt). Later, andesitic-rhyolitic volcanism of Paleogene age was accompanied by Au and base metal ores in the Carpathians, Inner Dinarides, and Rhodopes. Magmatism continues until today (Santorin, Milos) with formation of sulfide ores, barite, bentonite, and perlite ores.

3.1 Eastern Alpine Metallogenic Province

The Eastern Alpine metallogenic province (Fig. 4) comprises a complex system of tectonic nappes including basement and post-Variscan cover rocks, exposed in Austria and northernmost Slovenia. Economically important mineral deposits occur in the pre-Variscan basement of the Penninic Tauern Window (tungsten deposit Felbertal, Salzburg), in the Paleozoic Greywacke zone (siderite deposit Erzberg, Styria, and abundant magnesite and talc deposits in Styria and Tyrol) and in the Permotriassic cover sequences (salt and anhydrite deposits within the "Haselgebirge" of Tyrol, Salzburg, and Styria). Historically, gold mining from Alpine-age vein systems in the Hohe Tauern area, sediment- and carbonate-hosted Pb-Zn deposits (e. g. Bleiberg-type), stratiform and vein-type Cu deposits (e. g. Mitterberg, Salzburg) as well as vein-type Sb deposits were of economic importance.

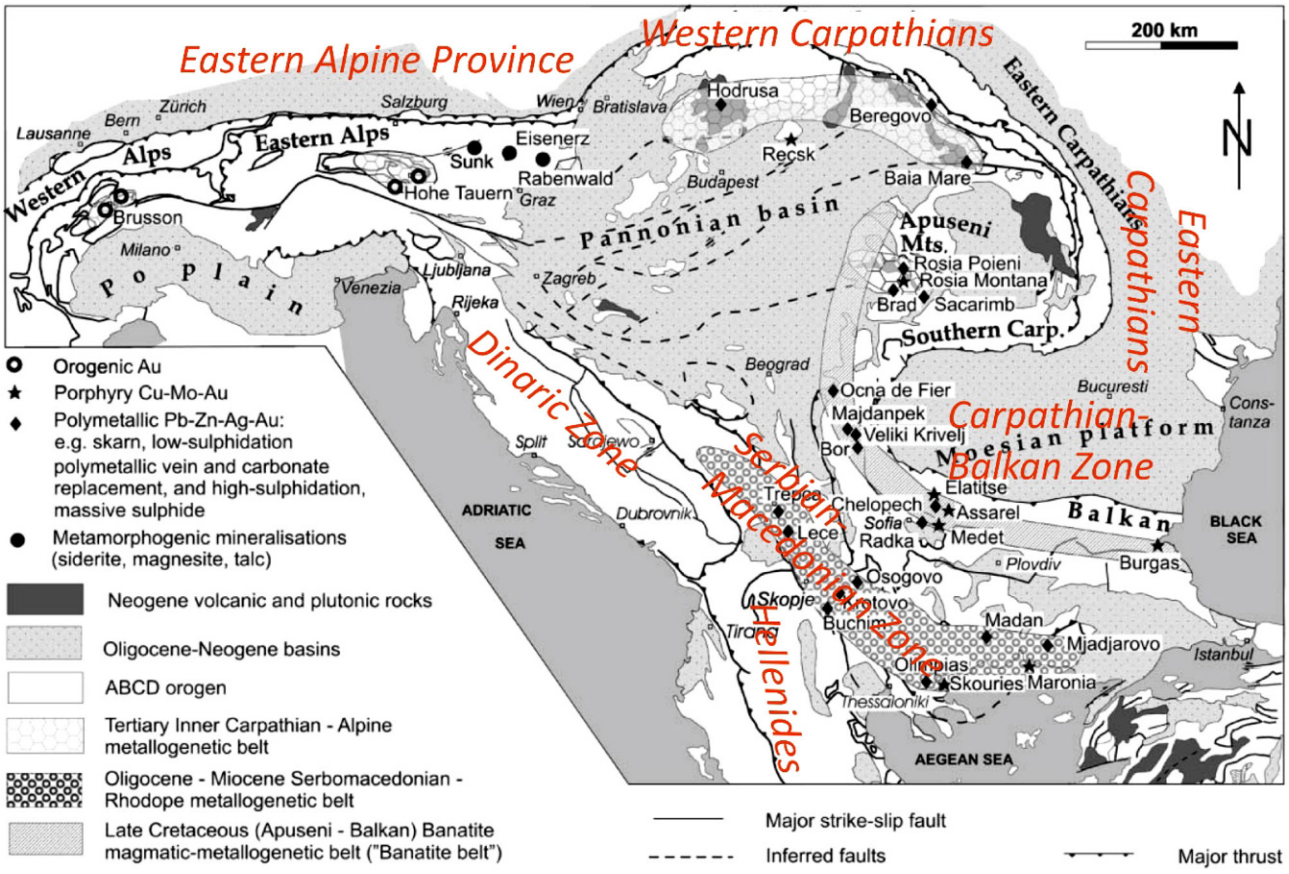

Fig. 4: Metallogenic provinces within the Alpine-Balkan Carpathian-Dinaride region, modified from [5], indicating the position of important mineral deposits

3.2 Western Carpathian Metallogenic Province

In the Western Carpathians (Fig. 4), a conspicuous similarity to the Greywacke zone in the Eastern Alps has long been recognized, manifested by the presence of metasomatic and vein-type siderite/sulfide and magnesite deposits in the Spiš-Gemer ore mountains (Gemerides). Important low-sulfidation epithermal base metal (Cu-Zn-Pb-Ag-Au) and Hg ores are related to Neogene (18–11 million years, Ma) volcanic rocks, e. g. at Banská Štiavnica and Hodruša. At the Rozalia mine, a NI43-101 compliant measured and indicated resource of 4.5 million metric tons (Mt) grading 0.86% Pb, 0.86% Zn, 0.22% Cu has recently been announced, and the Biely Vrch gold project has an indicated resource of 14.3 tons Au [9]. Recsk (Hungary) is a large Eocene (35 Ma) porphyry Cu deposit (109 Mt grading 0.96% Cu) hosted by Eocene andesite and altered Triassic limestone intruded by porphyrite. Bauxite deposits in NW Hungary (Bakony and Halimba mines) represent relics of weathering.

3.3 Eastern Carpathian Metallogenic Province

The Eastern Carpathian province, also comprising the South Carpathians and Apuseni Mountains (Fig. 4), is characterized by an Upper Cretaceous to Paleogene banatite stage (banatite is a local term for calc-alkaline, alkaline, and shoshonitic magmatic rocks), and by a Neogene stage comprising andesites with subvolcanic vein, stockwork, and metasomatic ores (Ag, Au, Te, As, Hg, Cu, Zn, Pb). In the Baia Mare zone, hundreds of veins carrying Cu, Au, Ag, Zn, and Pb have been mined in the past, and two deposits are still in operation. The noble metal-rich Brad-Sacarimb district (Apuseni Mts) contains low-sulfidation epithermal and impregnation ores in explosion breccias and limestones. The Banatite Belt extends over 1500 km from the Apuseni Mountains in Romania south towards Banat, Timok, and finally to Bor in Serbia at the transition into the Carpathian-Balkan zone, hosting world-class porphyry copper deposits, epithermal low-sulfidation deposits, skarn, vein-type, volcanogenic massive sulphide, and replacement deposits. The Cupru Min Rosia Poieni mine (Romania) is the largest Cu mine in Romania with total resources of 1 billion metric tons grading 0.36% Cu. A proposal to mine one of the largest undeveloped gold deposits in Europe (184 tons Au, 1.1 Mt Ag) at Rosia Montana was rejected in November 2013 by a Romanian parliamentary commission [9].

3.4 Carpathian-Balkan Zone

The Carpathian-Balkan zone in Serbia and Bulgaria (Fig. 4) is the southern continuation of the Eastern Carpathian

province and contains several Late Cretaceous, large porphyry copper deposits (e. g. Bor, Veliki Krivelj and Maidanpek in Serbia; Assarel and Elatsite in Bulgaria) with total resources of >3.5 billion metric tons of ore grading 0.4–0.6% Cu, and Mo, Au, Pd and Pt as potential by-products [6]. Numerous low- and high-sulfidation deposits in the Panagyurishte area (Bulgaria) have been mined in the past; the active Chelopech Cu-Au deposit (Dundee Precious Metals) has measured and indicated resources of 28.72 Mt grading 1.25% Cu, 4.03 ppm Au and 9.25 ppm Ag [9]. The large metasomatic iron ore deposit at Kremikovtsi north of Sofia closed in 2005.

3.5 Serbian-Macedonian Zetallogenic zone

The Serbian-Macedonian zone (Fig. 4) is characterized by a variety of deposit types and commodities, comprising Cyprus-type volcanogenic copper deposits, porphyry copper deposits, carbonate-hosted replacement Pb-Zn deposits, and epithermal polymetallic deposits. The Trepca mine in the Srebrenica region (Kosovo) is a Paleogene skarn deposit hosted by Upper Triassic limestones that has been mined since the Middle ages; it contains 29 Mt grading 3.45% Pb, 2.3% Zn, and 80 g/t Ag [9]. Porphyry copper deposits are of Paleogene to Neogene age; a mid-size porphyry copper deposit at Skouries in Greece contains 130 Mt ore with 0.56% Cu and 0.89 ppm Au, and the Buchim deposit in Madedonia is similar in size and grade [6]. The Rhodope Mountains carry abundant Paleo- and Neogene Pb-Zn-Ag vein and replacement deposits, e. g. in the Madan (>95 Mt ore mined) and Kudjali districts (Bulgaria), where reserves of 23.4 Mt, grading several percent Pb + Zn are known. Laurion is a famous Pb-Zn-Ag deposit in Greece with long mining history. The Stratoni mine (Olympias deposit, Chalkidiki) announced proven and probable resources of 1.8 Mt grading 8.5% Zn, 6.3% Pb, and 177 g/t Ag. Of economic importance are Ni laterites in Greece. In the Ljubija district, Bosnia and Herzegovina, large replacement-type siderite-barite-polysulfide deposits of Permian age (total resource 500 Mt at 40–49% Fe, probable reserves 29 Mt grading 45.8% Fe) occur in Carboniferous shales [10]; they are mined by Arcelor Mittal Prijedor. Rio Tinto's Jadar project in western Serbia comprises Miocene salt lake sediments that carry a resource of 118 Mt grading 1.6% Li_2O and 18 Mt borates. It is the type locality of the new mineral jadarite $LiNaB_3SiO_7(OH)$ [9].

3.6 Dinaric Zone and Hellenides

The Dinaric zone and Hellenides (Fig. 4) comprise the westernmost metallogenic province of the ESEE region. Within this zone, two ophiolite belts occur, separated by the Pelagonian Massif: both, the Dinaric-Pindos ophiolite in the west and the Vardar-Axios ophiolite in the east are host to chromite (with possible by-product PGE) and volcanogenic massive sulfide deposits, along with magnesite, asbestos and Ni laterite. Active Cr mining takes place at Bulqiza in the Mirdita ophiolite, Albania. Chromite ore reserves in Albania are estimated at 36.9 Mt, those of Cu at 27 Mt [9]. In 2013–2014, Ni ore was produced in four mines in Albania, one in Macedonia, three in Greece, and two in Kosovo. Bauxite is abundant in Triassic to Eocene carbonate host rocks throughout the Dinarides, e. g. in Greece (several mines on Euboea island and in northern Greece), Montenegro (Zagrad deposit), Bosnia and Herzegovina (Milici deposit), and Kosovo (Grebnik mine). The Idrija district, Slovenia, is host to a world-class mercury deposit with more than 145,000 tons Hg mined from 1490 until 1994.

3.7 Variscan Metallogenic Province

In the ESEE region, the Moldanubian and Saxothuringian zones of the Variscan orogeny are only exposed in northeastern Austria and Czech Republic. They resulted from collision of the Gondwana continent with Avalonia, and finally with Laurussia about 300 Ma ago during the Carboniferous. The pre-Variscan and Variscan rocks are well endowed with Sn, Ag, Pb-Zn, Li, but also with W, Mo, Nb-Ta, Au (Čelina-Mokrsko deposit, 150 tons Au reserves), U, and other commodities. At present, no metal mining takes place in the historically very important Erzgebirge and the Kutná Hora and Přibram regions of central Bohemia. The Cinovec (Zinnwald) Sn-W-Li project is well advanced, with 36.8 Mt grading 0.8% Li_2O and a total of 100,000 tons Sn recoverable [9]. On a world scale, the Czech Republic ranks number 4 in kaolin and number 13 in feldspar production from weathered and fresh granitic rocks of Variscan age. The Rozna I mine at Dolni Rozinka is the last uranium mine in the area.

4. Conclusions

Mining of mineral deposits plays an important role in the economy of the ESEE region. The proportion of mining and quarrying activities relative to the GDP (gross domestic product) of the ESEE countries ranges from 0.2% (Hungary) to 4.2% (Bulgaria), with most countries for which information is available having a share of mining and quarrying activities of 1–2% of the GDP [9]. Austria reports a share of 7.5% of the GDP for its marketed mineral industry production.

Many of the raw materials defined as critical by the EU Commission [2] are metals that are geochemically associated with copper, zinc, and lead ores; they include germanium (Ge), indium (In), cobalt (Co), gallium (Ga), antimony (Sb), and platinum-group metals (PGM). Others are found in association with granitic pegmatites, e. g. tantalum (Ta), niobium (Nb), and rare earth elements (REE). Information on the resources of most of these metals in the ore deposits of the ESEE region is missing.

Some of the critical elements, namely PGM, Co, Sb, Ga, and Ge are known to occur in elevated concentrations relative to the background in primary ores of the ABCD. Especially in Bulgaria, Serbia and Romania, mining of base metals and precious metals is well advanced and metallurgical plants are in operation providing significant raw mate-

rials to the European industry. Bulgaria ranks as number 3 among Europe's copper and gold producers and is also a significant producer of zinc and lead. The ores mined in the region have a high potential for some of the critical metals. However, knowledge on these materials is poor and the critical raw materials are not recovered. The same applies to Romania, Serbia, Bosnia and Herzegovina, Macedonia, Kosovo, Montenegro and Greece that share similar geological features and raw material potentials. The ESEE region produces more than 30% of the European bauxite, and the potential for Ga as a by-product from aluminum production is large. A significant potential for Pb-Zn and associated critical metals, such as Ge, In, and Ga, exists in Triassic carbonate platforms throughout the region, especially in the Triassic carbonates of the Eastern Alpine province. During collision, granitic magmatism produced rare-element pegmatites that carry Li, Be, Nb, Ta, Cs, REE, and other valuable by-products. Such systems are known to occur associated with Carboniferous to Permian tectonic events in the Czech Republic, Slovakia, and Austria and may be present in other countries of the region. Albania, Greece, Macedonia, and Kosovo have a high potential for chromium and nickel ores, some with associated PGM in ophiolite sequences representing ancient oceanic mantle and crustal sequences.

The economic geology of the ESEE region is complex, and it is promising for the future. Despite a decline of primary mineral raw material production within the past 20 years, a huge potential exists and needs to be unraveled, especially with respect to the critical raw materials for which data are almost non existing. The ESEE region has the potential to supply the European market with raw materials for decades to come.

A large amount of data has accumulated in the 15 countries of the region during the period of extensive mining activities. Geological surveys and Mining Ministries, Academies of Sciences, universities, companies, EU-funded projects, and others have collected data and published maps describing the status of ancient and current mining and exploration activities. As an example IRIS, the Austrian Interactive Raw Materials Information System, describes 6150 mineral occurrences in Austria (ores, industrial minerals, and energy raw materials) grouped into 176 metallogenic provinces [11]. In order to develop a metallogenic model for the ESEE region from which predictive tools may emerge, a GIS-based compilation of information across borders is urgently needed, and it is hoped that cross-border cooperation on this matter will be enhanced in the future.

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Conflict of interest. F. Melcher and C. Reichl declare that they have no competing interests.

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