

Croatian Critical Mineral Commodity Letters: Bauxite

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doi: 10.4154/gc.2026.10



Review paper

Article history:

Manuscript received: October 2, 2025

Revised manuscript accepted: May 8, 2026

Available online: June 17, 2026

Abstract

Bauxite is a critical raw material with high importance for the European Union economy. Bauxite has versatile applications in industries: aluminium production ($\approx 90\%$), the chemical industry (aluminium sulphate, chloride, sodium aluminate, trihydrate), cement (high-alumina cement), refractory production, and abrasives (brown- and white-fused alumina). The Republic of Croatia hosts bauxite deposits with variable potential: (1) High-potential deposits include Jurassic bauxites in Istria (total reserves >5 Mt; Al_2O_3 50–60 wt %, Fe_2O_3 10–22 wt %, SiO_2 >16 wt %) suitable for cement and structural clay production, and Upper Eocene Promina bauxites in Dalmatia (total reserves >5 Mt) suitable for cement and/or structural clay production; the REE content in the Promina bauxites reaches up to 3,495 ppm, representing a potential secondary sources of critical elements. (2) Medium-potential deposits are the Upper Triassic clayey bauxites (at Lika, Kordun, north Dalmatia), with individual deposits up to several hundred thousand tons, and total remaining reserves of several million tons. Their low Al_2O_3 and high SiO_2 make them suitable for brick and structural clay production. (3) Low- or no-potential deposits include the Lower Cretaceous, Miocene, Palaeocene, Upper Cretaceous, and Mid Eocene bauxites, with small reserves (10–35 kt) and limited industrial use. A case study of the Upper Eocene Promina bauxite beds (≈ 2.4 Mt remaining reserves) shows lens-shaped or pseudo-layered deposits in karstified limestones (up to 30 m thick). Historical extraction used open-pit and underground mining (Čveljo Dolac $\approx 80\%$ underground, Mamutovac 100% surface, Krste Radas 100% underground). Bauxite is mainly suitable for cement and structural clay production; the bulk value of remaining reserves is estimated at ≈ 42 M€ (market price ≈ 20 €/t). The deposits are enriched in critical elements: Ti ≈ 10.4 kt, Cr ≈ 0.6 kt, V ≈ 0.5 kt, Ni ≈ 0.2 kt, and $\sum\text{REE} \approx 1.4$ kt, representing potential secondary sources for future industrial and strategic uses.

Keywords: Critical raw materials, bauxite, Croatia, case-study Promina

1. INTRODUCTION

Bauxite is the second commodity addressed in a series of reviews focused on critical raw materials and published in Croatia as Croatian Critical Mineral Commodity Letters. The series aims to raise awareness of the Croatian mineral raw materials stakeholders (industry, research, academia, policy-makers, investors), as well as the local community, on valuable CRM resources that exist, but are not being currently exploited in Croatia. For more background information, the reader is kindly referred to the Introduction by BOROJEVIĆ ŠOŠTARIĆ et al. (2025) Croatian Critical Mineral Commodity Letters: Magnesium.

Selected Croatian CRM commodities, evaluated according to INSPIRE-based size thresholds and exploration–mining criteria (Suppl. 1), are as follows:

- 1) of high geological potential, high economic value and reasonable exploration/exploitation opportunities: magnesium from dolostone (BOROJEVIĆ ŠOŠTARIĆ et al., 2025),
- 2) of moderate geological potential: bauxite (this paper), barite, graphite and rare earth elements (this paper), and
- 3) of indicative geological potential: borates and lithium.

Croatia still hosts significant quantities of bauxite: at least 8 Mt of economically viable and 14.2 Mt of non-economic bauxite still exist without any significant exploration being conducted in the last 35 years (historical data; JISMS RH (2025) – *Jedinstveni Informacijski Sustav Mineralnih Sirovina* / Unique Information System of Mineral Resources; MARKOVIĆ, 2002 and references therein). Current mining activities are sporadic, serving the purpose of cement and rock-wool industries with annual extractions below 10 kt (JISMS RH, 2025). Recent research (KOVAČEVIĆ GALOVIĆ et al., 2025) demonstrate the rare earth elements (REE) potential of various Croatian bauxite deposits. Authors outlined eight bauxite horizons (from Upper Triassic to Miocene ages), with the largest $\sum\text{REE}$ in the Middle and Upper Eocene bauxite horizons (median values of 570 ppm). The aim of this manuscript is to: (1) elaborate on the important properties of bauxite deposits (including their potential as a secondary source of rare earth metals (REE)), as well as common mining and processing methods and applications; (2) provide a comprehensive overview of the bauxite and REE-bauxite occurrences and potentiality maps within the Republic of Croatia; (3) present a selected bauxite case-study; (4) propose hypothetic mining and extraction technologies, and potential applications for the selected case study.

2. BAUXITE

2.1. History of bauxite exploitation in Croatia

The world's oldest bauxite mine is located in Croatia.

Within the Istria, in the underground mine Minjera, pyrite-bearing bauxite has been mined since the 16th century and used for the production of sulphuric acid and alumen ($KAl(SO_4)_2 \times 12H_2O$) for the leathercraft, paper and paint industries, as well as an antiseptic in medicine and an antidote to lead poisoning (MINJERA, 2013–2024; MARUŠIĆ et al., 1993; NEŽIĆ, 2015). Mining activities in 17 shallow shafts (30–80 m deep) lasted for almost 400 years, peaking in the 18th century when an innovative extraction and processing plant was built on-site, employing 100 men. Close to 150 kt of bauxite was mined. Mining and processing activities within the Minjera mine reached an international audience via the scientific work of TURINI (1808).

Throughout history, bauxite has been one of the most important mineral resources mined in Croatia. Extracted deposits were high-grade but small-scale karstic sinkholes, lenses and layers of few thousand to several hundred-thousand tons in size, closely packed around tectonic-erosional discontinuities of the Dinaric carbonate platform (MARKOVIĆ, 2002). Extraction from Istrian bauxite mines (Mirna valley, Rovinj, Umag) in 1938, ranked Italy as the 4th largest bauxite producer in the world (close to 100% of the country's bauxite production was from Istria), whereas extraction from Dalmatian bauxite mines ranked the Kingdom of Yugoslavia as the 2nd largest bauxite producer (50% of the country's production). Production from both regions ramped up after the Second World War, leading to the establishment of an alumina processing plant *Jadranboksit* in Obrovac, Croatia in 1979 (GANZA, 2021). The total amount of excavated bauxite ore in the Istrian region is estimated at approximately 11.5 million tonnes (Mt), while the cumulative national extraction in Croatia is estimated at 28 Mt (MARKOVIĆ, 2002 and references therein). During the operational period of the *Jadranboksit* alumina plant (*Jadral*) in Obrovac (1977–1981), bauxite production peaked at 400–480 kt per year, which was sufficient to support the production of 120–160 kt of alumina annually

(GANZA, 2021). Bauxite production declined sharply prior to and during the conflicts in the former Yugoslavia during the 1990s. According to historical records, annual production decreased from 310 kt in 1990 to 112 kt in 1991 and basically stopped in 1992 (USBM & USGS, 1990). Currently, bauxite production in Croatia is negligible, averaging below 10 kt annually (JISMS RH, 2025: *Jedinstveni Informacijski Sustav Mineralnih Sirovina* / Unique Information System of Mineral Resources).

2.2. World production and reserves

Total annual European production of bauxites in 2023 was 2.8 Mt, of which 2.1 Mt was produced in Greece, followed by Bosnia and Herzegovina, Serbia and other South European countries (Table 1 and references therein). Production of bauxite from primary European sources accounts for only ≈ 5–5.5 % of the annual European consumption (which ranges between 50–55 Mt of bauxite), while benchmarks defined by the EU Critical Raw Materials Act are set to reach 10% of the annual European consumptions by 2030. European reserves of bauxite are 200 Mt and constitute only 0.7% of the world reserves (close to 30 gigatonnes; USGS, 2024), that are mainly located in Guinea, Vietnam, Australia, Brazil, Jamaica, and Indonesia (Table 1). European annual production of bauxite in 2023 was 2.8 Mt representing 0.7% of the total world production, while Europe was consuming about 50–55 Mt of bauxite in the same year (13.5–14 % of the world production), mainly relying on imports from other countries (Guinea (close to 20 Mt), followed by Brazil, Sierra Leone, Turkey, Jamaica, Australia and other countries; INTERNATIONAL TRADE CENTRE, 2025).

2.3. Bauxite definition and classification

Bauxite is a sedimentary rock composed of aluminium minerals, mostly oxyhydroxides and hydroxides, iron and titanium oxides, usually some clay minerals (generally kaolinite), quartz, iron sulphides and carbonates, and other minor constituents. It can be variously coloured, from most commonly shades of red, to yellow, pink, light grey, and dark brown. The bauxite colour depends on the size and type of the predominant

Table 1. The largest World and European producers of bauxite, together with reserves, reference-year 2023 (data taken from GROHOL & VEEH (2023); USGS (2024).

Country	Reserves (Bt)	2023 Production (Mt)	Country	Reserves (Mt)	2023 Production (Mt)
Guinea	7.4	97	Greece	100	2.1
Vietnam	5.8	3.7	Hungary	30	0.1
Australia	3.5	98	Bosnia and Herzegovina	20	0.2
Brazil	2.7	31	Montenegro	15	0.05
Jamaica	2	6	Romania	10	0.06
Indonesia	1	20	Serbia	8	0.12
China	0.71	93	Albania	6	0.09
India	0.65	23	France	5	0.02
Russia	0.48	5.8	Slovenia	3	0.02
Kazakhstan	0.16	4.3	Germany	2	0.01
Saudi Arabia	0.18	4.6	Europe total	199	2.77
Turkey	0.063	2	European consumption*		50-55
Other countries	5.1	5.6			
Total 12 largest	29.743	394			

iron minerals. Basically, red-coloured bauxite is due to haematite and goethite usually causes an ochre tint. Bauxite textures are quite versatile, ranging from oolitic, pisolitic to fine-grained or sometimes pseudomorphous (BARDOSSY, 1982), reflecting a range of styles of weathering, depositional regimes and source material origin. It has been shown that geologically older bauxites tend to be diasporic-rich, hard and more dense, whereas younger deposits are more gibbsitic-rich, softer and often of lower density (CHANG, 2002). Bauxite was widely formed and deposited during emersion episodes, which allowed weathering of parent rocks and deposition of detrital (residual) material in geomorphological depressions during warm and humid periods. Generally, favourable conditions for bauxite formations were postulated by SHAFFER (1983) to include: increased rock permeability to allow desilication, a tropical climate, good drainage and fluctuation of the ground-water table within a topographically low to moderate relief. Alternatively, a decreased rate of erosion and long-time landscape-stability support the accumulation of weathered material.

Aluminium minerals in bauxite are mainly represented by gibbsite [$\text{Al}(\text{OH})_3$], boehmite [$\gamma\text{-AlO}(\text{OH})$] and diasporic [$\alpha\text{-AlO}(\text{OH})$], followed by haematite, goethite, quartz, halloysite and titanium minerals. Boehmite and gibbsite most commonly occur together, while other mineral tandems are less common. The mineral composition of bauxite is crucial for its later processing treatment post excavation.

2.4. Deposit types

In general, two major types of bauxite deposits are distinguished based on their mode of occurrence and parent rock petrography: a) lateritic bauxites that contain material produced by *in situ* weathering of rocks rich in Al-silicates including igneous rocks, and b) karst bauxites, which are deposited in karst depressions containing materials derived from weathering of carbonate rocks and/or Al-silicate rich rocks (e.g. VALETON, 1972; BARDOSSY, 1982; BARDOSSY & ALEVA, 1990; DILL, 2010 and references therein). Both types are economically important products of surficial chemical weathering processes, associated with *in situ* pedogenesis in the regolith. Their origin is related to the dissolution of water-soluble minerals, leaching of silica over a range of pH values (4.5–9), hydrolysis of aluminosilicate minerals (feldspar (loss of Si) \rightarrow kaolinite (loss of Si) \rightarrow gibbsite ($\text{Al}(\text{OH})_3$), hydration of any pre-existing evaporite (karstic bauxite) and clay minerals, oxidation of iron in ferromagnesian minerals and cation exchange. As a result, most deposits display two distinguished horizons: an upper layer resulting from eluviation or removal of clays and leachable elements, and a lower layer resulting from illuviation or the accumulation of material. Lateritic bauxite generally contains lower quantities of Fe-oxides/oxyhydroxides, compared to ferruginous laterite, where the Fe_2O_3 contents in the upper zone can reach 20%.

Lateritic bauxite formation requires an average temperature of $\approx 22^\circ\text{C}$, high (≥ 1000 mm) rainfall (an important factor for the dissolution of Fe oxides/oxyhydroxides and other unwanted ingredients), and seasonal climatic variations allowing for effective groundwater fluctuation. Residual bauxite is typically enriched in dehydrated Al-oxides/

oxyhydroxides (boehmite or diasporic $>$ gibbsite; up to 15% H_2O); exhibiting higher mechanical strength and lower grindability, and contains some Fe (haematite) and Ti phases and clay. Most authors consider twofold formation of bauxites: (1) lateritic bauxite (Al-rich laterite) overlying Al-rich bedrocks (granite, mafic rocks, arkose sandstone) or (2) karst bauxite as insoluble residue derived by weathering of carbonate rocks and/or Al-rich silicate rocks, the weathering products of which accumulated in karst depressions, reflecting their polygenetic origin (e.g. BARDOSSY & ALEVA, 1990; VALETON, 1972). Karstic bauxites can also be enriched in REE, Ga, Sc, V and other elements (for example ECONOMOU-ELIOPOULOS & KANELLOPOULOS, 2023; RADUSINOVIĆ & PAPADOPOULOS, 2021; KOVAČEVIĆ GALOVIĆ et al., 2025 and references therein).

Ferruginous laterite requires a higher average temperature (28°C), high humidity and no seasonal climatic variations (intertropical region, rain-forest zone). Laterites are typically enriched in hydrated Fe-oxyhydroxides (goethite) and Al-oxyhydroxides (gibbsite $>$ boehmite or diasporic; up to 35% H_2O ; easy to grind), and may contain significant concentrations of Ni, Mn, Au, Cu and PGE, depending on their bedrock (DILL, 2010; ECONOMOU-ELIOPOULOS & KANELLOPOULOS, 2023 and references therein).

2.5. Mining methods

Globally, approximately 327 million tonnes of bauxite were mined in 2018, increasing to approximately 385 million tonnes in 2022 — a rise of close to 18% (WORLD MINING DATA, 2024). Lateritic bauxite is usually found near the surface of the terrain and can be economically strip-mined. The industry has taken a leadership role in environmental conservation efforts. When the land is cleared prior to mining, the topsoil is stored so it can be replaced during rehabilitation. During the strip-mining process, bauxite is broken up and transported from the mine to an alumina refinery. Once mining is complete, the topsoil is replaced and the area undergoes a restoration that can span decades. On average, 80% of forested land mined globally is returned to its native ecosystem (THE ALUMINIUM ASSOCIATION, 2026), though the restoration of full ecological complexity — including old-growth structural characteristics and soil biodiversity — can require timescales of 50 years or more.

Karst bauxite deposits however, are found in regions with limestone bedrock and are often located in localised, irregular and deeper bodies. These deposits are usually situated in underground caverns or depressions and require different mining methods. Depending on the depth and size of the deposit, underground mining methods, such as sublevel mining, may be used. There are two main subsurface bauxite mining methods:

- 1) Sublevel-caving mining method with roof caving, applied in ore deposits where the roof has poor physical and mechanical characteristics,

- 2) Sublevel-stopping mining method with open excavated areas, applicable under conditions of solid and stable roof rocks and for ore bodies of limited size (MAJSTOROVIĆ & TOŠIĆ, 2016).

In cases where karst bauxites occur closer to the surface but are more irregularly distributed, open pits or even a combination of open pits and underground mining methods can be used.

2.6. Extraction methods

2.6.1. Aluminium extraction

Since the aluminium industry is the major consumer of bauxite, aluminium minerals are currently the most important constituents of this raw material. They can be separated into two distinct groups (CHANG, 2002): (1) trihydrates – gibbsite [γ -Al(OH) $_3$], bayerite [α -Al(OH) $_3$], nordstrandite [β -Al(OH) $_3$] and (2) monohydrates – diaspore [α -AlO(OH)] and boehmite [γ -AlO(OH)]. Structural properties of the aluminium minerals are related to their crystallization conditions with diaspore being the most stable phase and boehmite being metastable. The structural distinction between the three major bauxite minerals also reflects their behaviour in alumina production: gibbsite is the most soluble, requiring lower NaOH concentrations, temperature and pressure; boehmite solubility requires more concentrated NaOH solutions (20–30 %) and higher temperatures (225 °C), as well as the presence of some hydrated aluminium silicates in bauxite in order to enhance process reactivity. Diaspore is quite demanding in terms of processing temperature (>250 °C) in order to achieve solubility comparable to that of boehmite (POWER et al., 2011).

Other most common minerals in bauxite are haematite [Fe $_2$ O $_3$] and goethite [γ -FeO(OH)], which may also contain some Al replacing Fe in the crystal structure, followed by quartz, kaolinite and halloysite. Although clay minerals can be considered to be the directly inherited constituents of the detrital material, it has been shown that they can also form *in situ* by reaction of amorphous aluminium hydrates and silica (WOLLAST, 1963). Aluminium present as substitution in the crystal lattice of iron oxihydroxides and oxides is not extractable in the Bayer process. Aluminosilicates are generally considered unfavourable constituents in bauxite with respect to Bayer processing, as they react with sodium hydroxide and thus reduce the content of extractable alumina (ADAMSON et al., 1963). Titanium oxides, especially fine-grained anatase, are quite common in bauxite, along with detrital rutile and ilmenite occurring in lesser amounts; however, they do not affect alumina extraction.

2.6.2. Extraction of critical elements from bauxite residue

Bauxite residue, or red mud, is a specific type of industrial waste generated during the processing of bauxite into alumina via the Bayer process. Depending on the amount of alumina in the primary bauxite, between 1.7 and 4 tonnes of bauxite are used to produce 1 tonne of alumina. Along with alumina, between 1 and 1.5 tonnes of residue (= red mud) are discharged at pH 10–13 (BROUGH & JOUHARA, 2020 and references therein). Mineralogically and geochemically, red mud mainly contains up to 42% of iron oxides (goethite, haematite, magnetite), and up to 17% of solid, alumina phases, either undissolved or formed during the Bayer process (sodalite, cancrinite [Na $_6$ Ca $_2$ [(CO $_3$) $_2$ Al $_6$ Si $_6$ O $_24$].2H $_2$ O], tricalcium aluminium iron silicate hydroxide, minor diaspore, boehmite, gibbsite), up to 10% of silica (sodalite, cancrinite, quartz); up to 9% of titanium oxide (rutile, anatase, perovskite, ilmenite), up to 9% of calcium oxide (calcite, perovskite, whewellite [Ca C $_2$ O $_4$.H $_2$ O]), around 5% of sodium oxide (sodalite, cancrinite, dawsonite) and 10% of loss on ignition (water, whewellite, flocculants, organics; KLAUBER et al., 2011). Along with major elements, bauxite residue may contain economic quantities of scandium (up to 120 ppm), gallium (<10 to 180 ppm), vanadium (400 to 500 ppm), and REE elements (500 to 1700 ppm; HABIBI et al., 2023; PAN et al., 2023). The extraction of these elements is rather complex and several methods have been suggested. Titanium extraction could proceed through reduction roasting or acid leaching using inorganic acids, while REE and vanadium extraction follows sulfation-roasting leaching, acid leaching using inorganic or organic acids or bioleaching. Scandium extraction can be conducted using ionic liquids, hydrochloric acid leaching or sulfation roasting leaching, whereas gallium extraction proceeds through acid leaching using inorganic acids, alkali leaching-carbonization process, or acid leaching-ion exchange process (LYMPEROPOULOU et al., 2019; CUSACK et al., 2019; HABIBI et al., 2023; PAN et al., 2023 and references therein).

2.7. Bauxite applications

The principal application of bauxite takes place in the aluminium industry where bauxite is the primary raw material. Data show that roughly 90% of all extracted bauxite is used in aluminium production, while the remainder is processed into

Table 2. Summary data of the uses of bauxite. Special ratios are referred to as: SM – silica module, Al $_2$ O $_3$ /SiO $_2$; FM ferric – module Al $_2$ O $_3$ /Fe $_2$ O $_3$; TM – titanium module Al $_2$ O $_3$ /TiO $_2$ after BROUGH & JOUHARA, 2020.

Industry	Al $_2$ O $_3$ (%)	SiO $_2$ (%)	Fe $_2$ O $_3$ (%)	TiO $_2$ (%)	Special Ratios	Source
Metallurgical (Alumina Industry)	40–52	1.5–15	5–30	1–6	Al $_2$ O $_3$ /SiO $_2$ \geq 7; Al $_2$ O $_3$ /Fe $_2$ O $_3$ \geq 1.5	Tran (2007); Jalili et al. (2022); Chang (2002); Fastmarkets
Chemical	Variable	Not critical	Very low (ratio based)	Not specified	Al $_2$ O $_3$ /Fe $_2$ O $_3$ \geq 23:1	Chang (2002)
High Al-cement*	High; 45–55	Low; <6	Low	Low	Al $_2$ O $_3$ /SiO $_2$ \geq 10:1; Al $_2$ O $_3$ /Fe $_2$ O $_3$ \geq 20:1; Al $_2$ O $_3$ /TiO $_2$ \geq 16:1	Chang (2002); Koegel et al., (2006)
Refractory*	High	<10%	<2.5%	<4%	None specified	Chang (2002)
Abrasive (Brown-fused)	>82%	<8%	<8%	<4%	N/A	Giltzen (1976); Power (1986)
Abrasive (White-fused)	\approx 99%	Trace	Trace	Trace	N/A	Giltzen (1976); Power (1986)

*if used for industry as corrective – chemistry might be variable

alumina and used in industries such as ceramics, abrasives, refractory materials, various chemicals and in the cement industry (JALILI et al., 2022; FASTMARKETS, 2024). The quality of bauxite ore significantly influences its use in industry. Metallurgical grade bauxite is used for aluminium production (Table 2). In the Hall-Heroult process, aluminium is produced after first obtaining alumina of high purity (at least 99% Al_2O_3) through the Bayer process (CHANG, 2002).

Chemical grade bauxite is used for the production of chemicals including aluminium sulphate, chloride, trihydrate and sodium aluminate. The grade of this bauxite is expressed as the $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$ ratio, which should be 23:1 or higher. Most of these chemicals originate from the Bayer process, and are used for the following purposes: aluminium sulphate in water purification (as a coagulant for suspended matter), aluminium chloride in refining mineral oils and in the production of some organic compounds, sodium aluminate in water treatment and in the paper industry, aluminium trihydrate as a filler in plastics (it acts as a fire retardant and suppresses smoke). Additionally, alumina is produced in activated form for water degassing, selective absorption in the oil industry and for use in industrial catalytic processes (CHANG, 2002).

High-alumina cement grade bauxite requires a very specific chemical composition: $\text{Al}_2\text{O}_3/\text{SiO}_2 \geq 10:1$, $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3 \geq 20:1$, $\text{Al}_2\text{O}_3/\text{TiO}_2 \geq 16:1$. The cement produced is used in casting concrete with a high resistance to chemical attack (CHANG, 2002).

Refractory grade bauxite is used in the production of alumina refractories, which can be produced from a range of aluminium-rich minerals. For this purpose, bauxite is calcined and mixed with binders, followed by ceramic treatments. To be suitable for refractory production, bauxite must have a high alumina content, with iron oxides below 2.5% (upon calcination), titanium dioxide below 4%, and alkalis, alkaline earths and free silica below 10% (CHANG, 2002).

Abrasive grade bauxite is directly used in the production of the so called brown-fused alumina. For this application, the bauxite must have a high alumina content (> 82%), with silica not exceeding 8%, and up to 8% of Fe_2O_3 and 4% of TiO_2 (GITZEN, 1976; POWER, 1986). To produce the so called white-fused alumina the alumina obtained through the Bayer process is used. It contains roughly 99% of Al_2O_3 along with minor amounts of Na_2O , silica and Fe_2O_3 .

3. BAUXITE DEPOSITS IN THE REPUBLIC OF CROATIA

3.1. Geological setting

Similar to the majority of bauxite deposits in the surrounding Mediterranean region, Croatian bauxites belong to the karst type. They are embedded within the carbonate succession of the Croatian Karst of the External Dinarides. These carbonate deposits, in some areas exceeding 8000 metres in thickness, span from the Middle Permian (or even Upper Carboniferous) to the Eocene in age (VLAHOVIĆ et al., 2005). The geological evolution of the Karst Dinarides area commenced on an extensive epeiric carbonate platform along the northern margin of Gondwana. Throughout the Carboniferous, siliciclastic material was deposited, succeeded by mixed

clastic-carbonate sediments in the Permian, and carbonate and mixed siliciclastic-carbonate deposits in the Lower Triassic. Significant tectonic activity in the Middle Triassic led to the break-up of the Adria Microplate, characterized by a locally notable volcanoclastic influence within the extensive sequence of shallow-water carbonates. The transition from the Middle to Upper Triassic was marked by a prolonged emersion phase, featuring frequent bauxite occurrences, followed by the establishment of the Southern Tethyan Mega-platform (VLAHOVIĆ et al., 2005). This vast isolated intraoceanic platform is characterized by shallow-water carbonate deposits such as the Late Triassic Hauptdolomit and Dachstein limestones. The fragmentation of this extensive platform into smaller carbonate platforms occurred in the Toarcian, leading to the formation of the Adriatic Basin, with the Adriatic Carbonate Platform (AdCP) along its eastern flank. Subsidence of the platform basement during the Late Jurassic and Cretaceous facilitated the abundant production of predominantly shallow-marine carbonates. However, fluctuations in eustatic sea levels and synsedimentary tectonics resulted in frequent local or regional emersions of varying durations, leading to the deposition of bauxites. During the Late Cretaceous, the gradual disintegration of the platform began due to collisional processes, resulting in the differentiation of sedimentary environments and the eventual formation of flysch basins. The transition from the Cretaceous to the Palaeogene witnessed a general emersion of varying duration on the AdCP, with the Palaeogene transgression occurring predominantly in the Eocene. Resurgence in carbonate deposition during the Palaeogene was largely influenced by ongoing intense tectonic activity, with carbonate deposition enduring on carbonate ramps, while clastic deposition increasingly dominated areas of primary carbonate production. The Lower Palaeogene Liburnian formation (including the Kozina beds) and Eocene foraminiferal limestones, were succeeded by transitional beds and flysch. Tectonic compression of the platform area during the Oligocene–Miocene led to the uplift of the Dinarides.

The deposits within the Croatian Karst Dinarides represent the remnants of several successive carbonate platforms of varying ages, types, and geotectonic settings. Carbonate sediments accumulated in shallow-water environments that were continuously subsiding. However, due to various geodynamic movements in the Dinarides, periods of dry-land surfaces of varying durations occurred, leading to the development of palaeokarst and bauxitization processes. Bauxites are found in various stratigraphic positions within the Croatian Dinaric karst region, ranging from the Triassic to the Miocene (Fig. 1). There are significant differences in chemical composition, mode of occurrence, and deposit type in between these bauxite deposits (SAKAČ & ŠINKOVEC, 1991). Based on their defined stratigraphic relationships with the basement and overlying layers, as well as their specific geotectonic positions across a wide geographic area, several previously identified stratigraphic horizons of bauxite deposits (ŠINKOVEC & SAKAČ, 1991), were grouped into two categories: (1) South Tethyan Megaplatfrom bauxite (i.e. Upper Triassic bauxite), and (2) Adriatic Carbonate Platform (AdCP) bauxite (Upper Jurassic, Lower Cretaceous, Upper Cretaceous, Palaeocene/Lower Eocene, Mid Eocene, Upper Eocene, and Miocene bauxite).

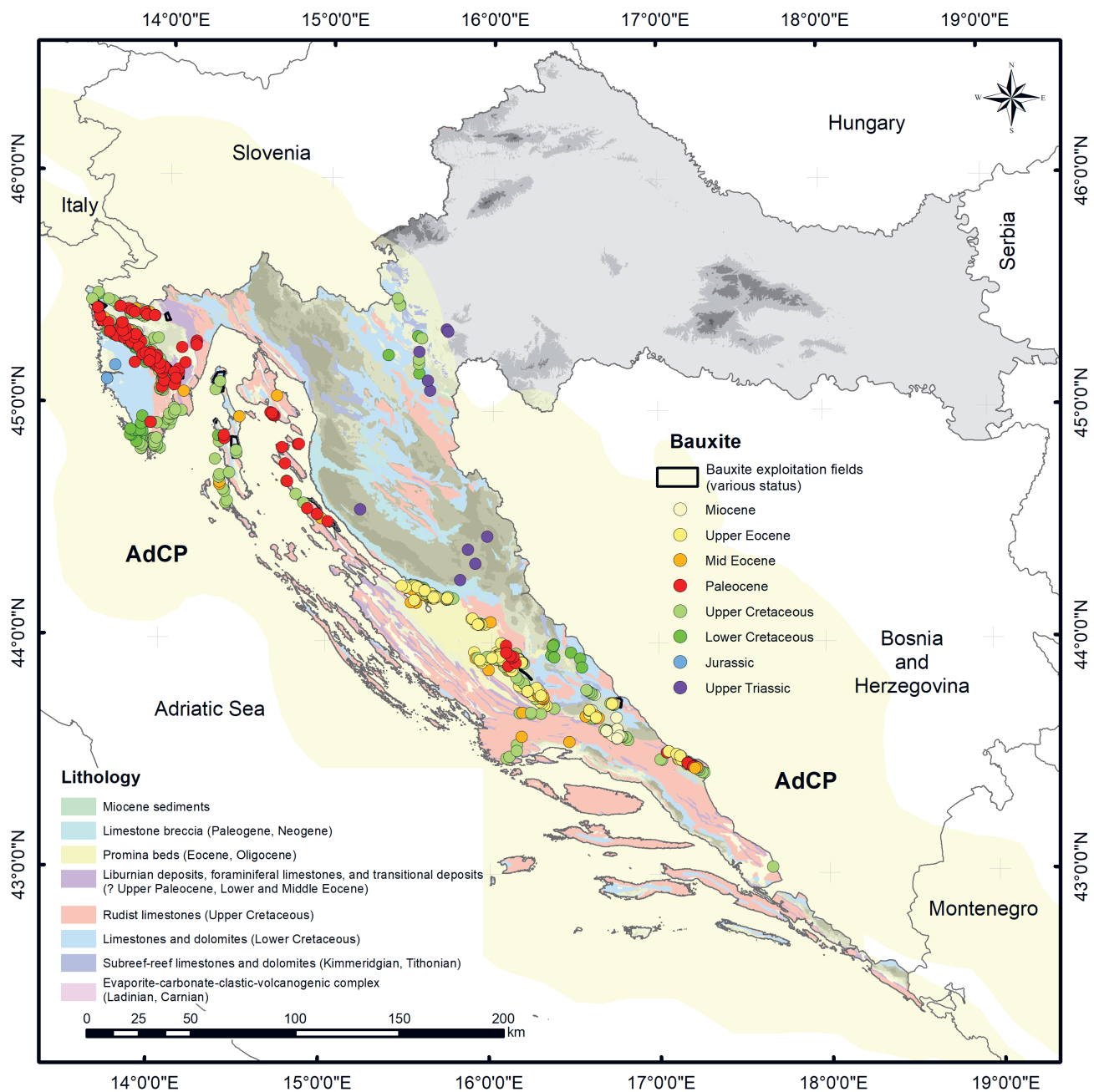


Figure 1. Map of the AdCP (VLAHOVIĆ et al., 2005) with state boundaries, general geology, bauxite-bearing areas, exploitation fields, deposits and occurrences, after the CROATIAN GEOLOGICAL SURVEY (2024): Map of Mineral Resources of the Republic of Croatia

3.2. South Tethyan Megaplatform bauxite

The first of the major periods of bauxite forming processes took place in the Upper Triassic, during a prolonged period of emergence of the epeiric carbonate platform located along the northern margin of Gondwana (sensu VLAHOVIĆ et al., 2005). Clayey bauxite of this age extends over Lika and Kordun (Central Croatia), and the north Dalmatia region (NE Velebit). Bauxite deposits fill a shallow karst depression formed on the surface of Anisian–Ladinian limestones with dolomite fragments (SAKAČ et al., 1984) and are overlain by Carnian conglomerates, tuffitic sandstones, clays and dolomites (ŠINKOVEC & SAKAČ, 1991). Their origin is linked with the weathering of associated pyroclastic and clastic sediments (MARKOVIĆ, 2002). Those bauxites are clayey, with an increased SiO_2 content (8.82–16.69 wt% SiO_2 ;

Table 3) and are not suitable for the alumina industry. Deposits reach up to several hundred thousand tons in size and consist primarily of boehmite-kaolinite±diaspore (JURKOVIĆ, 1962). Past exploitation was minor (a few tens of thousands of tons), and it is estimated that remaining reserves within numerous deposits reach several million tons (KOVAČEVIĆ GALOVIĆ et al., 2025 and references therein).

3.3. Adriatic carbonate platform bauxite

Jurassic bauxites, disconformably intercalated within Malmian (Late Jurassic) shallow water carbonates are located in Western Istria. They are underlain by Kimmeridgian limestones and dolomites and overlain by Tithonian limestones. SAKAČ et al. (1984) links their origin with the weathering of clay-rich carbonate substrates and aeolian material. These layer-type

Table 3. Major oxides chemical composition in mass % and content of some critical elements in ppm of the selected bauxite deposits in Croatia (data from REEBAUX project Report: Bauxite-related resources in the ESEE region and REE – focus on Croatia, Hungary, Montenegro and Slovenia, 2020). Abbreviation n.d. – not determined.

Locality	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	Cr ₂ O ₃	Ni	Ga	V	Sc	ΣREE
<i>Middle/Late Triassic</i>										
Rudopolje	8.82-16.69	50.75-64.05	10.81-18.00	1.51-2.13	0.012-0.019	38-77	49-65	120-174	33-42	431-846
Vrace	12.69-21.04	46.87-51.59	16.26-20.01	1.78-1.95	0.011-0.012	60-90	60	235	36-40	465-868
<i>Late Jurassic</i>										
Rovinj	14.24-29.23	34.25-60.03	1.78-21.85	1.43-2.79	0.03-0.09	38-273	36-66	142-329	n.d.	508-1294
<i>Late Cretaceous/Paleogene</i>										
Mandići	2.00-5.45	26.4-46.19	9.91-19.68	1.29-1.94	0.091-0.129	415-1125	21-39	650-1155	45-75	595-1099
Turban Kosa	3.75-3.81	45.68-47.23	19.91-31.42	1.91-3.14	0.164-0.179	270-536	39-46	804-1051	67-76	419-800
<i>Middle Eocene</i>										
Ćosići	3.57-4.92	46.17-49.96	17.81-28.64	1.99-2.46	0.171-0.206	162-875	39-45	889-1014	47-74	381-1229
<i>Late Eocene</i>										
Gljevo	2.05-11.86	44.51-55.76	16.24-21.12	2.05-2.67	0.081-0.241	488-790	41-43	621-800	46-60	1144-1791
Jukići-Đidare	3.09	49.08	21.23	2.41	0.135	545	36	1005	63	1019
Mamutovac	5.69-19.88	41.08-54.19	14.11-20.85	1.33-4.71	0.086-0.184	322-780	47-59	1107-1387	39-57	312-772
Obrovac-Stari Gaj	16.82-25.96	37.25-42.28	11.87-16.08	1.34-2.03	0.048-0.088	237-300	48-53	900-1074	31-63	403-733
Tošići-Dujići	2.21-14.2	33.79-47.34	12.57-35.08	1.54-2.38	0.092-0.165	393-704	31-39	1110-1501	55-75	959-3496
<i>Neogene</i>										
Košute	23.47-26.92	38.4-39.07	9.45-13.98	1.32-1.66	0.043-0.048	311-334	37	558-588	35	440-639
Strmendolac	1.11-4.75	47.4-51.94	17.19-23.23	2.08-2.54	0.096-0.134	278-610	36-46	482-669	49-58	417-769

deposits reach up to several million tons in size with thicknesses of 20 metres. Jurassic bauxites have a high SiO₂ content (>16 wt%), composed of boehmite-kaolinite-haematite±chlorite, anatase, rutile (MARKOVIĆ, 2002). An active bauxite mining site (Rovinj-1, Western Istria) is located within the Jurassic bauxite, where bauxite is mined and used as a corrective for cement production (JISMS RH, 2025). The total reserves of five deposits, including Rovinj-1, exceed 5 million tonnes of bauxite (KOVACHEVIĆ GALOVIĆ et al., 2025 and references therein).

The bauxite deposits of the Lower Cretaceous are disconformably underlain by Kimmeridgian limestones and overlain by Lower Cretaceous carbonate sediments. Small accumulations (tens of metres, thickness 1–2 m) of this clayey bauxite with low alumina and high SiO₂ content (up to 23 mass %) are found in the wider area of the Cetina river spring in Dalmatia (ŠUŠNJARA et al., 1990). Those bauxites are considered to have formed via incomplete bauxitization from kaolinic-clays. Their composition is kaolinite-boehmite-goethite-haematite ± anatase (MARKOVIĆ, 2002). There is no evidence of past exploitation activities.

Upper Cretaceous bauxites occur in the area of Kordun (Central Croatia). Their basement consists of white Cenomanian to Turonian limestones. The overlying sequence comprises Santonian to Maastrichtian limestone breccias, grey limestones and clastic flysch-type sediments, indicating that major changes in the sedimentary regime occurred after deposition of the bauxites (ŠINKOVEC et al., 1985). Bauxite is high in boehmite, having 63–72 wt% of Al₂O₃, followed by kaolinite, goethite and anatase. However, deposits are small-scale lenses, having up to 3 m thicknesses, with single economic exploitation in the past.

The Cretaceous–Eocene interval is considered to be the most favourable period for bauxitization (BARDOSSY, 1982) and most of the bauxite deposits of the Croatian Karst Dinarides were formed during the Early to Late Palaeogene (ŠINKOVEC & SAKAČ, 1991), in connection with three separate stratigraphic gaps.

- 1) The oldest gap occurs between the Upper Cretaceous and the Palaeocene Kozina beds. Depending on the level of karstification, bedrock as old as the Albian has been found below the Palaeocene bauxites. The favourable bauxite-forming conditions were contemporaneous with the beginning of the disintegration of the Adriatic carbonate platform during the Early Palaeocene Laramian movements and the emergence of the palaeo-surface across the entire platform. Thousands of small-scale bauxite deposits are in Istria (10,000 discoveries by 1976; MARKOVIĆ, 2002), the North Adriatic islands and Dalmatia. Although small (up to 25 kt, max. 35 kt), these deposits have a high alumina content ranging between 54–60 wt% Al₂O₃ and are composed of boehmite-gibbsite-haematite-goethite-kaolinite-anatase. As a result of peak bauxite production in Croatia during the 20th century, most of these deposits are now largely exhausted (MARKOVIĆ, 2002).
- 2) Carbonate sedimentation resumed with the lower Eocene transgression and continued until the middle Lutetian. A new Palaeogene land surface emerged along the northeast edge of the previous carbonate platform and bauxite accumulation lasted there from the Upper Lutetian to, in places, the Lower Oligocene (SAKAČ & ŠINKOVEC, 1991). Bauxite filled a tectonically controlled relief with a moderate to large angular unconformity, and the overlying sequence showed

considerable facies change in comparison with the underlying bedrock formations (ŠINKOVEC & SAKAČ, 1991). Mid-Eocene bauxites are underlain by Upper Cretaceous to Lower Eocene limestones and locally carbonate breccias and are overlain by the Upper Lutetian Jelar breccias. Those small deposits are predominantly found in Dalmatia, with up to 10 kt of gibbsite-kaolinite-haematite-goethite ore with variable Al_2O_3 to SiO_2 contents not suitable for alumina extraction (MARKOVIĆ, 2002).

- 3) The youngest Palaeogene gap is represented by Upper Eocene bauxites (also referred to as the Promina bauxite) which overlies the Upper Cretaceous to Upper Eocene limestone bedrock, again depending on the level of karstification, and these are overlain by the Upper Eocene/Lower Oligocene Promina conglomerates. Individual deposits contain up to several hundreds of thousand tonnes of bauxite ore, and appear in lenses, pseudo-layers or irregular bodies infilling depressions of the karstified surfaces. The ore is boehmite-gibbsite-haematite-goethite-anatase-kaolinite, with variable Al_2O_3 ranging from 44–50 mass % (MARKOVIĆ, 2002). Upper Eocene bauxite deposits, primarily located in Dalmatia, contain over 5 million tonnes of high-alumina bauxite, with 2 million tonnes concentrated in the Mamutovac, Krste Radas, and Čveljo Dolac deposits—here referred to as the Promina case study (JISMS RH, 2025; KRUK et al., 2014).

The Miocene bauxite, present today in Dalmatia and Kordun, accumulated between the Upper Cretaceous to Upper Eocene limestones and breccias and Middle Miocene marls, clayey marls and clastic sediments. It is suggested that this bauxite is at least partly redeposited and it is, as yet unknown to what extent it results from Miocene bauxitization processes. Due to their high clay content, they are classified as clayey bauxites to bauxitic clays. The major mineral constituents are

gibbsite, kaolinite, haematite, chlorite and goethite, with some detrital tourmaline, zircon and rutile. Their Al_2O_3 content is low (19–43 mass %), with a high SiO_2 content (18–38 mass %). Individual deposits occur as 100 m size lenses with thicknesses of 15–20 metres. The material has been used for brick manufacturing (MARKOVIĆ, 2002).

3.4. Exploitation status of Croatian bauxites

The quantities of bauxite mined in the Republic of Croatia were relatively small, ranging from 100 to 29,100 tonnes annually between 1998 and 2024. The extracted material is used as a modifier for the cement industry. Currently, there are only two active bauxite exploitation fields (EP) in the Republic of Croatia:

1) Kruševo EP, located in Zadar County and operated under a concession by Fassa Bartolo. Kruševo EP contains three types of raw materials: bauxite, carbonate minerals for industrial processing, and crushed stone aggregates, extracted via open-cast mining. Total economic reserves of bauxite in 2024 were 660 kt, while non-economic reserves reach up to 1.1 Mt (JISMS RH, 2025),

2) EF Rovinj, located in Istria County with an annual extraction of bauxite between 12,500 and 15,000 cubic metres. Bauxite, along with crushed stone aggregates, is extracted through open-cast mining. Total economic reserves in 2024 were 165 kt, and non-economic reserves were 540 kt (JISMS RH, 2025).

Despite the limited number of currently active bauxite exploitation fields, historical data reveals the existence of two inactive and 21 decommissioned fields, indicating a significant level of past bauxite mining activity (Fig. 2). These inactive fields collectively cover an area of 32,510 hectares.

The most recent reliable data on total bauxite reserves in the Republic of Croatia was published in 2011 by the JISMS RH (2025). It reported reserves for 18 fields, with a total of 22.6 million tonnes (Mt), of which 8.4 Mt were classified as economic and 14.2 Mt as non-economic reserves.



Figure 2. Graphical presentation of the total reserves (in million tonnes) vs. the number of bauxite fields demonstrates that the decrease in total reserves recorded in the Croatian national register is primarily due to the removal of dozens of bauxite exploitation fields from the register, rather than due to the actual depletion of the reserves (data taken from JISMS RH, 2025)

Since only 166,000 tonnes of bauxite were extracted between 2011 and 2024 (JISMS RH, 2025), it can be concluded that Croatia still retains a minimum of 8 Mt of economic and 14.2 Mt of non-economic reserves.

4. CASE STUDY: THE UPPER EOCENE PROMINA BAUXITE

The Promina beds are a transgressive unit of an approximately 3 km thick Palaeogene sedimentary sequence within the North-Central Dalmatian foreland basin. It comprises Cretaceous–Eocene carbonates, often rudist-bearing, Eocene–

Oligocene clastic sediments, and minor Neogene to Quaternary deposits. During the Mesozoic, the area was part of an extensive carbonate platform. Foreland basin formation began in the Middle Eocene as Dinaric deformation propagated toward the southwest (e.g. IVANOVIĆ et al., 1976; BRČIĆ et al., 2023), following the typical migration of orogenic fronts and basins (BEAUMONT, 1981). Basin evolution progressed from forebulge exposure to the deposition of ramp carbonates, hemipelagic sediments, and turbidites, passing later into a molasse stage. In the Promina municipality, Central Dalmatia, a total of 160 bauxite occurrences and deposits have been

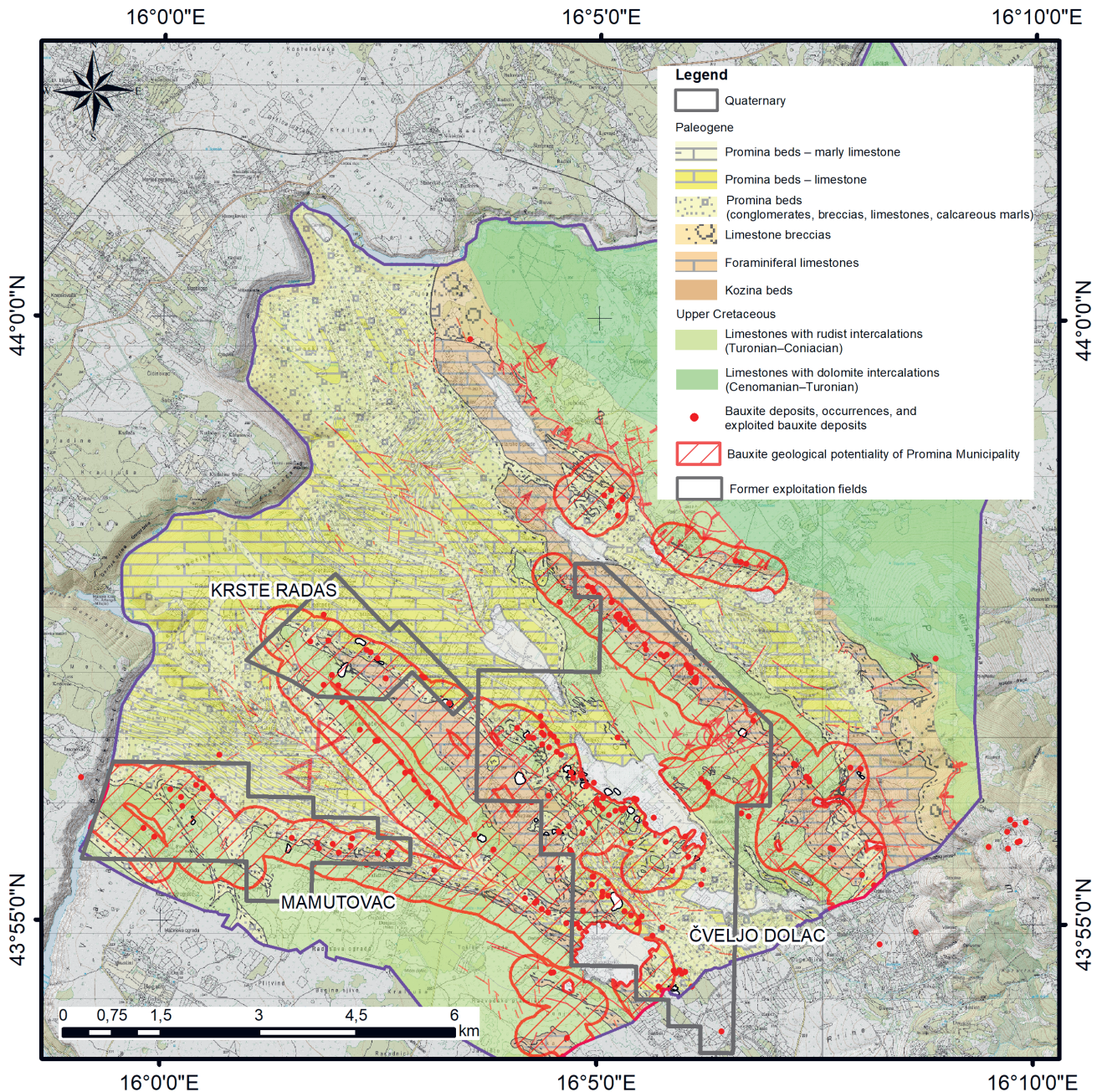


Figure 3. Geological map of the Promina municipality with administrative boundaries, general geology, bauxite-bearing areas, potentiality, exploitation fields, deposits and occurrences after KRUK et al. (2014). The outlined prospective bauxite exploration area is 31,60 km². The bauxite potential is based exclusively on geological criteria derived from the official geological map. This method represents what the authors define as unrestricted geological potential—a conceptual model that does not exclude areas based on existing land use, legal restrictions, or environmental protections. Instead, it focuses purely on the geological likelihood of bauxite presence, offering a broad overview of favourable conditions regardless of current spatial constraints. Such an approach is intended to serve as a preliminary step, laying the groundwork for more refined, multidisciplinary analyses that incorporate socioeconomic and environmental considerations

identified, the majority intercalated within the Upper Eocene Promina beds (Fig. 3). The bauxite deposits occur as infill of the karstified palaeorelief of the Upper Cretaceous rudist-bearing limestones or Lower Eocene foraminiferal limestones and are covered with sediments Eocene–Oligocene clastics (conglomerates, marls; BABIĆ & ZUPANIĆ, 2012; LUKŠIĆ et al., 2004; Fig. 3). The ore bodies are elongated lenses, irregular or pseudo-layered, reaching nearly 30 m in thickness at some places. These deposits belong to the category of small-scale bauxite deposits (INSPIRE Directive, Infrastructure for Spatial Information in the European Community (2007/2/EC), deposits below 10 Mt of bauxite ore, EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, 2007), which underwent exploration and exploitation, either through open-pit or underground mining methods, during the second half of the 20th century. They are grouped within three inactive bauxite exploitation fields: Mamutovac, Krste Radas, and Čveljo Dolac (KRUK et al., 2014).

In Figure 3, all references to unrestricted geological potential and prospective areas refer exclusively to geological favourability and exclude land-use constraints, environmental protection status, and permitting or regulatory considerations.

Following the completion of surface mining, the remaining exploitable reserves (categories A+B+C1) at the Mamutovac site total to 290 kt of bauxite, with an average Al_2O_3 content of 43.6 wt% and variable SiO_2 content ranging from 9.2 to 19.2 wt% (Suppl. 1). Mamutovac bauxites have a uniform Fe_2O_3

content ranging from 15.6 to 19.8 mass % and are classified as bauxite with a high degree of lateritization according to ALEVA (1994) and SCHELLMANN (1986; Fig. 4).

In the Krste Radas bauxite exploitation field, a total of 213 Kt of bauxite remains available for underground mining, characterized by a higher Al_2O_3 content of 46.5 wt% and a notably low SiO_2 content of 7.3 wt%. Krste Radas bauxites have high Fe_2O_3 content of 18.3 wt% and are classified as bauxite – ferritic bauxite with high degree of lateritization according to ALEVA (1994) and SCHELLMANN (1986; (Fig. 4; Suppl. 1).

The largest exploitation field in the region, Čveljo Dolac, contains remaining reserves close to 2 Mt located within numerous small deposits (Suppl. 1). This exploitation field consists of individual deposits that are categorized as (i) exploited deposits (27 deposits); (ii) partially exploited deposits which have experienced previous bauxite extraction, but still retain a proportion of their mineral reserves, indicating the potential for further exploitation (5 deposits), and (iii) unexploited deposits: have been explored and confirmed to contain bauxite reserves (20 deposits which never were mined). Deposits were extracted by both underground and open pit mining.

The Čveljo Dolac bauxite has average 47.2 mass % of Al_2O_3 with a very low to moderate SiO_2 content (2.7–17.4 mass %), while the Fe_2O_3 is high and ranges from 17.8 to 24.9 mass

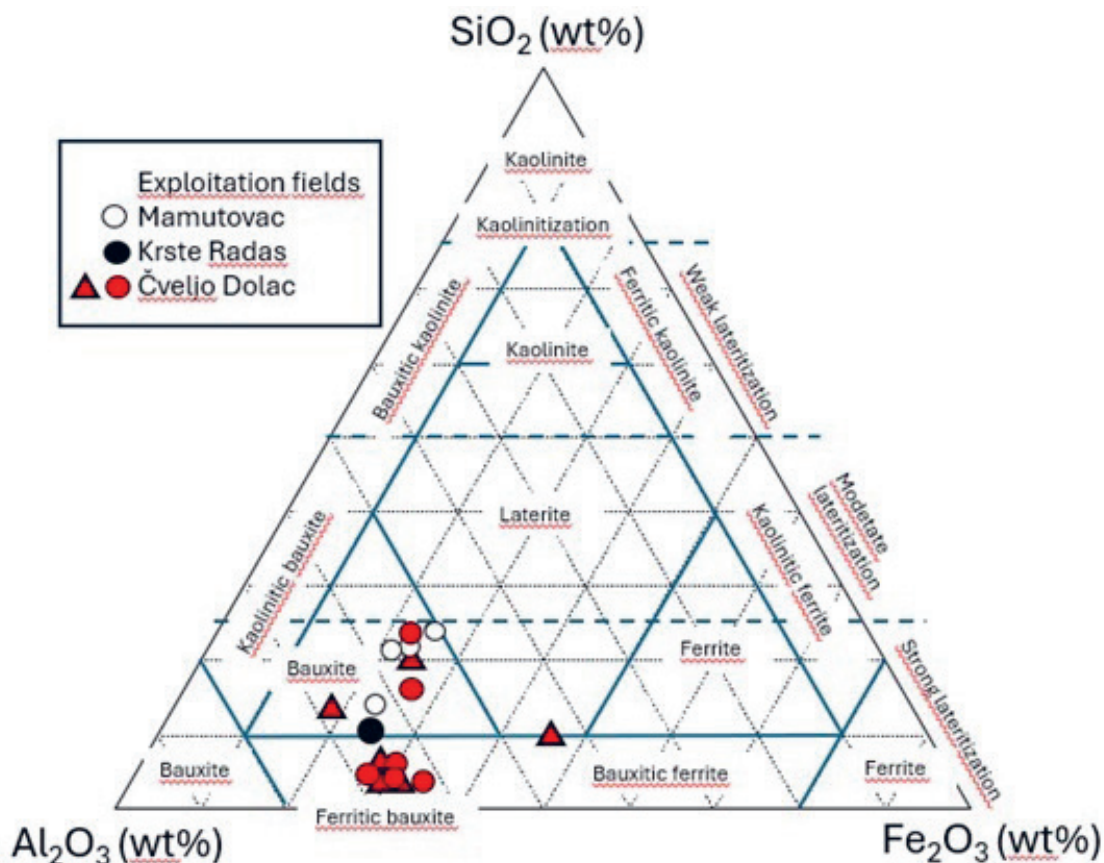


Figure 4. Tricomponent Al_2O_3 – SiO_2 – Fe_2O_3 composition of Upper Eocene Promina bauxite modified after ALEVA (1994) and SCHELLMANN (1986). Data taken from KRUK et al. (2014; (circles); TOMAŠIĆ et al. (2021; (triangle). Note the variable Al_2O_3 and SiO_2 ranging from 35.7 to 47.2 mass % and 2.7 to 19.2 mass % respectively. Fe_2O_3 range from 15.7 to 24.9 mass %. Average compositions for Mamutovac field generally show lower Al_2O_3 and SiO_2 compared to the Krste Radas and Čveljo Dolac fields

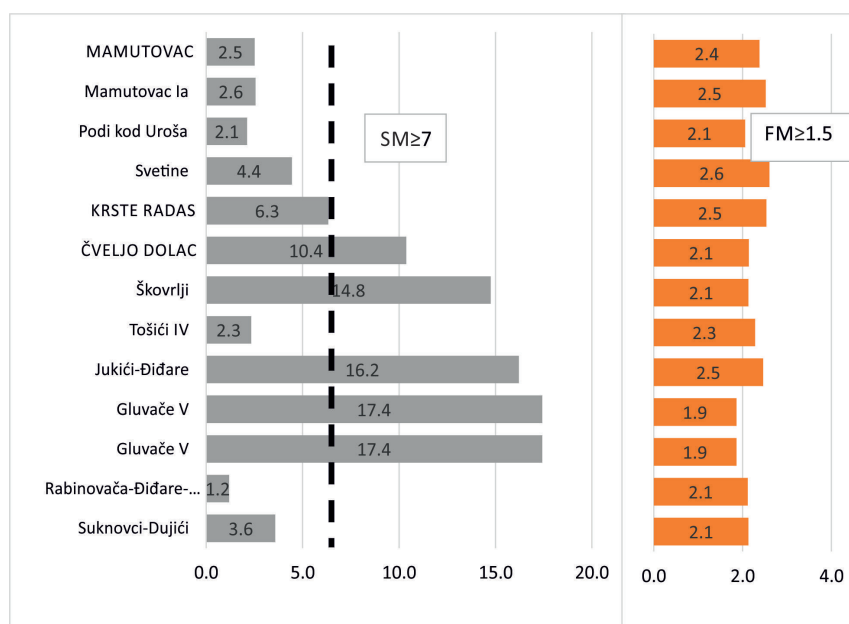


Figure 5. Graphic presentation of: SM – silica module, Al_2O_3/SiO_2 ; values ≥ 7 suggest low silica and favourable Bayer processing, and FM ferric - module Al_2O_3/Fe_2O_3 ; values ≥ 1.5 suggest low Fe and favourable alumina recovery of Upper Eocene Promina bauxite, calculated after BROUGH & JOUHARA (2020), showing preferable ratios of the major oxide in respect to bauxite use for alumina industry via the Bayer process

%. Bauxites are classified as ferritic bauxite to bauxite with a high degree of chemical weathering (Fig. 4).

Silica and ferric modules ($SM = Al_2O_3/SiO_2$; $FM = Al_2O_3/Fe_2O_3$) of the deposits discussed are presented in Figure 5 (BROUGH & JOUHARA, 2020). While all deposits exhibit favourable FM values ($FM \geq 1.5$), only a subset meet the threshold of $SM \geq 7$, indicating their suitability for alumina production via the Bayer process. However, it should be noted that the presented thresholds are only indicative and industrial feasibility would depend on the selected processing route and impurity management.

Typical “bauxitophile” microelements (Co, Ni, Cr, V, Ga; sensu SCHROLL & SAUER, 1968; MONDILLO et al., 2011; HERRINGTON et al., 2016) have been selected for further

analysis of their relative concentration compared to upper continental crust (RUDNICK & GAO, 2005).

The sum of selected trace elements in the Croatian Upper Eocene bauxite ranges from ≈ 900 to >2000 ppm (Fig. 6). Relative to Upper Continental Crust (UCC; RUDNICK & GAO, 2005), cobalt (10–40 ppm; UCC 17 ppm) shows depletion to minor enrichment ($EF \leq 2.1$). In contrast, Ni, Cr, V, and Ga are consistently enriched: Ni 170–580 ppm (UCC 47 ppm; EF 3.6–12.4), Cr 395–850 ppm (UCC 92 ppm; EF 4.3–8.8), V 230–970 ppm (UCC 97 ppm; EF 2.4–10), and Ga 50–100 ppm (UCC 18 ppm; EF 2.9–5.8).

The Upper Eocene bauxite also contains elevated total REE (300–5000 ppm; mean ≈ 770 ppm) with strong LREE enrichment ($\sum LREE (La-Sm) / \sum HREE (Eu-Lu) = 3.6–15.7$),

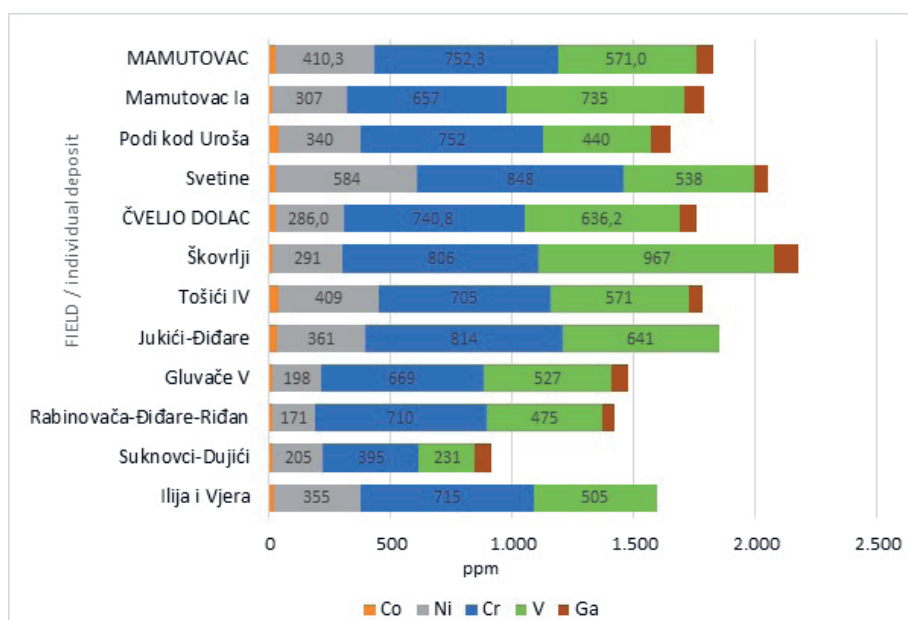


Figure 6. Graphic representation of selected microelements (Co, Ni, Cr, V, Ga) of Upper Eocene Promina bauxite (data from KRUK et al., 2014).

compared to Late Triassic, Late Jurassic, Early Cretaceous, Late Cretaceous, Palaeocene, Middle Eocene, Late Eocene, and Miocene bauxites (KOVAČEVIĆ GALOVIĆ et al., 2025).

5. DISCUSSION

5.1. Geological potential and uses of the Croatian bauxite

Bauxite geological potential is based on the following factors: historical data on exploration and exploitation, deposit size, remaining reserves, favourable mineralogy and chemistry aligned with potential industrial uses. Possible uses of Croatian bauxite deposits depend on the viability of their exploitation as well as cost-related factors (e.g. exploitation methods, transport and processing requirements).

Dinaric bauxite deposits are generally categorized as small-scale deposits (<10 Mt of bauxite ore; INSPIRE Directive (EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION, 2007)). The largest individual bauxite deposits in the Dinarides are located in Bosnia and Herzegovina and Montenegro and could reach up to several million tons, whereas Croatian deposits are much smaller, reaching up to a maximum of several hundred thousand tons (BOROJEVIĆ ŠOŠTARIĆ et al., 2022; RADUSINOVIĆ & PAPADOPOULOS, 2021; MARKOVIĆ, 2002; JISMS RH, 2025). Furthermore, the chemical composition of the major oxides (described as silica, ferric and titanium modules), microelements and REE of individual deposit strongly depends on the associated geological horizon, corresponding climatic conditions, and microenvironment, as well as the proximity to flysch, or ophiolite units and/or the intensity of volcanic eruptions on the regional scale (sensu BILIĆ et al., 2025; PERKOVIĆ et al., 2024; ECONOMOU-ELIOPOULOS & KANELLOPOULOS, 2023; RADUSINOVIĆ & PAPADOPOULOS, 2021; TOMAŠIĆ et al., 2021 and references therein).

Bauxites were evaluated from the aspect of critical commodities including Ti, V, Ni, Co, REE, and Ga. In Croatia, Ti is found in amounts ranging from 2 to 3% TiO₂ in most deposits, irrespective of their age, with some cases even exceeding 3% TiO₂. Mineralogical analysis has shown that most of the TiO₂ is present as anatase, while rutile is subordinate (REEBAUX, 2020). Croatian bauxites have increased ΣREE. The highest values were observed in the Upper Eocene bauxites where ΣREE reach up to 5000 ppm (median value 570 ppm), whereas median values of Middle Eocene, Upper Jurassic, Lower Cretaceous, Upper Cretaceous, Palaeocene and Neogene show similar and high median Total REE ranging from 575–400 ppm (KOVAČEVIĆ GALOVIĆ et al., 2025). For comparison, numerous other karst-type bauxite deposits of the Mediterranean region also exhibit high total REE content, including the Vojnik–Maganik (ΣREE = 970) and Prekornica Bauxite Region (Total REE = 1057 ppm; Montenegro; RADUSINOVIĆ & PAPADOPOULOS, 2021), Parnassos–Giona Bauxite District (ΣREE = 387–1282 ppm; Greece; DEADY et al., 2014, 2016), Vecchia Miniera (ΣREE = 718–984 ppm and Campo Felice, Abruzzi (ΣREE = 689–1038 ppm; Italy; PUTZOLU et al., 2018), Iharkút ΣREE 1023 ppm (Hungary) (TOMAŠIĆ et al., 2021).

5.1.1. High potentiality for exploration and extraction

Two Croatian bauxite horizons, both associated with the AdCP are considered to have high potentiality for further exploration and exploitation (Table 3).

Jurassic bauxites from Western Istria with total reserves exceeding 5 million tonnes of bauxite, including the Rovinj-1 deposit that is currently under exploitation (MARKOVIĆ, 2002; JISMS RH, 2025; KOVAČEVIĆ GALOVIĆ et al., 2025 and references therein). Reserves of Jurassic bauxites deposits reach several hundred thousand tonnes and have a high SiO₂ content (>16 wt%), high Al₂O₃ (50–60 wt%) and Fe₂O₃ (10–22 wt%) content. They are currently used as a corrective for cement production. Considering its properties, structural clay production for building construction (roof tiles or bricks etc.) might be taken into consideration. Rovinj deposit in Istria have a high Total REE, reaching up to 1295 ppm (REEBAUX, 2020).

Upper Eocene Promina bauxites located in Dalmatia, with over 5 million tonnes of high-alumina bauxite, have variable Al₂O₃, SiO₂ and Fe₂O₃. Their ferric module (FM ≥ 1.5) is favourable to meet criteria for the Bayer process, however, only a part of those deposits have appropriate silica module (SM ≥ 7; data after KRUK et al., 2014). Therefore, the majority of Promina bauxites would not be suitable for alumina production via the Bayer process, however, they might be used for cement or structural clay production. Upper Eocene Promina bauxites are particularly enriched in REE. In Čveljo Dolac exploitation field in Promina municipality (Tošići–Dujjići, Jukići–Đidare) ΣREE reach up to 3495 ppm, in Gljev in the Sinj area ΣREE reach up to 1790 ppm (REEBAUX, 2020).

5.1.2. Medium potentiality – extraction

Upper Triassic clayey bauxite of Lika and Kordun (Central Croatia), and the north Dalmatia region (Coastal Croatia) are associated with the Southern Tethyan Megaplatform. These Bauxites have a low alumina and high SiO₂ content. Individual deposits reach up to several hundred thousand tons and the remaining reserves within numerous deposits are several million tons (MARKOVIĆ, 2002; JISMS RH, 2025; KOVAČEVIĆ GALOVIĆ et al., 2025 and references therein). Due to its generally high clay content, the ore is suitable for structural clay and brick production only.

5.1.3. Low- or no-potentiality

All the remaining deposits are small and with limited reserves. Lower Cretaceous and Miocene clayey bauxite with low alumina and high SiO₂ content from Dalmatia and Kordun area could be used for brick production. The majority of Palaeocene bauxite deposits from Istria, the North Adriatic islands and Dalmatia, with high alumina of metallurgical and cement grade were exploited. The maximum size of these deposits was up to 25 to 35 kt. Upper Cretaceous and Mid Eocene bauxites from Central Croatia and Dalmatia are small-scale (10 kt each) with variable Al₂O₃ to SiO₂ composition and could potentially be used for the cement industry. However, since the annual domestic production of correctives for the cement industry from two larger deposits is only 17 kt, the conclusion is that those deposits are generally too small for sustainable and long-term supply of the cement industry.

Table 4. Available exploitable reserves of the inactive bauxite exploitation fields in the Promina municipality, along with the different exploitation methods and their total value (KRUK et al., 2014).

Bauxite exploitation field	Quantity			Total (t)	Total (€) using average 20 €/t (*)
	Surface method (t)	Underground method (t)	Combined methods (t)		
MAMUTOVAC	290 918	0	0	290 918	5 527 442
KRSTE RADAS	0	213 500	0	213 500	3 416 000
ČVELJO DOLAC	11 3089	1 789 445	9 800	1 912 334	33 229 811
Total	404 007	2 002 945	9 800	2 416 752	42 173 253

* The quantities of bauxite reduced for exploitation losses (5% for surface mining (after MIHOVILOVIĆ et al., 2023), 20% for underground mining and 12.5% for combined methods; GALIĆ, 2006) and multiplied by the average price

5.2. Economic assessment of the Promina case study

5.2.1. Suggested mining and extraction methods

Although the likelihood of future exploitation is minimal, the hypothetical value of the remaining bauxite reserves has been calculated. The quantities of bauxite presented in Table 3 have been adjusted to account for extraction losses, estimated at approximately 5% for surface mining, 20% for underground mining, and 12.5% for combined methods (underground and open-pit (GALIĆ, 2006)). These adjusted quantities were then multiplied by the average market price for unprocessed, low-quality (cement) bauxite, which is approximately 20.00 €/t (MIHOVILOVIĆ et al., 2023). The total value of the remaining bauxite, without the extraction of valuable elements, would reach 42 M€. It represents an indicative gross in situ value of the raw material, as the costs of mining, processing, transport, environmental protection, taxes, and other related expenses are not deducted. Considering the amount of bauxite and overburden, as well as the position and depth of the deposit, it turned out that almost 80% of the total exploitable reserves in the largest bauxite exploitation field (Čveljo Dolac) and 100% of the exploitable reserves from Krste Radas can be extracted through underground mining, while approximately 20% of the total reserves (Čveljo Dolac) and 100% of the exploitable reserves of Mamutovac are suitable for surface (open pit) exploitation (Table 4).

In addition to the bulk bauxite value, recent geochemical analyses suggest notable enrichment in certain microelements. The selected microelements (Suppl. 1, Fig. 6) were extrapolated for the Mamutovac and Čveljo Dolac deposits and multiplied

by the total reserves to estimate their tonnages in bauxite (Table 5). The deposits contain approximately 10.4 kt of titanium, 0.6 kt of chromium, 0.5 kt of vanadium, and 0.2 kt of nickel, while gallium content is low. Furthermore considering a median Σ REE value of 570 ppm for the Upper Eocene Promina bauxites (KOVAČEVIĆ GALOVIĆ et al., 2025), an additional 1.4 kt of rare earth elements (REE) can be expected within the remaining 2.4 Mt of ore. These elements represent a potential added value that, although not immediately exploitable under current market conditions, may become economically significant in the context of increasing demand for strategic and critical raw materials. Their presence further supports consideration of re-evaluating bauxite tailings and low-grade ores not only as a source of aluminium but also as a future reservoir of critical metals.

5.2.2. Potential uses of the Promina bauxite

Nominally, bauxite from all three exploitation fields in the Promina area (Čveljo Dolac, Mamutovac, Krste Radas) is generally less suitable for metallurgical, and particularly for abrasive, chemical, and refractory applications, as it typically contains less than 50% Al₂O₃. However, certain deposits, such as Jukići–Đidare and Gluvače, exhibit a more favourable Al₂O₃/SiO₂ ratio, along with acceptable Fe₂O₃ and TiO₂ levels, making them potentially suitable for metallurgical use. Otherwise, most of the bauxite is more appropriate for cement production due to its chemical composition.

Importantly, recent investigations have highlighted the presence of valuable microelements within these deposits. For example, significant quantities of titanium, chromium,

Table 5. Quantities of microelements within bauxite, in situ content only assuming 100% recovery (recalculated after KRUK et al., 2014).

Deposit	Ni (t)	Cr (t)	V (t)	Ga (t)	Ti (t)
MAMUTOVAC	56.63	118.81	113.80	13.32	2,516.14
Mamutovac Ia	34.38	73.58	83.32	8.84	1,665.44
Podi kod Uroša	17.00	37.60	22.00	4.00	725.51
Svetine	5.25	7.63	8.48	0.48	125.19
ČVELJO DOLAC	164.52	458.85	349.20	27.18	7,881.30
Škovrlji	14.55	40.30	48.80	5.10	602.59
Tošići IV	5.93	10.22	8.28	0.85	215.61
Jukići–Đidare	77.26	136.42	107.43	n.a.	2,985.53
Gluvače V	6.93	23.41	18.44	2.38	572.91
Rabinovača–Đidare–Riđan	59.85	248.50	166.25	18.85	3,504.66
Total	221.15	577.66	463.00	40.50	10,397.44

vanadium, nickel, and rare earth elements (REE) have been identified in the remaining reserves of Čveljo Dolac and Mamutovac, contributing to their potential as secondary sources of critical raw materials. Additionally, in the Tošići–Dujjići deposit, REE concentrations of up to 3,500 ppm have been recorded (REEBAUX, 2020), further underscoring the strategic importance of microelement content in regional bauxites. Though the aforementioned deposit has been largely exhausted, it can present a showcase for similar still prospective deposits in this area. Therefore, future exploration in the Promina area should not only reassess the conventional exploitation potential but also prioritise the evaluation of microelement enrichment, especially in the context of increasing demand for critical and strategic raw materials.

6. CONCLUSION

The important properties of bauxite as well as common mining and processing methods and applications are:

- 1) Bauxite is a sedimentary rock composed mainly of free aluminium minerals (gibbsite, boehmite, diaspore) along with iron and titanium oxides, clays, quartz, and other minor constituents; its colour, texture, and density vary with iron content, depositional environment, and geological age, all of which critically influence its suitability for processing.
- 2) Bauxite deposits are classified into lateritic and karst types: lateritic bauxites form from weathering of Al-rich rocks under tropical to subtropical climates, while karst bauxites accumulate in karst depressions from weathered carbonate or Al-silicate rocks. Both may display distinct upper (eluviation) and lower (illuviation) horizons, and can be variably enriched in Fe, Ti, and critical elements such as REE, Ga, Sc, and V, with mineralogy and water content influencing their grindability and industrial suitability.
- 3) Bauxite is primarily used as the raw material for aluminium production ($\approx 90\%$ of global extraction), with lateritic deposits typically mined via surface methods and karst deposits requiring underground or combined mining; its mineralogy – dominated by gibbsite, boehmite, and diaspore – determines processing conditions, while residues (red mud) can contain economically valuable critical elements such as scandium, gallium, vanadium, and REE, which can be recovered through specialized extraction techniques.
- 4) Bauxite is classified by industrial grade for specific applications: chemical-grade ($\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3 \geq 23:1$) is used for aluminium chemicals and water treatment; high-alumina cement-grade ($\text{Al}_2\text{O}_3/\text{SiO}_2 \geq 10:1$, $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3 \geq 20:1$, $\text{Al}_2\text{O}_3/\text{TiO}_2 \geq 16:1$) produces chemically resistant cement; refractory-grade requires high alumina with low Fe, Ti, and silica for alumina refractories; and abrasive-grade ($>82\%$ Al_2O_3 , silica $\leq 8\%$) is used for brown-fused alumina, while white-fused alumina derives from high-purity Bayer alumina ($\approx 99\%$ Al_2O_3).

The bauxite deposits within the Republic of Croatia can be subdivided to:

- 1) High potentiality deposits, encompassing (i) Jurassic bauxites (Istria), with total reserves exceeding 5 Mt (e.g. Rovinj-1 currently exploited), high Al_2O_3 (50–60 wt%), Fe_2O_3 (10–22 wt%), $\text{SiO}_2 > 16$ wt%; suitable for cement and potentially structural clay; REE up to 1,295 ppm, and (ii) Upper Eocene Promina bauxites (Dalmatia), with over 5 Mt of high-alumina bauxite, favourable ferric module, partially meeting silica module criteria and suitable for cement/structural clay: Further bauxite reserves have REE contents up to 3,495 ppm, representing potential secondary sources for future industrial and strategic uses.
- 2) Medium potentiality Upper Triassic clayey bauxites (Lika, Kordun, north Dalmatia), where individual deposits reach several hundred thousand tons; total remaining reserves across numerous deposits reach several million tons, having low Al_2O_3 , high SiO_2 and are suitable for structural clay and brick production.
- 3) Low/no potentiality Lower Cretaceous, Miocene, Palaeocene, Upper Cretaceous and Mid-Eocene deposits with maximum size of 10 to 35 kt, limited reserves, variable composition, only minor use for cement or brick production. These deposits are insufficient for sustainable long-term supply.

Bauxite case study: Upper Eocene Promina bauxite beds in Central Dalmatia (Čveljo Dolac, Mamutovac, Krste Radas; with remaining reserves ≈ 2.4 Mt), up to 30 m thick, occur as lens-shaped or pseudo-layered infill of karstified Upper Cretaceous rudist-bearing and Lower Eocene foraminiferal limestones. Extraction methods include historical open-pit and underground mining; Čveljo Dolac $\approx 80\%$ underground / 20% surface, Krste Radas 100% underground, Mamutovac 100% surface. The remaining bauxite reserves are estimated at approximately €42 million (market price ≈ 20 €/t) based on medium quality material for cement industry use, while higher quality bauxite suitable for metallurgical applications could reach a value of up to €68 million. Deposits are enriched in critical and strategic microelements, including ≈ 10.4 kt Ti, 0.6 kt Cr, 0.5 kt V, 0.2 kt Ni, and ≈ 1.4 kt REE (median 570 ppm), representing potential secondary sources for future exploitation.

REFERENCES

- ADAMSON, A.N., BLOORE, E.J. & CARR, A.R. (1963): Basic Principles in Bayer Process Design.– In: GERARD, G. & STROUP, P.T. (eds.): Extractive Metallurgy of Aluminium: Proceedings, Vol. 1. Interscience Publications, New York, 23–56.
- ALEVA, G.J.J. (1994): Laterites: Concepts, Geology, Morphology and Chemistry.– International Soil Reference and Information Centre (ISRIC), Wageningen, 169 p.
- BABIĆ, L. & ZUPANIĆ, J. (2012): Laterally variable development of a basin-wide transgressive unit of the North Dalmatian foreland basin (Eocene, Dinarides, Croatia).– *Geologia Croatica*, 65/1, 1–27. <https://doi.org/10.4154/GC.2012.01>
- BÁRDOSSY, G. (1982): Karst bauxites: Bauxite Deposits on Carbonate Rocks. Developments in Economic Geology, 14.– Elsevier, Amsterdam, 441 p.
- BÁRDOSSY, G. & ALEVA, G.J.J. (1990): Lateritic bauxites.– Akad. Kiadó, Budapest; ElsevierSci Publishers, Amsterdam, 624 p.
- BEAUMONT, C. (1981): Foreland basins.– *Geophysical Journal of the Royal Astronomical Society*, 65/2, 291–329. <https://doi.org/10.1111/j.1365-246X.1981.tb02683.x>

- BILIĆ, Š., PEYTCEVA, I., GEORGIEV, S. & HOLMA, M. (2023): Petrography and geochemistry of Cretaceous bauxites from Jajce, Bosnia and Herzegovina.– Review of the Bulgarian Geological Society, 84/3, 77–80. <https://doi.org/10.52215/rev.bgs.2023.84.3.77>
- BOROJEVIĆ ŠOŠTARIĆ, S., MARKEJL, A., JAŠAREVIĆ, E. & HAINDL, A. (2022): Geological potential of antimony, bauxite, fluorite, and magnetite of the Central Dinarides (Bosnia and Herzegovina): Exploration and exploitation perspective.– *Geologia Croatica*, 75/2, 269–287. <https://doi.org/10.4154/gc.2022.21>
- BOROJEVIĆ ŠOŠTARIĆ, S., TOMAŠIĆ, N., BOHANEK, V., GIZDAVEC, N. & MIKO, S. (2025): Croatian critical mineral commodity letters: Magnesium.– *Geologia Croatica*, 78/1, 87–101. <https://doi.org/10.4154/gc.2025.04>
- BRČIĆ, V., DUNKL, I., MINDSZENTY, A., BRLEK, M., TRINAJSTIĆ, N., BAJO, P., BAULUZ, B., MIŠUR, I., KARIUS, V., ŠUICA, S., KUKOČ, D., YUSTE, A., LAITA, E., VON EYNATTEN, H. & ZEH, A. (2023): A time-space window between Eocene karst bauxite genesis and the first molasse deposition in the Dinaric Foreland Basin in North Dalmatia, Croatia.– *Frontiers in Earth Science*, 11, 1224164. <https://doi.org/10.3389/feart.2023.1224164>
- BROUGHT, D. & JOUHARA, H. (2020): The aluminium industry: A review on state-of-the-art technologies, environmental impacts and possibilities for waste heat recovery.– *International Journal of Thermofluids*, 12, 100007. <https://doi.org/10.1016/j.ijft.2020.100007>
- CHANG, L.L.Y. (2002): *Industrial Mineralogy – Materials, Processes and Uses*.– Prentice Hall, Upper Saddle River. 472 p.
- CUSACK, P.B., CALLERY, O., COURTNEY, R., UJACZKI, É., O'DONOGHUE, L.M.T. & HEALY, M.G. (2019): The use of rapid, small-scale column tests to determine the efficiency of bauxite residue as a low-cost adsorbent in the removal of dissolved reactive phosphorus from agricultural waters.– *Journal of Environmental Management*, 241, 273–283. <https://doi.org/10.1016/j.jenvman.2019.04.042>
- DEADY, É., MOUCHOS, E., GOODENOUGH, K., WILLIAMSON, B. & WALL, F. (2014): Rare earth elements in karst-bauxites: A novel untapped European resource?– In: *Proceedings of the 1st European Rare Earth Resources Conference (ERES 2014)*, Milos, Greece.
- DEADY, É., MOUCHOS, E., GOODENOUGH, K.M., WILLIAMSON, B.J., WALL, F., BASHAM, I., BIDE, T. & ZHAO, F. (2016): Rare earth elements in karst bauxites: a novel untapped European resource?– *Ore Geology Reviews*, 72, 604–624. <https://doi.org/10.1016/j.oregeorev.2015.07.024>
- DILL, H.G. (2010): The “chessboard” classification scheme of mineral deposits: Mineralogy and geology from aluminium to zirconium.– *Earth-Science Reviews*, 100/1–4, 1–420. <https://doi.org/10.1016/j.earscirev.2010.06.002>
- ECONOMOU-ELIOPOULOS, M. & KANELLOPOULOS, C. (2023): Abundance and genetic significance of lithium in karst-type bauxite deposits: A comparative review.– *Minerals*, 13/7, 962. <https://doi.org/10.3390/min13070962>
- GALIĆ, I. (2006): Glavni rudarski projekt eksploatacije ležišta boksita u eksploatacijskom polju “Bešpelj” [in Croatian].– *Rudarsko-geološko-naftni fakultet*.
- GANZA, H. (2021): 101 godina električne energije u Splitu: Elektrodalmacija 1920.–2021. [*101 Years of Electrical Energy in Split: Elektrodalmacija 1920–2021* – in Croatian].– HEP-Operator distribucijskog sustava d.o.o. / Elektrodalmacija, Split, 472 str.
- GITZEN, W.H. (1976): *Alumina as a ceramic material*.– American Ceramic Society, Wiley, 264 p.
- HABIBI, H., MOKMELI, M., SHAKIBANI, S., PIROUZAN, D. & POURKARIMI, Z. (2023): Separation and recovery of titanium and scandium from the red mud.– *Separation and Purification Technology*, 317, 123882. <https://doi.org/10.1016/j.seppur.2023.123882>
- HERRINGTON, R., MONDILLO, N., BONI, M., THORNE, R. & TAVLAN, M. (2016): Bauxite and nickel-cobalt lateritic deposits of the Tethyan Belt.– In: *Tectonics and Metallogeny of the Tethyan Orogenic Belt*. Society of Economic Geologists Special Publication, 19. Society of Economic Geologists, Littleton, CO, 349–387.
- IVANOVIĆ, A., SAKAČ, K., SOKAČ, B., VRŠALOVIĆ-CAREVIĆ, I. & ZUPANIĆ, J. (1976): Osnovna geološka karta SFRJ 1:100 000. Tumač za list Obrovac L 33-140 [*Basic Geological Map of SFRJ 1:100 000. Explanatory notes for the Obrovac sheet L 33-140* – in Croatian].– Institut za geološka istraživanja, Zagreb, Savezni Geološki Zavod, Beograd, 61 p.
- JALILI, Z., BAHRAMI, A., GHADRI, M., NEMATI AKHGAR, B. & KAZEMI, F. (2022): Leaching for iron removal from low-grade bauxite ore to access refractory instruction.– *Rudarsko-geološko-naftni zbornik*, 37/1, 55–64. <https://doi.org/10.17794/rgn.2022.1>
- JURKOVIĆ, I. (1962): Boksiti Like i susjednih područja [*Bauxites of Lika and neighboring areas* – in Croatian with English summary].– *Geološki vjesnik*, Vol. 15/1, Zagreb.
- KLAUBER, C., GRÄFE, M. & POWER, G. (2011): Bauxite Residue Issues: II. Options for Residue Utilization.– *Hydrometallurgy*, 108 (1–2), 11–32. <https://doi.org/10.1016/j.hydromet.2011.02.007>
- KOVAČEVIĆ GALOVIĆ, E., ILJANIĆ, N., GIZDAVEC, N., MIKO, S. & PEH, Z. (2025): Geochemical insights and mineral resource potential of rare earth elements (REE) in the Croatian karst bauxites.– *Minerals*, 15/2, 192. <https://doi.org/10.3390/min15020192>
- KRUK, B., DEDIĆ, Ž., MIKO, S., GIZDAVEC, N. & KOVAČEVIĆ GALOVIĆ, E. (2014): *Rudarsko-geološka studija Šibensko-kninske županije [Mining and Geological Study of Šibenik-Knin County* – in Croatian].– Croatian Geological Survey, Department for Mineral Resources and Marine Geology, Zagreb, unpublished report.
- LUKŠIĆ, B., PENCINGER, V., JURIĆ, A. & JURIĆ, J. (2004): Elaborat o rezervama boksita u eksploatacijskom polju mamutovac [*Elaboration on the bauxite reserves in the Mamutovac exploitation field* – in Croatian].– Fund of professional documents 032/04: Unpublished report; Croatian Geological Survey: Zagreb, Croatia, p. 24.
- LYMPEROPOULOU, T., GEORGIU, P., TSAKANIKI, L.-A., HATZILYBERIS, K. & OCHSENKUEHN-PETROPOULOU, M. (2019): Optimizing Conditions for Scandium Extraction from Bauxite Residue Using Taguchi Methodology.– *Minerals*, 9(4), 236. <https://doi.org/10.3390/min9040236>
- MAJSTOROVIĆ, S. & TOŠIĆ, D. (2016): Analysis of ore losses and dilution factors in bauxite underground exploitation.– *Archives for Technical Sciences*, 2/15, 15–22. <https://doi.org/10.7251/afst.2016.0815.015M>
- MARKOVIĆ, S. (2002): *Hrvatske mineralne sirovine*.– Institut za geološka istraživanja, Zagreb, 544 p.
- MARUŠIĆ, R., VUJEC, S. & SAKAČ, K. (1993): Minjera – svjetski značajan mineraloški i rudarski lokalitet Istre [*Minjera – a world-famous mineralogical and mining site in Istria* – in Croatian].– *Buzetski zbornik*, 18, 49–77.
- MIHOVILOVIĆ, M., MIHOVILOVIĆ, T. & JURINOVIĆ, A. (2023): Elaborat o obnovi rezervi boksita i tehničko-gradevnog kamena na eksploatacijskom polju boksita “Rovinj” sa stanjem 31. prosinac 2022 [in Croatian].– *Sedma obnova, GEO-5 d.o.o., Rovinj*.
- MONDILLO, N., BONI, M., BALASSONE, G. & ROLLINSON, G. (2011): Karst bauxites in the Campania Apennines (southern Italy): A new approach.– *Periodico di Mineralogia*, 80, 407–432.
- NEŽIĆ, M. (2015): Minjera: Pregled rudarske i prerađivačke djelatnosti podno Sovinjaka [*Minjera: Overview of mining and processing activities at the foot of Sovinjak* – in Croatian].– *Reprezent d.o.o., Katedra Čakavskog sabora Buzet, Buzet*, 160 str.
- PAN, X., WU, H., LV, Z., YU, H. & TU, G. (2023): Recovery of valuable metals from red mud: A comprehensive review.– *Science of the Total Environment*, 904, 166686. <https://doi.org/10.1016/j.scitotenv.2023.166686>
- PERKOVIĆ, I., CVETKO TEŠOVIĆ, B., MARTINUŠ, M. & DURN, G. (2024): Genesis of the Rovinj-1 bauxite deposit (Istria, Croatia): Record of palaeoclimatic trends and palaeoenvironmental changes during the latest Jurassic of the Adriatic Carbonate Platform.– *Ore Geology Reviews*, 173, 106236. <https://doi.org/10.1016/j.oregeorev.2024.106236>
- POWER, T. (1986): *Fused materials – the high purity high performance oxides*.– *Industrial Minerals*, 37–51.

- POWER, G., LOH, J. & THORNE, R. (2011): Regenerating the Bayer process: The history, the future and the theoretical and practical limits.– *Hydrometallurgy*, 108/1-2, 45–59.
- PUTZOLU, F., PICCOLO PAPA, A., MONDILLO, N., BONI, M., BALASSONE, G. & MORMONE, A. (2018): Geochemical characterization of bauxite deposits from the Abruzzi mining district (Italy).– *Minerals*, 8/7, 298. <https://doi.org/10.3390/min8070298>
- RADUSINOVIC, S. & PAPADOPOULOS, A. (2021): The potential for REE and associated critical metals in karstic bauxites and bauxite residue of Montenegro.– *Minerals*, 11/9, 975. <https://doi.org/10.3390/min11090975>
- REEBAUX (2020): Bauxite and bauxite residue as a potential resource of REE in the ESEE region - Booklet (ed. Nenad Tomašić). KAVA REEBAUX - Prospects of REE recovery from bauxite and bauxite residue in the ESEE region – EIT RM. ISBN 978-953-6076-89-5.– University of Zagreb Faculty of Science. p. 86.
- RUDNICK, R.L. & GAO, S. (2005): Composition of the Continental Crust.– In: HOLLAND, H.D. & TUREKIAN, K.K. (eds.): *Treatise on Geochemistry*, Vol. 3: The Crust. Elsevier-Pergamon, Oxford, 1–64.
- SAKAČ, K. & ŠINKOVEC, B. (1991): The bauxites of the Dinarides.– *Travaux*, 23, 1–12.
- SAKAČ, K., ŠINKOVEC, B., JUNGWIRTH, E. & LUKŠIČ, B. (1984): Opća obilježja geološke građe i ležišta boksita područja Imotskog [*General characteristics of geological framework and bauxite deposits of Imotski area – in Croatian*].– *Geološki vjesnik*, 37, 153–174.
- SCHELLMANN, W. (1986): A new definition of laterite.– *Memoirs of the Geological Survey of India*, 120, 1–7.
- SCHROLL, E. & SAUER, D. (1968): Beitrag zur Geochemie der seltenen Elementen in Bauxiten [*Contribution to the geochemistry of rare elements in bauxites – In German*].– in: *Proceedings of the 1st International Congress: Erschienen in Travaux du Comité international pour l'étude des bauxites, des oxydes et des hydroxydes d'aluminium ICSOBA*. Zagreb, 201–226.
- SHAFFER, J.W. (1983): Bauxite raw materials.– In: LEFOND, S.J. (Ed.): *Industrial Minerals and Rocks*, 5th edition. Society of Mining Engineers, AIME, New York, 503–527.
- ŠINKOVEC, B. & SAKAČ, K. (1991): Bauxite deposits of Yugoslavia – the state of the art.– *Acta Geologica Hungarica*, 34/4, 307–315.
- ŠINKOVEC, B., ŠUŠNJARA, A. & SAKAČ, K. (1985): Boksiti Korduna i susjednih područja [*Bauxites of Kordun and neighbouring areas – in Croatian*].– *Geološki vjesnik*, 38, 215–233, Zagreb.
- ŠUŠNJARA, A., SAKAČ, K., GABRIĆ, A. & ŠINKOVEC, B. (1990): Boksiti područja Sinja u Srednjoj Dalmaciji [*Bauxites in the Sinj area in Middle Dalmatia – in Croatian*].– *Geološki vjesnik*, 43, 169–179.
- TOMAŠIĆ, N., ČOBIĆ, A., BEDEKOVIĆ, M., MIKO, S., ILIJANIĆ, N., GIZDAVEC, N. & MATOŠEVIĆ, M. (2021): Rare Earth Elements Enrichment in the Upper Eocene Tošići-Dujići Bauxite Deposit, Croatia, and Relation to REE Mineralogy, Parent Material and Weathering Pattern.– *Minerals*, 11/11, 1260. <https://doi.org/10.3390/min11111260>
- TURINI, P. (1808): Della preparazione dell'allume nella Miniera di San Pietro nel dipartimento dell'Istria [*On the preparation of alum in the San Pietro Mine in the Istrian region – in Italian*].– *Stamperia di Antonio Curti q. Giacomo, Venezia*, 67 p.
- USBM & USGS (1990): U.S. BUREAU OF MINES & U.S. GEOLOGICAL SURVEY: Mineral Commodity Summaries 1990.– U.S. Government Printing Office, Washington, D.C., 199 p.
- VALETON, I. (1972): Bauxites. *Developments in Soil Sciences*.– Elsevier, Amsterdam, 226 p.
- VLAHOVIĆ, I., TIŠLJAR, J., VELIĆ, I. & MATIČEC, D. (2005): Evolution of the Adriatic Carbonate Platform: Palaeogeography, main events and depositional dynamics.– *Palaeogeography, Palaeoclimatology, Palaeoecology*, 220, 333–360. <https://doi.org/10.1016/j.palaeo.2005.01.011>
- WOLLAST, R. (1963): Aspect chimique du monde de formation des bauxites dans Le Bas-Congo Confrontation des données thermodynamiques et expérimentales.– *Académie Royale des Sciences d'Outre-Mer*, 7, 392–412.
- Web sources:
- CROATIAN GEOLOGICAL SURVEY (2024): Map of Mineral Resources of the Republic of Croatia. Croatian Geological Survey. Available at: <https://www.hgi-cgs.hr/karta-mineralnih-sirovina-republike-hrvatske-1200-000/>. Accessed on: October 2nd, 2025.
- EUROPEAN PARLIAMENT AND THE COUNCIL OF THE EUROPEAN UNION (2007): Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE).– *Official Journal of the European Union*, L 108, 25.04.2007, 1–14. Available at: <https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32007L0002>. Accessed on: October 4th, 2025.
- FASTMARKETS (2024): Bauxite and Alumina – A comprehensive market guide for bauxite and alumina. Available at: <https://www.fastmarkets.com/industrial-minerals/bauxite-alumina/>. Accessed on: October 4th, 2025.
- GROHOL, M. & VEEH, C. (2023): Study on the Critical Raw Materials for the EU 2023 – Final Report.– European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW), Publications Office of the European Union, Luxembourg, <https://data.europa.eu/doi/10.2873/725585>. Available at: https://single-market-economy.ec.europa.eu/publications/study-critical-raw-materials-eu-2023-final-report_en. Accessed on: June 9th, 2026.
- INTERNATIONAL TRADE CENTRE (2025): Trade Map – Trade Statistics for International Business Development. Available at: <https://www.trade-map.org/>. Accessed on: October 4th, 2025.
- JISMS RH (2025): MINISTARSTVO GOSPODARSTVA REPUBLIKE HRVATSKE (2025): Jedinstveni informacijski sustav mineralnih sirovina Republike Hrvatske (JISMS RH). WebGIS portal. Available at: <https://jisms.gospodarstvo.gov.hr/>. Accessed on: October 4th, 2025.
- MINJERA (2013–2024): Hrvatska enciklopedija, mrežno izdanje. Leksikografski zavod Miroslav Krleža. Available at: <https://www.enciklopedija.hr/clanak/minjera>. Accessed on: October 2nd, 2025.
- THE ALUMINUM ASSOCIATION (2026): Bauxite 101.– The Aluminum Association, Washington, D.C. Available at: <https://www.aluminum.org/bauxite-101>. Accessed: June 7th, 2026.
- USGS, 2024: U.S. GEOLOGICAL SURVEY: Mineral Commodity Summaries 2024.– U.S. Geological Survey, Reston, Virginia, 212 p. Available at: <https://doi.org/10.3133/mcs2024>. Accessed on: October 4th, 2025.
- WORLD MINING DATA (2024): Federal Ministry of Finance (Republic of Austria).– Vienna: Federal Ministry of Finance. Available at: <https://www.world-mining-data.info/wmd/downloads/PDF/WMD%202024.pdf>. Accessed on: October 2nd, 2025.