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Artículo

Origins of architectural heritage: the resources and variety of natural stones in Slovenia

Origen del patrimonio arquitectónico: los recursos y la variedadde piedras naturales en Eslovenia

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Abstract: The distinct geological variation of Slovene's territory, which includes all three major types of natural stone (sedimentary, igneous and metamorphic), offers an ample selection of building and art materials to be chosen based on their properties and/or aesthetic appearance. The tectonic diversity of the area caused some difficulties in extracting some of the natural stones, resulting in quarries being abandoned for economic and spatial reasons, but some beautiful examples of the use of lasting value in both construction and art still persist. Examples include the abandoned quarries of Pohorje marble and Podpeč limestone, where extraction has been documented from as early as the Roman times, with the latter also designated as a Global Heritage Stone Resource. The Pohorje mountains are an area of granodiorite as well as green cizlakite, the latter being Slovenian endemic. Furthermore, the Kras (Karst) region is one of the most interesting areas containing natural stone reserves in Slovenia, with a large variety of Cretaceous shallow-water limestones. All of these are abandoned, with the two natural stone quarries still operating being associated with the presence of rudist biostromes and bioherms, which are responsible for the aesthetic appearance of these natural stones. It is also characteristic of Slovenia to use a variety of local rocks, such as sandstone, conglomerate, breccia, shale and tuff, to give character to vernacular architecture. Some of the quarries are designated and protected as valuable natural features or natural monument, while several buildings decorated with Slovene natural stones are declared as cultural monuments of local or national importance or included in the UNESCO World Heritage List. This paper presents the most significant Slovene quarries of natural stones that have been used in architectural heritage, the mineralogical and physical-mechanical characteristics of these stones, as well as examples of their use in monuments.

Keywords: Slovenian quarries; natural stone; stone monuments; cizlakite; Kras (Karst) quarry region

Key points:

The distinct geological variation of the territory of Slovenia, which includes all three major types of natural stone—sedimentary, igneous, and metamorphic.

Limestones of the Classical Karst (Kras), Podpeč limestone—designated as a Global Heritage Stone Resource (GHSR)—and green cizlakite (a Slovenian endemic) are most distinguished types of natural stone.

Significant Slovene quarries of natural stones that have been used in important architectural heritage included in the UNESCO World Heritage List.

Resumen: La geología de Eslovenia, que incluye rocas sedimentarias, ígneas y metamórficas, proporciona una gran selección de materiales para la construcción y el arte debido a sus propiedades y/o apariencia estética. La tectónica, que causa dificultades en la extracción, ha provocado el abandono de algunas canteras, aunque han perdurado bellos ejemplos de su uso. Este es el caso de las canteras abandonadas de mármol de Pohorje o la caliza de Podpeč, cuya extracción está documentada desde la época romana. Esta última está designada como Global Heritage Stone Resuorce (GHSR). Además, la región del Kras (Karst) es una de las áreas más interesantes, con abundantes reservas de piedra natural, y una gran variedad de calizas del Cretácico. Todas estas canteras abandonadas y las dos que están aún operativas, están asociadas con rudistas. En las montañas de Pohorje afloran granodioritas y cizlakitas verde, un endemismo esloveno. Eslovenia también se caracteriza por el uso de diferentes variedades de rocas locales, como areniscas, conglomerados, brechas, pizzaras y tobas, que dan carácter a la arquitectura vernácula. Algunas de las canteras están declaradas y protegidas por sus valiosas características naturales o como monumentos naturales. Igualmente, varios edificios decorados con piedras naturales eslovenas están declarados como monumentos culturales de importancia local o nacional o están en la lista de la UNESCO. El artículo presenta las canteras eslovenas más significativas de piedras naturales utilizadas en el patrimonio arquitectónico, sus características mineralógicas y físico-mecánicas, así como ejemplos de su uso en monumentos, tanto a nivel nacional como internacional.

Palabras clave: canteras eslovenas; piedra natural; monumentos de piedra; cizlakita; canteras de la región de Kras (Karst).

Puntos clave:

La variedad geológica distintiva de Eslovenia incluye los tres tipos principales de piedra natural: sedimentaria, ígnea y metamórfica.

Las calizas de la región “Classical Karst” (Kras), la caliza de Podpeč, designada como Global Heritage Stone Resource (GHSR) y una cizlakita verde, endémica de Eslovenia, son las piedras más distinguidas.

Canteras eslovenas significativas han proporcionado la piedra natural que ha sido utilizada en el importante patrimonio arquitectónico, también en la lista de la UNESCO como Sitio Patrimonio de la Humanidad (WHS).

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Supplementary information ↓

1. INTRODUCTION

The history of architectural stone is linked to humankind since the beginning of our time. Being one of the first raw materials used by man, natural stone was used for various purposes. Tools were first made from stone in the Early Stone Age, and inscription stones and tombstones are considered some of the oldest monuments. Later, stone was mainly used for construction. At the beginning of the 20th century, after the discovery of Portland cement, the importance of natural stone began to decline. An architect, stonemason or artist chose the stone for their work according to its aesthetic (decorative) characteristics, mechanical usability and the durability in the place where it should serve its purpose, with the goal of it lasting as long as possible. The choice of natural stone depends, to a certain extent, on its economic availability, but, particularly in the past, the primary limitation was often its availability in any given location.

The landscape of Slovenia and its heritage in stone is, in geological terms, primarily identified through the application of various types of natural stone (Golež & Mirtič, 2015). The territory of Slovenia consists of many different types of rock, which serve as resources for various natural stones. The tectonic diversity of the area has caused difficulties for the extraction of some of the natural stones, resulting in the abandonment of quarries for both economic reasons and spatial limitations (Mirtič *et al.*, 1999). However, the remaining abandoned quarries, as well as some beautiful examples of the stone being used in construction and art, leave a lasting value.

This paper presents the most significant Slovene quarries of natural stone used in architectural heritage in Slovenia, the mineralogical and physical-mechanical characteristics of the stone, as well as examples of its use in monuments, both in Slovenia and abroad.

2. BRIEF OVERVIEW OF THE GEOLOGICAL SETTING OF SLOVENIA

The territory of Slovenia is positioned in the transitional area between the Alps, the Dinarides and the Pannonian Basin (Placer, 1998, 2008), as shown in Figure 1. The Alps are further divided into the Eastern and Southern Alps, delineated by the Periadriatic fault system. The former are characterized by north-verging thrust units, being composed of metamorphic and magmatic rocks in the lower part, while the upper nappes are carbonate-dominated. The Southern Alps were thrusted towards the south and are predominantly composed of Triassic platform carbonates and subordinate Paleozoic mixed clastic-carbonate successions in the central thrust units, with Mesozoic deep-marine units in the lowermost and topmost nappes (Buser, 1987a; Goričan *et al.*, 2018). The Dinarides constitute several large scale nappes thrusted in the southwest direction. They consist of Paleozoic clastites overlain with thick shallow-marine carbonates interrupted by laterally highly variable deep-shallow marine, alluvial and vulcaniclastic Ladinian strata and Carnian alluvial deposits. They end up with the most recent Cretaceous to Eocene flysch deposits, which become progressively younger towards the southwest (Buser, 1996). Practically equal succession (its topmost part) is outcropping also in the almost undeformed Adria foreland found in Istria (Rožič & Žvab Rožič, 2023). In eastern Slovenia, the Oliogene-Miocene Pannonian Basin (Paratethys) deposits overlie all of the thrust units mentioned previously. They are predominantly composed of alluvial, marine and lacustrine clastites interrupted by vulcaniclastic Oligocene/Miocene and carbonate-rich Middle Miocene deposits (Buser, 2010). The predominantly fluvial Pliocene and Quaternary sediments fill the river valleys and the lowlands of northeastern Prekmurje (Markič, 2009).

3. QUARRIES OF NATURAL STONES

A map of Slovenia with the quarries marked is shown in Figure 1. Among the igneous rocks, granodiorite and cizlakite are representative natural stones in Slovenia, while tuff is a pyroclastic rock, and marble, gneiss and mica-schist are representatives of metamorphic rocks. Sedimentary rocks are the most common type of natural stones in Slovenia. These include different types of limestone and tufa, but also clastic sedimentary rocks, such as sandstones, breccia, conglomerate and shale. The summary of representative natural stones with formation name, geological age, prevalent lithologies, tectonic setting, macrophotos and microphotos is shown in Table 1.

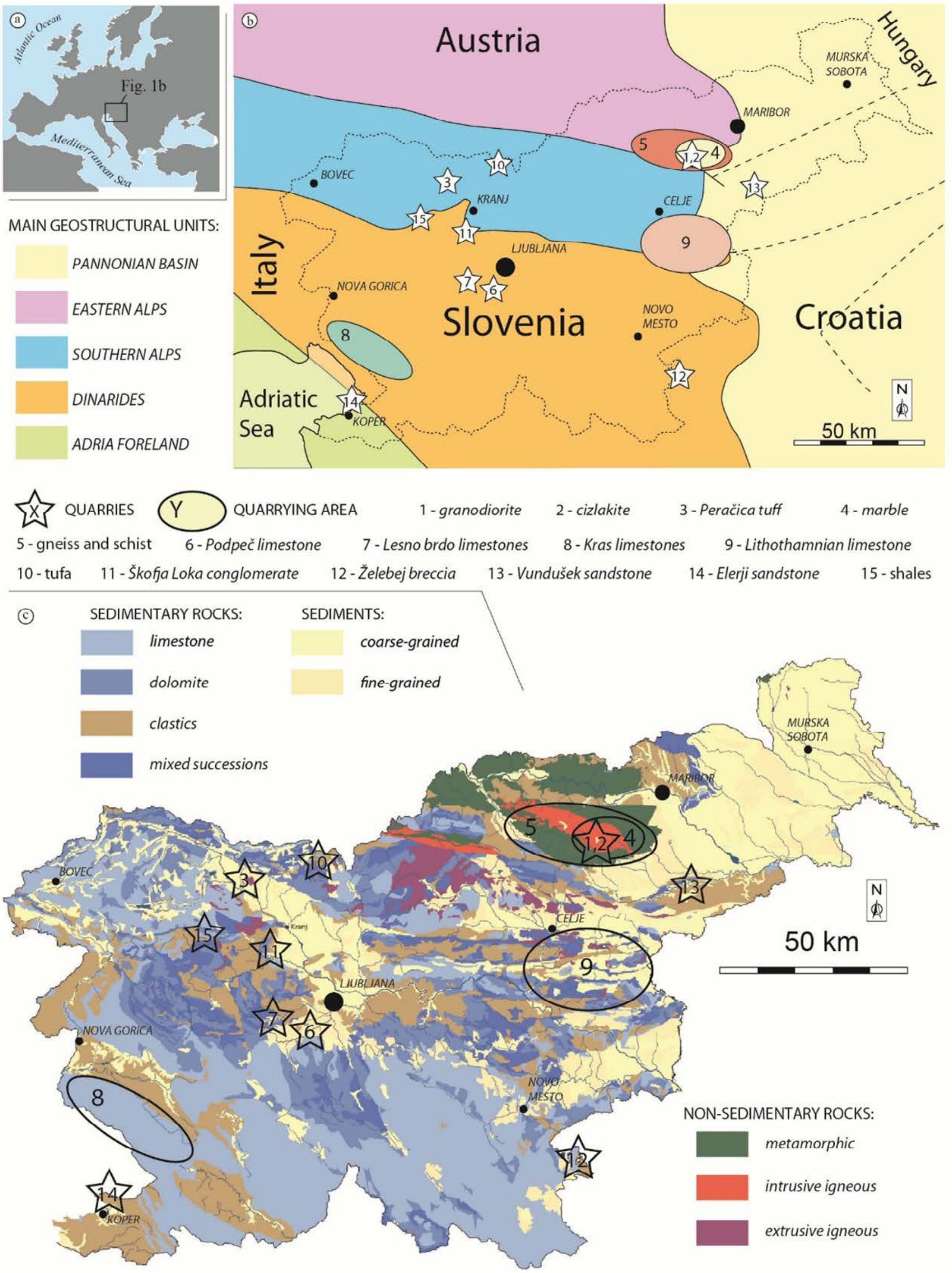
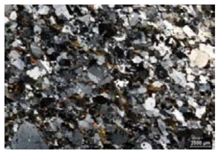
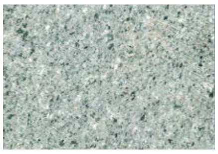
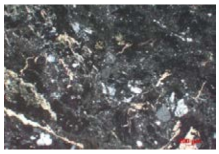
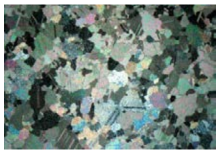
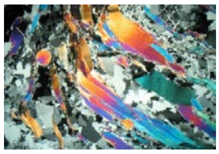
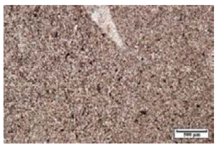
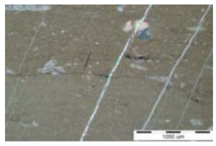
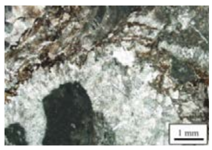


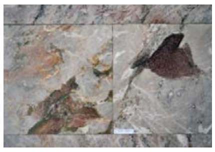
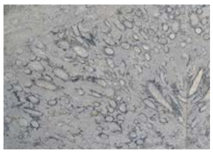
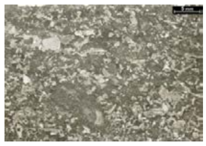
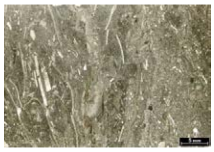
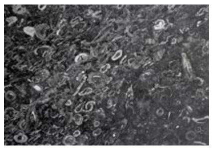
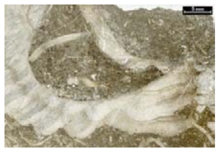
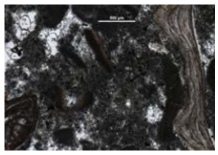
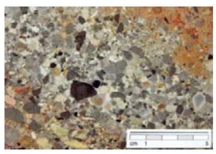
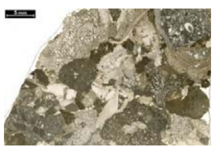
Figure 1. (a) Position of Slovenia within Europe, and simplified (b) geotectonic (after Placer, 1998, 2008) and (c) lithological (after Novak, 2016b) maps of Slovenia and the surrounding areas marked with the locations of the natural stone quarries and areas.

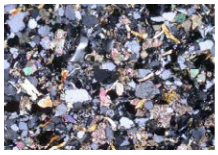
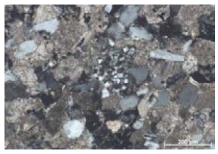
Figura 1. a) Posición de Eslovenia dentro de Europa y mapas simplificados (b) geotectónicos (según Placer, 1998, 2008) y (c) litológicos (según Novak, 2016b) de Eslovenia y las áreas circundantes marcadas con las ubicaciones de las canteras y áreas de piedra natural.

Table 1. The summary of representative natural stones with formation name, geological age, prevalent lithologies, tectonic setting, macrophotos and microphotos.

Tabla 1. Resumen de piedras naturales representativas con nombre de formación, edad geológica, litologías predominantes, macrofotografías y microfotografías.

	Formation name	Geological Age	Prevalent lithology/ies	Tectonic setting	Macrophoto	Microstructures
Granodiorite	Granodiorite plutonic body	Early Miocene	Granodiorite, aplite, pegmatite, lamprophyre	Pohorje mountains block, Austroalpine, Eastern Alps		
Cizlakite	Granodiorite plutonic body	Early Miocene	Quartz monzo gabbro aplite, pegmatite, lamprophyre	Pohorje mountains block, Austroalpine, Eastern Alps		
Pyrclastic rocks						
Peracica tuff	Smrekovec volcanic complex	Late Oligocene-Early Miocene	Andesitic or dacitic tuff and lapilli tuff	Pannonian basin		
Metamorphic rocks						
Pohorje marble	Pohorje metamorphic series	Cretaceous	Calcitic to calcitic-dolomitic marble	Pohorje massif, Austroalpine, Eastern Alps		
Pohorje gneiss and mica schist	Pohorje metamorphic series	Cretaceous	Muscovite-biotite and biotite gneiss, mica-schists	Pohorje massif, Austroalpine, Eastern Alps		
Sedimentary rocks - biogenic						
Podpeč limestone	Podbukovje formation	Early Jurassic	Limestone	External Dinarides		
Drenov grič limestone	Raibl formation	Late Triassic	Limestone	External Dinarides		
Lesno brdo limestone	Schlern formation	Middle-Late Triassic	Limestone	External Dinarides		

Hotavlje limestone	Schlern formation	Middle-Late Triassic	Limestone	External Dinarides		
Lipica Fiorito limestone	Lipica formation	Late Cretaceous	Limestone	Trieste-Komen plateau, External Dinarides		
Lipica Unito limestone	Lipica formation	Late Cretaceous	Limestone	Trieste-Komen plateau, External Dinarides		
Repen limestone	Repen Formation	Late Cretaceous	Limestone	Trieste-Komen plateau, External Dinarides		
Kopriva	Repen Formation	Late Cretaceous	Limestone	Trieste-Komen plateau, External Dinarides		
Kazlje	Lipica formation	Late Cretaceous	Limestone	Trieste-Komen plateau, External Dinarides		
Lithothamnion limestone	Laško formation	Middle Miocene	Limestone	Pannonian basin		
Jezersko tufa	Jezersko tufa	Holocene	Calcareous tufa	Southern Karavanke mountains, Southern Alps		
Sedimentary rocks - clastic						
Škofja Loka conglomerate	Škofja Loka conglomerate	Oligocene	Calcareous conglomerate	Pannonian basin		
Želebej breccia	Veliki trn formation	Late Cretaceous	Calcareous breccia	Slovenian basin, Internal Dinarides		

Vundušek sandstone	Vundušek sandstone	Early Miocene	Sandstone	Pannonian basin		
Jelarji sandstone	Eocene flysch	Eocene flysch	Sandstone	Adria foreland		
Podgora shale	Upper Carboniferous beds	Late Carboniferous	Shale	Sava folds, External Dinarides		
Zali log shale	Lower flyschoid formation	Early Createaceous	Shale	Slovenian basin, Internal Dinarides		

3.1. Igneous rocks

3.1.1. Granodiorite

The quarrying of igneous rocks is limited to the northern part of Slovenia, in the Pohorje mountains—a tectonic block belonging to the Austroalpine units of the Eastern Alps. Despite covering an area of over 200 km^2, exposures suitable for exploitation are rare, due to Late Miocene brittle deformations. Four quarries were active in the past (Cezlak, Hudi kot, Josipdol and Recenjak), with only the one near Cezlak village now still operating. In this Cezlak I quarry, so-called Pohorje granodiorite is exploited. The quarry is situated at the southern margin of the Pohorje igneous body. It is surrounded by metamorphic rocks. Granodiorite has been exploited from the Cezlak I quarry since 1891 (Figure 2a). Larger-scale production started in 1910 and is still in operation (Mirtič *et al.*, 1999). The second largest quarry, Josipdol, near Ribnica na Pohorju, is occasionally still active.

Figure 2. (a) Cezlak I quarry of granodiorite (photo Matevž Novak) and (b) Cezlak II quarry of cizlakite (photo Samo Jenčič, Archive ZRSVN).
Figura 2. (a) Cantera de granodiorita "Cezlak I" (foto Matevž Novak) y (b) cantera de cizlakita "Cezlak II" (foto Samo Jenčič Archive ZRSVN).

Granodiorite forms the largest plutonic body in Slovenia, found in the Pohorje mountain range. It is dated to the Lower Miocene with ages varying from 16.4 +/- 0.4 Ma to 19.5 +/- 5 Ma. It has a holocrystalline texture, is prevailingly heterogranular and is medium- to fine-grained. It shows a parallel structure in the marginal parts of the massif. It is prevailingly (80-98%) composed of plagioclases, quartz and K-feldspars, subordinate biotite and hornblende. The accessory minerals are apatite, sphene, orthite, epidote, clinozoisite, zircon, garnet and opaque minerals. The igneous body is crosscut with multi-generation veins of aplite, pegmatite and lamprophyre (Trajanova *et al.*, 2009).

3.1.2. Cizlakite

An abandoned cizlakite quarry is situated only about 1 km from the granodiorite quarry. In this quarry, Cezlak II (Figure 2b), a lenticular body of this dark coarse-grained mafic rock, about 200 m wide and 1,000 m long, represents the uniqueness of the Pohorje mountains igneous massif. It is embedded at the margin of the granodiorite pluton, not far from the village of Cezlak. The rock is called cizlakite, named after the village close to the quarry. The exploitation started before World War 2 (WWII), but the quarry was closed between 1958 and 1980 due to the presumed depletion of the productive horizon. Later it was reactivated for a short period, but it is curently inactive.

Cizlakite forms a small igneous body associated with the granodiorite pluton. Petrologically, it is assigned to the quartz monzogabbro. It probably represents the oldest rock of the Pohorje igneous complex, dated to approximately 20 Ma, although some presumably rejuvenated ages suggest 17.5 Ma. It has a holocrystalline but heterogeneous texture, the mineral composition and granularity. It is predominantly composed of femic minerals (70-80%), namely light green augite and dark green hornblende. The salic minerals are plagioclase (anorthite ratio is 52-35%), subordinate quartz and K-feldspar, while the accessory minerals are sphene, apatite and biotite. As with the granodiorite, it is crosscut with aplite, pegmatite and lamprophyre veins (Trajanova *et al.*, 2009). The only known site of cizlakite—a Slovene endemic natural stone—is in Cezlak near Oplotnica.

3.2. Pyroclastic rocks

3.2.1. Tuff

Greenish andesitic tuff, which strongly characterises the architecture of the Upper Carniola region, has been exploited since Roman times, and especially so in the 16th and 17th centuries. It is part of the Oligocene Smrekovec volcanic complex within the Pannonian basin, cropping out from the surroundings of Radovljica in central Slovenia into a broad range along the Savinjska dolina valley, all the way to Rogaška Slatina in the east. The most commonly used variety is Peračica tuff, named after quarries in the valley of the Peračica creek near Brezje (the abandoned quarries of Bogataj (Figure 3a), Klinar and Pernuša). The exploitation was gradually abandoned at the beginning of the 20th century (Ramovš, 2008). Tuff was also excavated in the Dedkov pruh quarry north of Stahovica pri Kamniku, although this is now also abandoned.

Volcanic pyroclastic and subordinate effusive rocks are Upper Oligocen and Lower Miocene in terms of age. They occur mostly in the eastern segment of the Southern Alps (Kamnik–Savinja Alps), where they are known as the Smrekovec volcanic complex, and in the northern part of the Ljubljana basin, with Peračica being the locality most renowned. They are mostly of andesitic or dacitic composition. Three main lithofacies have been distinguished: A) coherent volcanic rocks (dykes and sills, lava flows and volcano vent fillings, B) autoclastic rocks (autoclastic lavas and hyaloclastic breccias), and C) volcaniclastic rocks (pyroclastic tuff and resedimented volcaniclastic deposits). The Peračica locality is characterized by analcime-bearing tuff with lapili-, coarse- and fine-grained varieties (Kralj, 2009).

3.3. Metamorphic rocks

3.3.1. Pohorje marble

The Pohorje mountains are the only source of marble in Slovenia. Some quarries and outcrops are placed in regional metamorphic mica schists and gneisses. The Pohorje metamorphic complex, located in NE Slovenia, is the SE margin of the Eastern Alps. Abandoned quarries have been known since Roman times, with the Roman quarry in the Bistrica valley near Slovenska Bistrica being the most well-known (Figure 3b). Small-scale marble quarrying still takes place in the Pohorje mountains. Excavation sites can be seen around the village of Loška Gora near Zreče.

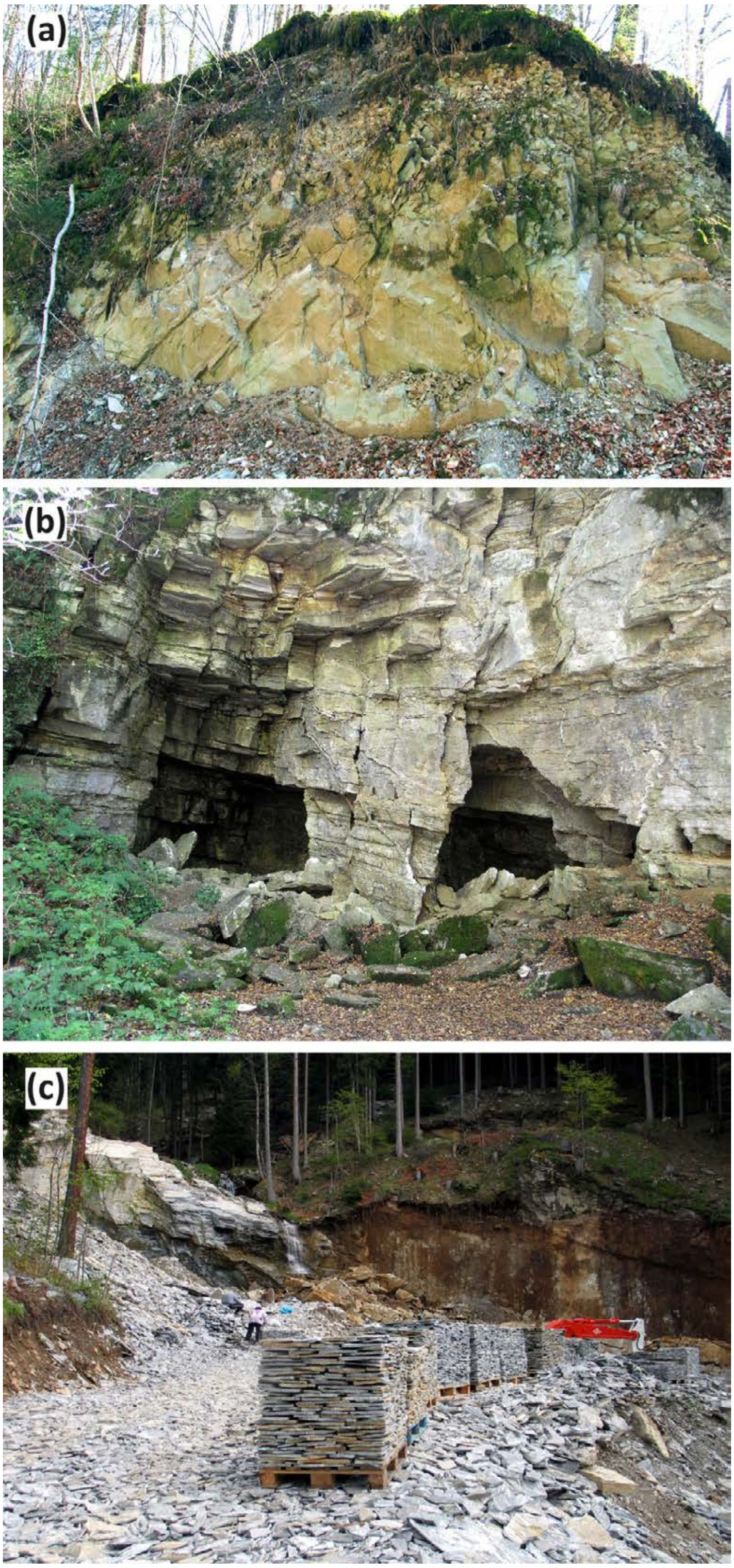


Figure 3. (a) Peračica tuff in the Bogataj quarry (photo Matevž Novak),(b) Roman marble quarry (photo Samo Jenčič, Archive ZRSVN), (c) Gneiss in Hudinja near Zreče (photo Martin Toman).

Figura 3. (a) Toba Peračica en la cantera Bogataj. (b) Cantera romana de mármol (foto Samo Jenčič Archive ZRSVN), (c) Gneiss en Hudinja cerca de Zreče (foto Martin Toman).

The metamorphic rocks of Slovenia are found in the Eastern Alps, constituting the lower nappes of the Eastern Alps (Austroalpine nappes). The highest grade of metamorphism is found in the Pohorje area, where a rich assemblage of metamorphic rocks is found (Hinterlechner-Ravnik & Trajanova, 2009; Janák *et al.*, 2015). Among these, marble lenses occur in the southern and south-eastern part of the Pohorje massif, which have been used since the Roman times as a natural stone. Marble is white, sometimes grayish and pinkish in color, and medium to coarse-grained. It is usually calcitic, but occasionally calcitic-dolomitic, with the calcite exhibiting intensive deformational e-type twinning. Marble contains up to 5% non-carbonate minerals, and its typical mineral assemblage is calcite (dolomite), tremolite and pyroxene. Other mineral phases incorporated are olivines (forsterite—in places replaced by serpentine), quartz, feldspars, epidote, zoisite, vesuvianite, scapolite, muscovite, biotite (partly replaced by chlorite), phlogopite, rare grains of titanite, rutile, zircone, apatite and small grains of ferric oxides and sulfides (Vrabec *et al.*, 2018; Jarc *et al.*, 2010).

3.3.2. Pohorje gneiss and mica-schist

Gneiss and mica-schists are some of the most common types of rock in the metamorphic complex of the Eastern Alps in north-eastern Slovenia. The majority of natural stone from these rocks was quarried at several locations in the southern and eastern parts of the Pohorje massif, e.g., gneiss in Koritno near Oplotnica, in Hudinja near Zreče (Figure 3c), in the Mislinja gorge, and north of Šmartno in Polskava creek, and mica-schist north of Oplotnica (Hinterlechner-Ravnik, 2002). In this massif, gneiss occurs in numerous varieties: muscovite-biotite and biotite augen gneiss with porphyroblasts of K-feldspars, coarse-grained gneiss, pegmatoid gneiss (often interbedded inside the amphibolite bodies), flaser gneiss with large almandine porphyroblasts, kyanite flaser gneiss, aplitoid gneiss and fine-grained biotite gneiss (Hinterlechner-Ravnik & Trajanova, 2009). Diamonds were found in the metapelitic gneiss near Visole, indicating UHP metamorphism (Janák *et al.*, 2015). Schists from the Pohorje massif include mica (biotite-muscovite) schists and coarse-grained quartz-muscovite schists with almandine porphyroblasts, while the local occurrence of amphibole schist has also been reported (Hinterlechner-Ravnik & Trajanova, 2009).

3.4. Sedimentary rocks

Biogenic

3.4.1. Podpeč limestone

The history of quarrying in the village of Podpeč at the northern foot of St. Ana's hill (External Dinarides, central Slovenia) goes back to the 2nd century A.D. (Djurić & Rižnar, 2017; Djurić *et al.*, 2022) when limestone blocks were supposedly transported 11 km north on the Ljubljanica River to the Roman outpost of Emona (present-day Ljubljana (Ramovš, 2000)). Numerous small quarries as well as one larger quarry have been exploited there. Following the demise of the Roman Empire, demand for this beautiful black limestone dried up and it was not until the late 18th century that it started to revive. Following the devastating earthquake that shook Ljubljana in 1895, large amounts of limestone were produced for the restoration of the city. Its decorative value became appreciated again in the 20th century, especially by the famous Slovenian architect Jože Plečnik (1872-1957), whose works in Ljubljana were inscribed on the UNESCO World Heritage List in 2021 (Spanžel *et al.*, 2020). The largest Podpeč quarry stopped operating in 1976, with only small-scale extractions for restoration purposes being allowed later (Ramovš, 2000). Podpeč limestone has been designated as a Global Heritage Stone Resource since 2017 (Kramar *et al.*, 2015a; IUGS, 2024).

Stratigraphically, the succession of the Podpeč quarry belongs to the Pliensbachian Lithiotid member of the Lower Jurassic Podbukovje formation. It is composed of bedded, shallow-marine, predominantly lagoonal limestone with indices of subaerial exposure, varying in color from medium gray to black. A rich variety of lithofacies characterize the quarried succession, including bioclastic limestones (bivalve and gastropod floatstones), micritic limestone (mudstone and bioclastic wackestone), ooidal and oncoidal limestone (grainstone and rudstone), and the most famous lithiotid limestone. The latter occurs in several beds within the succession. It is floatstone and subordinate rudstone (lumachelle), characterized by large (several tens of cm in length), whitish lithiotis-type bivalves. These are oriented mostly parallel to the bedding, but they sometimes occur in the living position. The matrix between the shells is dark-gray to black micrite and mostly devoid of other fossils (Debeljak & Buser, 1997; Gale, 2015; Kramar *et al.*, 2015a; Brajkovič *et al.*, 2022).

3.4.2. Black Drenov Grič limestone, variegated Lesno Brdo limestone, and Hotavlje limestone

Several types of Middle/Upper Triassic limestones occur in the External Dinarides in central Slovenia. Historically, the most important of these is the black, bedded Drenov Grič limestone, also known as Black Lesno Brdo limestone (Kramar *et al.*, 2020). This Lower Carnian (Julian) limestone was exploited as early as the first half of the 19th century (Ramovš, 2000). The largest exploitation site was the Kucler quarry at Drenov Grič (also known as the Eastern black quarry) and the Western black quarry (Figure 4a), both of which are now inactive (Kramar *et al.*, 2020). The black Lesno Brdo limestone occurs above the unconformity in the basal part of the clastics-dominated Carnian succession (Celarc, 2008). It forms a 20 m thick interval of restricted lagoonal to brackish, dark-gray to black, bedded limestone with shale intercalations. It is mostly dense micrite (mud/wackestone) with sporadic microfossils (foraminifera, ostracods, dasycladalean algae), while bivalve shells can be common close to the shale interlayers and within some beds. It is rich in organic matter, with even coal interlayers occuring within the limestone locally. White calcite veins crosscut the limestone (Jelen, 1990; Kramar *et al.*, 2020; Malenšek Andolšek & Markič, 2021).

Another commercially important natural stone from the same area is the variegated Lesno Brdo limestone. This was quarried in Vodnik quarry before WWII (Mirtič *et al.*, 1999), then afterwards another quarry—Lesno Brdo quarry—was opened next to it (Figure 4b). This indistinctly bedded to massive, gray, red, and rosy limestone has been quarried since the end of the 19th century (Ramovš, 2000). It occurs below the aforementioned unconformity and belongs to the upper Ladinian to lower Carnian succession, regionally being known as the Schlern formation. It is a platform-margin, massive, gray to reddish limestone, which is often rich in fossils such as calcisponges, dasycladalean and red algae, corals, microproblematica, bryozoans and others. In detail, three facies occur: A) fine-grained limestone as a groundmass, B) blocks and globular masses of sponge-microbialite boundstone, and C) lens-like aggregations of polychaete (terebellid) tubes. Limestone exhibits recrystallization and contains paleokarstic voids filled with calcitic cements, often replaced with coarse-crystalline yellowish dolomite and fractures and nests filled with green or violet clays (Jelen, 1990; Gale *et al.*, 2018).

An almost identical rock to the variegated Lesno Brdo limestone goes by the name of Hotavlje limestone, but the latter contains additional breccias with a red-clay matrix, which could be partly paleokartic in origin. This variegated rock, the color of which grades from gray and pink to deep-red and purple, holds the primary status among Slovenian ornamental stones. It was named after the village of Hotavlje at the foothills of Mt. Blegoš in the Poljane valley (20km NW from the Lesno Brdo area), where it is still exploited in the underground galleries of a large modern quarry. The oldest known products from Hotavlje limestone date back to the 16th century (Ramovš, 1995).

Figure 4. (a) Black Drenov Grič limestone quarry—Western black quarry (photo Matevž Novak), (b) Lesno Brdo Quarry (photo Helena Tehovnik, Archive ZRSVN).

Figura 4. (a) Cantera de caliza Black Drenov Grič - cantera negra de la zona oeste; (b) cantera Lesno Brdo (foto Helena Tehovnik Archive ZRSVN).

3.4.3. Limestones of the Classical Karst - Kras area

The Kras area (often also referred to as the Triaste-Komen plateau) is geologically famous, because it gave its name to karst phenomena (the germanised name Karst was given for the description), and it is often referred to as Classical Karst area. Numerous varieties of limestone, commercially called the "Kras marbles", have been exploited from the Kras area (External Dinarides, SW Slovenia) as natural stone (Kramar *et al.*, 2015b). The area consists of a thick succession of Cretaceous to Paleogene limestones and subordinate dolomites. Several types of rock come from this area, all characterized by pachiodont (rudist-type) bivalves and/or their debris. Their names originate from the villages in proximity to the locations where they were quarried.

From the Santonian to the Campanian Lipica formation two important rocks originate. The most commercially valuable rock shares the name with the formation, i.e. it is the Lipica limestone. Two closely-situated quarries (Lipica I and Lipica II) lie northeast of the well-known Lipica stud farm, in the economically most promising part of the Lipica formation in the north limb of the Lipica syncline. Today, large rock blocks are exploited in underground galleries (Figure 5a). Lipica limestone is shallow-marine, light-gray massive limestone, characterized by rudist bivalves. If shells are well preserved, they form a floatstone sub-type known as flowery Lipica "Fiorito". Alternatively, rudist shells are completely crushed (grain/rudstone), which results in the homogenous texture of the Lipica "Unito" subtype.

Figure 5. Limestone Quarries of the Kras area—Classical Karst: (a) Lipica I quarry (Archive ZVSRN), (b) Kazlje quarry (Archive ZVSRN), (c) Kopriva Quarry (Archive ZVSRN).

Figura 5. Canteras de calizas de Classical Karst - Kras: (a) cantera Lipica I (archive ZVSRN); (b) cantera Kazlje (archivo ZVSRN), (c) cantera Kopriva (archive ZVSRN).

The second, historically important, dark-gray variety of the rudist limestone from the Lipica formation is known as Kazlje (or Avber) limestone (Figure 5b). The economically productive unit is max. 41 m thick. All the quarries (Brje, Kamna Gorica, Tomaj, Kazlje and Avber) have long since been abandoned. Kazlje limestone is shallow-marine floatstone characterized by dark-gray well-preserved rudist bivalves within an even darker micrite matrix rich in organic matter. These limestones are associated with (i.e. were deposited close to) the dark, organic-rich, thin-bedded and platty limestones of the Tomaj limestone, a member of the Lipica formation which originated in intraplatform, often anoxic, deeper-marine basins. We note that Tomaj and similar Komen limestones from underlying formations were used in the past as a building material for roofs (Jurkovšek *et al.*, 1996, 2013; Jurkovšek, 2010).

From the upper Cenomanian to the lower Turonian Repen formation, two rocks, known as the Repen and Kopriva limestones, appear. They have been exploited in numerous quarries (Lisično I and II, Vitez, Polževo, Doline, Povir, Pliskovica, Kopriva (Figure 5c), Gabrovica and Kamna Gorica), of which only the Doline and Povir quarries are still operating. The Repen formation is otherwise dominated by deeper-marine limestones but it contains a lens of shallow-marine, massive limestone, several tens of meters thick, from which these limestones are quarried. Repen limestone is a massive light-gray limestone, weakly recrystallized biomicrite (mud/wackestone), which passes into fossil-rich limestone (rud/floatstone) characterized by large, rounded, whitish caprinid bivalves and dark debris consisting of radiolid bivalves. It changes both laterally and vertically into a second distinctive lithotype of Kopriva Limestone (rudstone) which is more homogenous and characterized by dark- and light-gray crushed and rounded mollusc shells, primarily rudists.

3.4.4. Lithothamnion limestone

The yellowish-gray Lithothamnion limestone of the Neogene age has been exploited in many quarries in the wider region of eastern Slovenia (the Pannonian basin). Some of the larger quarries are sited along the lower Sava river, e.g., in Hrastnik, Zidani Most, Sevnica, Krško polje and the eastern slopes of Gorjanci. To the north, there are quarries around Podsreda, further north in the belt running from Šentjur to Rogaška Slatina, and still further north around Maribor (two larger abandoned quarries in Zgornji Duplek) and in Ciringa at Svečina (Mirtič *et al.*, 1999).

Lithothamnion limestone occurs within the Middle Miocene Paratethys sediments. Although it is known from a few formations, it was quarried almost exclusively from the Badenian marl-dominated Laško formation. Within the formation, it usually occurs as a member in its lower part, with a thickness of several tens of meters. It is shallow-marine, thick-bedded and massive, light-gray to whitish limestone. It is either calcarenite (grain/rudstone) or biolithite (boundstone), characterized by Lithothamnion (red) algae, which can form grain-size bioclasts, crusts and, rarely, also rhodolits (red-algae oncoids) several centimeters in size (Figure 6a). Other fossils occur, among which bryozoans, molluscs, echinides, corals and foraminifera are the most common. In some localities, quartz and lithic pebbles occur within the limestone. Inter- and intra-granular porosity is often typical for this type of rock (Aničič *et al.*, 2002; Pavšič & Horvat, 2009).

3.4.5. Jezersko tufa

A localized deposit of calcareous tufa, covering an area of about 4 ha, occurs on the left bankshore of the Kokra river near Spodnje Jezersko in the Southern Karavanke mountains (Southern Alps, northern Slovenia) (Figure 7). Deposited from the spring over the Carboniferous black shale and limestone breccia, it does not exceed 20 m in thickness. Excavation of the so-called Jezersko tufa in the Jezersko quarry started in 1950, while its larger-scale exploitation took place between 1970 and 2004.

Tufa is a common subrecent rock found throughout Slovenia in areas dominated by carbonates. It precipitates from the carbonate-rich waters as a calcite growing over plants (particularly moss) and their fragments, such as branches and leaves, but often also over animal remains, such as gastropod shells. It is characterized by high porosity, mostly related to the decaying remains of the plant. It most commonly occurs immediately downstream of the springs, where the intense degassing of waters accelerates mineral precipitations, but it also appears downstream in karstic rivers (e.g., the Krka), particularly along the rapids and dams (Zavadlav *et al.*, 2016). Economically interesting, an accumulation several tens of meters thick was quarried from the Jezersko area in the Karavanke mountains. In this locality, the tufa participated from water oversaturated with calcite, which springs from the Devonian and Lower Carboniferous limestones (Brenčič & Polting, 2008).

Clastic

Figure 6. (a) Lithothamnion limestone with characteristic Lithothamnion (red) algae. Detail of the Hipokren fountain (Ljubljana) (photo Matevž Novak), (b) St. John of Nepomuk is one of the outdoor sculptures at Dornava castle that is made from Lithothamion limestone.

Figure 6. (a) Caliza de lithoitamnimum con las características algas lithothamnian (rojo). Detalle de la fuente Hipokren (Ljubljana) (foto Matevž Novak); (b) St. John of Nepomuk es una de las esculturas al aire libre del Castillo de Dornava que está hecha con la caliza de litothaminium.

Figure 7. Tufa quarry, Jezersko (photo Miha Jeršek).
Figura 7. Cantera de toba Jezersko (foto Miha Jeršek).

3.4.6. Škofja Loka conglomerate

A colorful Oligocene calcareous conglomerate occurs in the broad environs of Škofja Loka (Škofja Loka Hills, Pannonian basin, central Slovenia). Named after the town, the Škofja Loka Conglomerate was quarried by the Romans. The two largest quarries are Kamnitnik I and II near the centre of Škofja Loka, both of which are today abandoned (Figure 8a).

Škofja Loka conglomerate is Oligocene in age and represents the basal formation of the Paratethys sediments in central Slovenia. With erosional contacts, it overlies the Mezosoic deep-marine deposits of the Southern Alps as well as the shallow-marine and clastic sediments of the External Dinarides. In the Kamnitnik hill, it forms a succession up to 70 m thick composed of fluvial deposits—predominantly coarse-grained bedded conglomerates and subordinate sandstones. Channelization, gradation, imbrications and cross- and even-lamination are common textures. A succession indicates sedimentations within a braided river system. The composition of the pebbles is almost exclusively carbonate. Namely, the pebbles are derived from shallow- and deep-marine limestones and subordinate dolomites. Chert and volcanic pebbles occur sporadically. The matrix between the pebbles is sandstone, which is red or subordinate greenish-gray in color and composed of mixed carbonate-clastic material, which is also observed in rare interlayers of the sandstone. The composition reveals the regional provenance of the material (Debevec, 2015; Demšar, 2016).

3.4.7. Želebej breccia

Želebej breccia forms the basal part of the Upper Cretaceous (upper Campanian to Maastrichtian) flysch deposits, known as the Upper flyschoid formation in north-western Slovenia and the Veliki Trn formation in eastern Slovenia (Buser, 1987b; Demšar, 2016; Poljak *et al.*, 2017). The formation itself is composed of alternating marlstone, sandstone and limestone (calciturbidites and calcidebrites). Limestone breccias occur at the base of the formation. They are thick-bedded or massive and can form a succession more than 100 m thick with pronounced lateral variations in the thickness (e.g., Miklavič & Rožič, 2008). The breccia is approximately 50 m thick in the Želebej village where it was quarried, but laterally thickens up to 100 m (Poljak *et al.*, 2005). The size and shape of the clasts vary significantly—they can reach several meters, but are usually around 10 cm large, angular, subangular to surrounded in shape. Breccia consists almost exclusively of diverse limestone lithoclasts which vary in color from light gray to almost black. Rare fragmented rudist shells occur. The matrix in breccia is mostly micrite, with small lithoclasts and diverse bioclasts, among which molluscs and foraminifera prevail (Brajkovič *et al.*, 2014).

3.4.8. Vundušek sandstone

In the past, sandstone was obtained from nine quarries, both large and small, mainly located on the left slope of the Vundušek valley in the western part of Haloze. The largest is the Občinski (municipal) quarry (Figure 8c), which is now abandoned (Kastelic & Kramar, 2005). Since 2020, the Vunduški quarry has been active.

Figure 8. (a) Kamnitnik Quarry of conglomerate (photo Helena Tehovnik Archive ZRSVN), (b) Two of the six columns made of škofjeloški conglomerate at the south entrance of the Roman wall in Mirje, Ljubljana. Most probably, the architect J. Plečnik reused these elements from an ancient monument in the 20th century (photo Nina Žbona); (c) Občinski quarry of Vunduški sandstone (photo Mojca Bedjanič); (d) Ptujska Gora church with Vunduški sandstone scultures (photo Mojca Bedjanič).

Figura 8. (a) Cantera de conglomerado Kamnitnik (foto Helena Tehovnik Archivo ZRSVN). (b) Dos de las seis columnas realizadas con el conglomerado škofjeloški en el sur de la entrada del muro romano en Mirje, Liubliana. Lo más probable es que el arquitecto J. Plečnik reutilizara estos elementos en el siglo XX de un antiguo monumento (foto Nina Žbona). (c) Cantera Občinski de arenisca de Vunduški (foto Mojca Bedjanič), (d) Iglesia de Ptujska Gora con esculturas de arenisca de Vunduški (Foto Mojca Bedjanič).

Vundušek sandstone occurs in the Haloze area in eastern Slovenia. It can form a succession up to 50 m thick in the upper part of the Miocene (Helvetian, i.e., upper Ottnangian to Karpatian) Paratethys sediments, which are otherwise dominated by sandy marlstone. It is also known as Ptujska gora sandstone in the literature, because it was used for the construction of this famous medieval sanctuary. The use of this name was aborted, however, because only younger (Badenian) Laško formation outcrops exist around the sanctuary. Vundušek sandstone was quarried in several localities along the Vundušek creek. It is bedded (up to 2 m), gray, greenish-gray, olive-gray, fine-grained sandstone. It is composed predominantly of quartz, dolomite lithoclasts and mica (muscovite). Other included grains are feldspars, biotite, and lithoclasts of limestone, chert, magmatic (volcanic) and metamorphic rocks. It contains a quartz-carbonate matrix. Apart from the sandstone, the fine-grained conglomerate with a similar composition occurs within the quarried succession (Aničić & Ramovš, 1998).

3.4.9. Elerji sandstone

Beds of graywacke- type sandstone, integral parts of the Eocene flysch sequence of the Adria foreland, hosted several excavation sites. Many were already exploited before WWI. The largest one is the Elerji quarry (formerly named Jelarji) on the northern slope of the hill ‘Hrvatinski hrib’ at the Škofije border crossing with Italy. The same type of flysch sandstone was quarried in Poljane-Puče on the southern slope of Plešivec hill near Sečovlje. In both quarries, the quarrying was temporarily stopped in 1957 and reactivated in 1991. Today, both the quarries are inactive.

The Slovenian coast (northern Istria) is dominated by Eocene flysch deposits. Generally, the succession is characterized by distal flysch deposits, namely, thin turbiditic sandstone beds alternating with marlstone. These beds are interrupted by rare limestone beds, i.e. calciturbidites and calcidebrites (Rožič & Žvab Rožič, 2023). Some of them reach several meters in thickness and three of them were used to divide the thick flysch succession into four subunits (Pavšič and Peckmann, 1996). Locally, the sandstone beds reach a greater thickness. One such interval is quarried in the Elerji quarry near Škofije. The thick beds that form the 9.5m thick interval are mostly between 50 to (a maximum of) 170 cm in thickness, but these are interlayered with some thinner beds. The sandstone in thick beds is medium-grained and homogenous, with only subtle lamination and minor gradation in its topmost part. This reveals the sedimentation not from the turbiditic flows, but from other processes such as hyperpycnal flows. Plant remains and rich ichnofacies, mainly observed on the bedding planes, are characteristic of the Elerji quarry sandstone. Sandstone is composed of carbonate lithoclasts and quartz. The subordinate grains are quartzite, mica-schist and chert lithoclasts, feldspars, garnets and zircons, and very rare bioclasts such as red algae, foraminifera, echinoderm plates and molluscs (Rožič *et al.*, 2023).

3.4.10. Shale

Two types of shale were widely used for roofing in the past in Slovenia—the Upper Carboniferous one in the middle Sava river valley, and the Lower Cretaceous one in the Selce and Poljane valleys. The oldest known Upper Carboniferous shale quarry is in Podgora, west of Dolsko, which began operation as early as the end of the 18th century. In the nearby villages of Klopce and Osredki, quarrying took place from the end of the 19th century until WW2. The Lower Createaceous shale was extracted in many quarries in the environs of the village Zali Log. Some of the larger quarries of this so-called ‘Zali Log roof slate’ were at the southern foot of Grebel vrh (Figure 9a) (Mirtič *et al.*, 1999). None of the quarries in either of those regions are still in operation today.

The Upper Carbonoiferous deposits of central Slovenia are composed exclusively of clastic deltaic and fluvial deposits. They form the oldest outcropping formation of the External Dinarides, so their thickness is unknown, but they surely reach a great thickness (up to 2 km). The composition varies significantly within the formation, but generally it is characterized by intervals dominated by quartz conglomerate and sandstone in the central part and mica-rich shale dominated intervals at the base and in the upper portion of the formation (Mlakar *et al.*, 1992). Due to deep burial prior to thrusting, they show a low-grade methamorphic overprint, which resulted in the slate-cleavage of shales used for their extraction.

The Aptian to lower Cenomanian Lower flyschoid formation is a succession up to 300 m thick within deep-marine deposits outcropping along the foothills of the Southern Alps. In its westernmost part it is characterized by abundant limestones (calciturbidites and calcidebrites), but towards the east it becomes dominated by marlstone and shale (Demšar, 2016; Schlaginweit *et al.*, 2024). The deep-marine deposits (Slovenian Basin) show a low-grade metamorphic overprint (Rainer *et al.*, 2016), which, in the Selška Sora valley, resulted in the formation of slate-cleavage in the shales of the Lower flyschoid formation. This was used in the past for the production of building materials for roofs. Large plates of dark-gray shale, one cm thick and up to several tens of cm in length, have been quarried at several localities in the vicinity of the village Zali Log. Consequently, a local name, "Zali Log roof slates", was used for this formation in older literature (Kossmat, 1903).

Figure 9. (a) Zali Log slate quarry on Grebel vrh (photo Nina Rman), (b) Roof shale slate at the St. Jakob church in Resenik (photo Maja Višnar).

Figura 9. (a) Pizarra laminada Zali cantera en Grebel vrh (photo Nina Rman),
(b) Tejado de pizarra de pizarra en la iglesia de St. Jakob en Resenik (photo Maja Višnar).

4. NATURE CONSERVATION STATUS OF THE VARIOUS QUARRIES

Most of the quarries presented are declared as valuable natural feature of local importance (VNFLI), protected as geological valuable features of national importance (GVFNI) or protected as natural monument (NM). The various quarries with their respective conservation status are given in Table 2. The quarries are declared or protected with the aim of preserving the rock deposits under certain nature conservation conditions and guidelines.

Table 2. Nature conservation status of the various quarries.

Tabla 2. Estado de conservación natural de las canteras.

	Rocks	Quarry	Nature conservation status	Main buildings/monuments and their location
Igneous rocks				
	Granodiorite	Cezlak – cizlakite and granodiorite deposit Josipdol – rock deposit	Cezlak, Oplotnica, southern outskirts of Pohorje: NF/N/ tp,r,sc,ev Josipdol, Ribnica na Pohorju, central Pohorje: NF/L/ tp,r,sc,ev	Square of the Republic in Ljubljana Parliament building in Ljubljana University of Ljubljana
	Cizlakite	Cezlak – cizlakite and granodiorite deposit	Cezlak, Oplotnica, southern outskirts of Pohorje: NF/N/ tp, r, sc, ts /NM	Parliament building in Ljubljana
Pyroclastic rocks				
	Tuff	Peračica – tuff deposit	Klinar quarry in the Peračica Valley: NF/N/ r,ts	Roman stone monument in Lesce Baroque Katzenstein Castle in Begunje Strmol Castle Church of the Assumption of the Virgin Mary in Bled
		Dedkov pruh	Abandoned Dedkov pruh quarry north of Stahovica pri Kamniku: NF/ L/ tp, sc	
Metamorfic rocks				
	Pohorje marble	Rimski kamnolom – Roman quarry Bojtina – marble deposit Hudinja - marble deposit Potnikov kamnolom – rock deposit	Abandoned Roman quarry, Pohorje: NF/ N/ tp, r, ts/ NM Abandoned Bojtina quarry, Pohorje: NF/ N/ tp, r, ts/ NM Abandoned Potnikov quarry: NM/ L/ tp, r, ts/ NM Hudinja – marble deposit: NM/ L/ r, ts	Roman necropolis in Šempeter in the Savinja valley Roman tombstones and other monuments in Ptuj
	Pohorje gneiss in mica schist	Lačna gora – rock deposit	Quarry at the foot of Pohorje Mts., north of Oplotnica: NF/ L/ ex, r	Complex of Žička Kartuzija Church of St. Peter and Paul in Veliko Tinje, Pohorje

Sedimentary rocks				
Biogenic	**Podpeč limestone**	Podpeč - fossil deposit	Quarry in Podpeč: NF/ N/ ex, sc	11,500 stoneware products were produced for Emona alone over three centuries Altar of St. Valentine in the Franciscan Church of the Assumption in Ljubljana National and University Library Façade of the Kozolc in Ljubljana
	Drenov Grič limestone, Lesno Brdo limestone, Hotavlje limestone	Kucler's quarry Lesno brdo – limestone deposit Hotavlje - deposit of Hotavlje limestone	Kucler's quarry; area of Drenov grič: NF/ N/ ex, tp, sc /NM Lesno Brdo quarry, north of Drenov grič: NF/ L/ tp, ts »V rudi« quarry, north of Hotavlje: NF/ L/tp, ts	Portal at the Seminary Palace In Ljubljana Jesuit Church of St James, figures at the altars, In Ljubljana, Black altars in Franciscan Church of the Annunciation in Ljubljana Robba Fountain in Ljubljana Church of the Holly Cross at Srednja vas National and University Library Cultural Center in Ljubljana Cankarjev dom
	Kras limestones	Kopriva – deposit of "kopriva" limestone Lipica - deposit of rudist limestone "fiorito" and "unito" and fossils Kazlje – Tomaj limestone and fossils deposit	Kopriva limestone, quarry north of Kopriva village: NF/ N/ tp, ts /NM Rudist limestone of the Lipiška Formation, near the village of Lipica: NF/ N/ ex, tp, sc, ts Tomaj limestone, abandoned quarry in the village of Kazlje on the Karst: NF/ N/ ex, tp, r, sc, ts	Dry-walled buildings of Karst, in villages Štanjel, Kopriva, Povir Parliament building in Ljubljana
	Lithotamnion limestone	Zgornji Duplek – fossil deposit 1 Zgornji Duplek - fossil deposit 2 Križan Vrh - Lithotamnion limestone	Lithotamnion limestone with fossils, abandoned quarries in Zgornji Duplek: NF/ N/ ex, tp, r /NM Lithotamnion limestone with fossils, abandoned quarries in Zgornji Duplek: NF/ L/ ex, tp, r /NM Lithotamnion limestone, deposit at Križan Vrh in Bistrica ob Sotli: NF/ N/ tp, ts	Negova Castle Podčetrtek Castle the Monument of Plague marker in Maribor Abbey Church in Celje, The Church of St. Daniel Žiče Carthusian Monastery Baroque sculptures of Dornava Manor Parliament Building in Budapest Natural History Museum in Vienna.

	Jezersko tufa	Spodnje Jezersko - tufa deposit with a tufa-forming spring	Tufa deposit and quarry, near Spodnje Jezersko: NF/ N/ ex, sc, ts	Municipalities in Kranj The facade of a hotel in Sant Moritz in Switzerland A fountain in Berlin
Clastic	**Škofja Loka conglomerate**	Kamnitnik - deposit of the Škofja Loka conglomerate	Oligocene conglomerate, an abandoned quarry in Kamnitnik in Škofja Loka: NF/ N/ tp, sc, ts	Monuments in Škofja Loka (Plague marker, St George’s Church)
	Želebej breccia		No conservation status	Staircase of the Church of the Holy Spirit in Črnomelj
	Vundušek sandstone	Jelovice – rock deposit	Municipality quarry, south-east of Majšperk: NF/ L/ tp, ts	Castles of Goričko, Ravno polje, Vurberg, and Štatenberg
	Elerji sandstone		No conservation status	Former 12th-century city tower in Koper, Salt storehouse of St Mark in Koper Defensive tower at Punta in Piran
	Shale		No conservation status	Roofs cover with slates in Podgora west of Dolsk

Type of protection
- protected geological valuable natural features (NF)
- protected natural monument (NM)

Significance:
- national importance (N)
- local importance (L)

Criteria for Determining Significance:
- typicality (tp)
- rarity (r)
- exceptionality (ex)
- scientific importance (sc)
- evidential value (ev)
- testimonial significance (ts)

Among the quarries, nine sites are protected as natural monument (the cizlakite deposit in the quarry in Cezlak - Oplotnica, marble deposits - abandoned Bojtina quarry, Roman quarry in Pohorje area and Potnikov quarry, Podpeč quarry of limestone, locality of black limestone – the Kuclerjev kamnolom quarry, the deposit of „karst limestone“ - Kopriva limestone in the quarry north of Kopriva, and the deposits of Lithotamnion limestone with fossils in abandoned quarries in Zgornji Duplek 1 and 2).

Some of the deposits are protected as a geological valuable natural feature of national importance due to their due to their typicality, rarity, scientific importance and evidential value (Cezlak - Oplotnica), their rarity and testimonial value (the Peračica tuff deposit in the area of the Klinar quarry), their exceptionality, tipicality and its importance for scientific research (locality of Drenov grič black limestone – the Kuclerjev kamnolom quarry), their typicality and testimonial value (the deposit of „karst limestone“ - Kopriva limestone in the quarry north of Kopriva village), their exceptionality, tipicality and its importance for scientific research and testimonial significance (deposit of rudist limestone of the Lipiška Formation in the Lipica I quarry, a deposit of Tomaj limestone in an abandoned quarry in the village of Kazlje), their importance due to their exceptionality, typicality and rarity (the deposits of Lithotamnion limestone with fossils in abandoned quarries in Zgornji Duplek), their typicality, state of preservation and testimonial significance (Lithotamnion limestone deposit at Križan Vrh in Bistrica ob Sotli), their exceptionality, state of preservation, importance for scientific research and testimonial significance (tufa deposit with a tufa-forming spring near Spodnje Jezersko, including a quarry), or due to their typicality, importance for scientific research and testimonial significance (a deposit of reddish Oligocene conglomerate in an abandoned quarry in Kamnitnik).

Several deposits are declared as as a valuable natural feature of local importance, either due to their typicality, rarity, scientific importance and evidential value (the location of granodiorite rocks Cezlak), their typicality, rarity and testimonial importance (abandoned quarry Hudinja – marble deposit), their typicality and testimonial importance (the deposit of the Lesno Brdo multicolored limestone in the Lesno Brdo quarry north of Drenov grič, the deposit of Hotavlje limestone in the »V rudi« quarry north of Hotavlje, deposit of Miocene sandstone, conglomerate, marl and claystone in abandoned Municipality quarry south-east of Majšperk), their typicality and importance for scientific research (the deposit of quartz keratophyre and tuff in the abandoned Dedkov pruh quarry north of Stahovica pri Kamniku), their exceptionality and rarity (the deposit of gneiss and mica schist in a quarry at the foot of Pohorje Mts., north of Oplotnica), or their exceptionality and its scientific research and testimonial value (the main quarry in Podpeč).

5. TECHNICAL CHARACTERISTICS OF NATURAL STONES

The main physical-mechanical properties of the natural stones from the quarries presented are given in Table 3. With only a few exceptions, the natural stones presented are, in general, characterised by low open porosity and water absorption. Granodiorite, Pohorje gneiss/mica shist, Lesno Brdo limestone and Repen limestone are classified as compact stones, while Peračica tuff is very porous and Lithotamnian limestone and Jezersko tufa are extremely porous. Other natural stones are grouped as low or moderately porous (Bilbija & Matović, 2009). Enhanced values of water absorption are characteristic for tuff, Lithothamnium limestone, tufa and Vunduški sandstone. As regards the mechanical strength, the majority of rocks are classified as high strength rocks, with the highest values reached for the Lipica Unito limestone. Peračica tuff, Pohorje marble and Hotavlje limestone are classified as moderate-high strength, with Lihtotamnian limestone having low strength, and tufa very low strength. Generally, all the natural stones presented have a high resistance to weathering, while Pohorje gneiss/mica schist, Drenov Grič limestone and tufa showed lower resistance to salt crystallization. Despite its low porosity, the durability of Drenov Grič limestone is mostly affected by the presence of phyllosilicate-filled discontinuities, resulting in flaking (Kramar *et al.*, 2010a), which also contributed to the slightly higher water absorption of this limestone compared to other Kras limestones. Granodiorite from the Pohorje Mountains (northeastern Slovenia) is considered the highest quality natural stone in Slovenia (Kramar *et al.*, 2015c).

6. USE IN ARCHITECTURE AND MONUMENTS

6.1. Granodiorite

Due to its appearance and durability, granodiorite is the most commonly used outdoor natural stone in Slovenia (Kramar *et al.*, 2015c; Novak, 2016a). It is used for all types of cladding, including kerbs, cobbles, building stone and for monuments. As one of the most resistant rocks in our environment, granodiorite has always been widely used for the most important monuments of national importance, such as the Square of the Republic (Figure 10a), the Parliament building, and the University of Ljubljana. In addition to its versatile use as an architectural and technical stone, it is also present in works of art, monuments, and memorials throughout the country (Čopič *et al.*, 1991; Žitko Durjava, 1996).

An unusual type of degradation of granodiorite cladding panels occurs in the form of bowing, which is one of the very few documented cases of igneous rock bowing. Depending on the conditions of exposure, slight limonitization may also occur, but this phenomenon is far less extensive than in many other rocks that contain pyrite (Kramar *et al.*, 2015c).

Table 3. Physical-mechanical properties of the natural stones.

Table 3. Propiedades físico mecánicas de las piedras naturales.

		Water absorption (wt. %) SIST EN 13755	**Apparent density (kg/m3) SIST EN 1936**	**Open porosity (%) SIST EN 1936**	**Uniaxial compressive strength (MPa) SIST EN 1926**	**Flexural strength SIST EN 12372**	**Resistance to salt rystallization (mass loss in wt. %) SIST EN 12370**
Igneous rocks							
	Granodiorite	0.3	2679	0.9	170	15.0	0.0
	Cizlakite	0.5	3070	1.6	199	18.3	-0.12
Pyroclastic rocks							
	Peracica tuff[1]	8.2	2178*	20.1	79	28.8*	-0.7*
Metamorphic rocks							
	Pohorje marble	0.2*	2720*	1.0*	118*	n.a.	-0.1*
	Pohorje gneiss and mica schist	1.6	2600	0.5	n.a.	34.4	-4.6
Sedimentary rocks							
Biogenic	**Podpeč limestone**	0.3*	2698*	2.7*	n.a.	n.a.	-0.03*
	Drenov grič limestone2	1.7*	2785*	0.7*	167*	6*	-3.1*
	Lesno brdo limestone	0.1	2700	0.4	144	11.3	-0.06
	Hotavlje limestone	0.1	2746	1.2	118	14.7	-0.25
	Lipica Fiorito limestone	0.2	2675	2.7	190	13.9	-0.07
	Lipica Unito limestone	0.6	2650	1.8	223	15.3	-0.03
	Repen limestone Lithothamnion	0.2	2680	0.5	143	14.1	-0.02
	limestone	6.8*	2136*	22.5*	33*	n.a.	-0.3*
	Jezersko tufa	8.5	1952	28.0	8	1.7	-4.6
Clastic	Škofja Loka conglomerate	1.3	2650	4.0	n.a.	8.7	n.a.
	Želebej breccia	0.07*	n.a.	n.a.	181*	17.0*	n.a.
	Vunduški sandstone	3.9*	2712*	1.2*	105*	n.a.	n.a.
	Jelarji sandstone	0.4	2640	1.0	168	11.3	-0.3
	Shale	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

*Values marked with an asterisk indicate historical data, obtained according to national standards which were in validity in Yugoslavia.
Uniaxial compressive strength: JUS B.B8.012
Flexural strength: JUS B.B8.017
Resistance to salt crystallization: JUS B.B8.002
Water absorption: JUS B.B8.010
Apparent density and porosity: B.B8.032

[1]Korat *et al.*, 2015; 2 Kramar *et al.* 2020

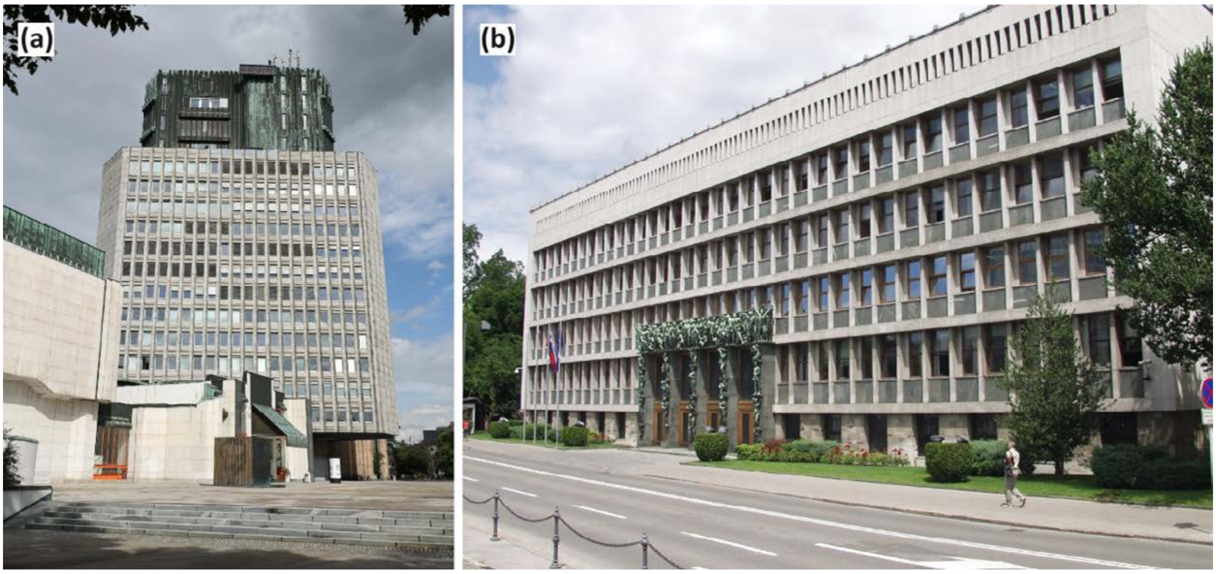


Figure 10. Monuments with application of igneous rock: (a) Granodiorite façade of the TR3 building in the Square of the Republic (photo Valentin Benedik), (b) Parliament Building, the façade of the building is richly decorated with greenish cizlakite cladding (photo Valentin Benedik).

Figura 10. Monumento de rocas ígneas: (a) fachada de granodiorite de el edificio TR3 de la plaza de la República; (b) edificio del Parlamento, la fachada del edificio está ricamente decorada con un revestimiento de cizlakita verdosa (foto ValentinTine Benedik).

6.2. Cizlakite

Like granodiorite, cizlakite adorns many of the exterior surfaces of our cities, villages, and landscapes. It is an excellent paving product for elaborate patterns; façade buildings are covered with it, and monuments and many architectural elements are made of it. The Parliament building in Ljubljana (Figure 10b), which is inscribed on the list of immovable cultural heritage as a monument of national importance, is richly decorated with cizlakite, both on the façade and inside the building (on the staircase), to name just one of the most important examples.

6.3. Peračica tuff

The characteristic light green colors of the tuff give the Gorenjska landscape its character. The tradition of using tuff dates back to ancient times, as evidenced by the discovery of a Roman stone monument in Lesce and the remains of Roman architecture in Mošnje in Gorenjska (Avguštin, 1987). Throughout history, tuff has been used as a construction material for many architectural details in buildings, e.g. portals, window frames, consoles, and other stonework in many townhouses, village buildings, outbuildings, churches and castles. This ranges from simple columns and door or window lintels to complex, profiled, and otherwise ornate architectural building elements. In addition to outdoor use on the exterior of the building, the stairs, balusters, pedestals and columns in the Baroque Katzenstein Castle in Begunje were all made from green tuff, as was the life-size stone figure that adorns Strmol Castle (Resman, 2006) (Figure 11)—both of these are declared as cultural monuments of national importance. A significant amount of historical pavements are still preserved in houses, castles and churches. In Bled, Slovenia’s only island, tuff can be found in the artistically designed portals and window frames of the Church of the Assumption of the Virgin Mary, as well as on all of the other buildings on the island.

The *in situ* preservation of tuff elements represents a major challenge for the conservation-restoration profession. The majority of artifacts are located in a climate zone where it freezes in winter, which causes numerous types of damage. Damage in the form of falling-off parts, peeling, swelling, cracks and fractures is recorded on portals, window frames, columns and other external elements along with any other damage which directly affects the loss of material. Usually, in combination with the aforementioned types of damage, crust and biological factors of decay and color changes are also present. When the elements are in close proximity to the ground, the damage is also a result of capillary moisture in water-soluble salts.

Targeted research is used to study the deteriorated condition and determine the most appropriate methods of tuff repair (Gutman Levstik, 2019; Korat *et al.*, 2015).

Figure 11. Outdoor sculpture from tuff, representing a male figure, probably from the Baroque period—Castle of Strmol, Cerklje na Gorenjskem. A greenish window frame made of tuff can be seen in the background (photo Nina Žbona).

Figura 11. Escultura al aire libre de toba, que representa una figura de comida, probalemente del Barroco, Castillo de Strmol, Cerklje na Gorenjskem. En el fondo, se observan los marcos de las ventanas de color verdoso, hechas de toba (foto Nina Žbona).

6.4. Pohorje marble

The rich history of the Styria region has left us many important monuments, of which the Roman stone monuments are undoubtedly some of the most recognizable. In Šempeter in the Savinja valley, a Roman necropolis with marble tombstones from the 1st to 3rd centuries A.D. is one of the most important outdoor monuments of national importance. The largest collection and most exceptional examples are preserved in Ptuj, among which the collection of the Ormož Ptuj Regional Museum stands out. Many Roman tombstones and other monuments have found their place on the façades of churches, city towers and other important buildings or simply reused for other purposes. White marble was also used for the construction of houses in Slovenska Bistrica, as well as for portals and altars, while during WWII even a new 3 km long marble road was built in Pohorje, among other things (Kuzman, 2012; Jeršek, 2020).

In Slovenia, we still keep some of the most important ancient monuments outdoors. In winter conditions, some are protected, but the material condition and importance of the monument, a protection is required in sheltered areas or appropriate year-round in-situ protection should be arranged. While this is already planned for some monuments, the surfaces of monuments that are already damaged deteriorate even faster due to atmospheric factors, and exposure to UV rays is also harmful to marble as it both affects the color and causes granular disintegration. We also record deterioration in the form of crushing and the loss of material on individual ancient pieces that were stored indoors, and it will be necessary to carry out consolidation before any other procedures are initiated.

6.5. Pohorje gneiss and mica-shist

Thick slabs are used for layering in different patterns or for the construction of walls. Thinner plates are more useful for the traditional craft of stone roofs. The custom of covering roofs with stone tiles has been widespread in several parts of Slovenia throughout history, but unfortunately this has become rarer over the last century and many of the original roofing materials have been replaced with brick, tin and other types of roofing material. The old craft is now reviving again and it is possible to replace or reconstruct the original roofing, where necessary, as in the case of the renovated roof on the complex of Žička Kartuzija (Kuzman, 2012). In Veliko Tinje, the church of St Peter and Paul, with its bell tower, is entirely covered with stone roofing.

6.6. Podpeč limestone

This highly decorative stone is an inseparable part of the most important monuments of Slovenia's cultural heritage (Kramar *et al.*, 2015a). Traces of its use date back to Roman times, when it is estimated that, over the course of three centuries, 11,500 stoneware products were produced for Emona alone (Djurić & Rižnar, 2017). A wide variety of products have been preserved, including architectural elements (columns, architraves, etc.), constructions, cloaca covers, stelae, fragments of opus sectile, paving slabs and boundary stones, amongst others (Djurić *et al.*, 2022). The Baroque period, and later the Slovenian architect J. Plečnik, undoubtedly elevated the use of stone even further. Baroque products made from Podpeč limestone still adorn churches in the capital and beyond. It was largely used in the group of the so-called Baroque black altars for columns, volutes and architectural parts, such as the altar of St Valentine in the Franciscan Church of the Assumption in Ljubljana.

Many of Plečnik's monuments that have been inscribed on the UNESCO World Heritage List are either made or decorated with this stone. One of the most striking buildings is undoubtedly the National and University Library (figures 12c and 12d), where the limestone from Podpeč can be immediately found on the façade, while in the interior the architect applied the decorative effects of polished limestone to many other elements, such as the flooring, the columns and the imposing portal to the Exhibition Hall. Many younger architects continued to use this limestone, as witnessed by the stone façade of the Kozolc, a building in the centre of Ljubljana listed on the Register of Intangible Cultural Heritage. Podpeč limestone was widely used, especially in the Baroque period, due to its exceptional color properties when polished. Today, such examples are known only in those monuments that are kept indoors. The degree of preservation of external architectural elements compared to, for example, altars or museum exhibits is enormous.

There is a pronounced color change on the external elements, with the stone no longer of an intense dark color, while the surface appears to be strongly embossed, with particles peeling and crumbling, and larger original parts have usually already fallen off. Cracks, breaks, biological factors of decay and crusts on the surface are evident. Most outdoors monuments are located in central Slovenia, where freeze-thaw cycles occur during the winter. The vast majority of monuments remain unprotected during this period, which leads to the additional loss of material for already-damaged surfaces. As with other monuments, direct proximity to the ground means an additional source of damage, especially in cities.

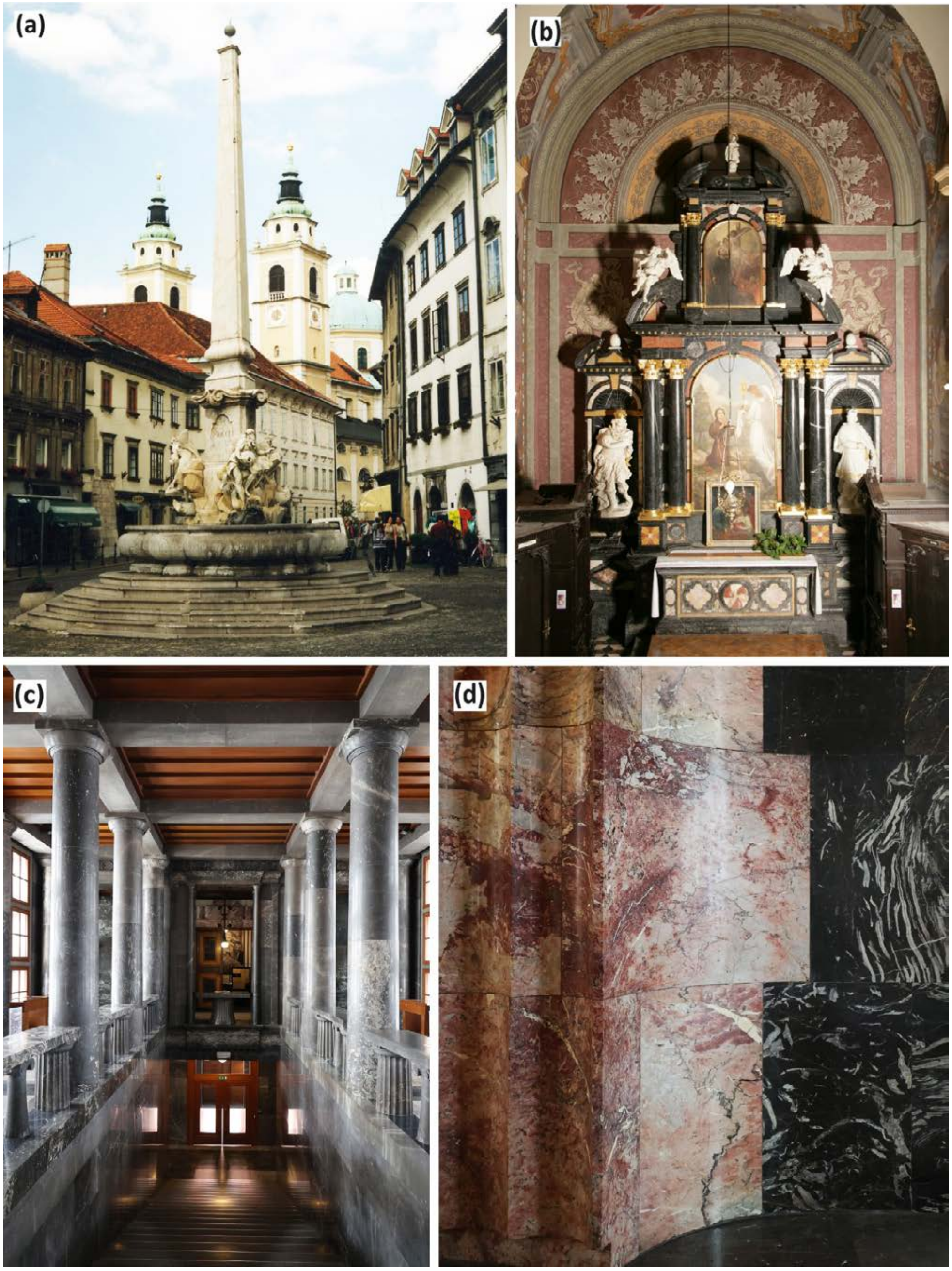


Figure 12. (a) The Robba fountain with the obelisk and bowl made of Lesno Brdo limestone; (b) Franciscan Church of the Annunciation, side altar of Three Kings, one of the so-called black altars from the Baroque period, due to the predominant use of black stone. All the columns, pilasters, mensa and stairs are made from Drenov Grič limestone; (c) Detail of the interior of the National and University Library in Ljubljana (UNESCO list; columns are made of Podpeč limestone); (d) Scarlet red Hotavlje limestone combined with darker limestone from Podpeč, shining with the abundancy of white ornamental lithiotid shells; used as wall cladding (photo Valentin Benedik).

Figura 12. (a) Fuente Robba con obelisco y cuenco de piedra caliza de Lesno Brdo. (b) Iglesia Franciscana de la Anunciación, altar lateral de los Reyes Magos, uno de los altares negros del barroco llamados, por el uso predominante de la piedra negra. Todas las columnas, pilastras, mensa, escaleras y otros están hechos de piedra caliza de Lesno Brdo. (c) Detalle del interior de la Biblioteca Nacional y Universitaria de Liubliana (lista de la UNESCO) (las columnas están hechas de piedra caliza de Podpeč). (d) Caliza rojo escarlata Hotavlje combinada con calizas más oscuras de Podpeč, brillando debido a la abundancia de conchas blancas ornamentales de litiotida, utilizadas como revestimiento de paredes (foto Valentin Benedik).

6.7. Drenov Grič, Lesno Brdo/ Hotavlje limestone

Because of its outstanding decorative qualities, many of the artworks and monuments in central Slovenia have been created from these rocks. A walk through Baroque Ljubljana, the capital of the country, is a walk among colorful limestones. Drenov Grič black limestone is used both in outdoor spaces in the form of imposing portals, such as the portal at the Seminary Palace, which is declared as a monument of local importance, and in the interiors of sacred buildings (Kramar *et al.*, 2020). The most prominent examples are in the Jesuit Church of St James and on the altar of St Francis Xavier in the chapel of the church of the same name. It is particularly remarkable in sculptural wroks szch as the seated king and the Moors. The main portal of the church is carved from dark limestone. The black altars in the Franciscan Church of the Annunciation are also made of Drenov Grič black limestone (Figure 12b). The most famous Slovenian Baroque fountain, the Robba Fountain from 1751, is also largely made of Lesno brdo limestone (the mighty obelisk is made of pink Lesno brdo limestone, while the bowl of the fountain, the columns and the steps are made of gray Lesno Brdo limestone).

Hotavlje limestone was mostly used in portals and has thus become part of Slovenian's technical and cultural heritage. The oldest known products of Hotavlje limestone, dating back to the 16th or 17th century, can be found in the church of the Holy Cross at Srednja vas (Ramovš, 1995). It was also used as cladding for the walls and floors at the National and University Library (Figure 12b) and at the Cultural Center in Cankarjev dom, Ljubljana (declared as a monument of national importance). As in the case of the Podpeč limestone, most of these monuments are located in central Slovenia, and, similarly, the colorful Baroque compositions, in their original splendor, can only be admired in the monuments that have been kept indoors. The most important Slovenian The Robba Fountain (Baroque period) in Ljubljana (Figure 12a), where these rocks are represented abundantly, was completely dismantled at the beginning of 2000, despite the efforts of professionals to preserve the monument on site. In 2006, a copy made of the same natural stone was placed on the site, and the original was conserved and placed in the National Gallery two years later. Experts have been monitoring the extremely poor condition of the monument since the 1970s, when they found that, despite interventions, the stone elements were rapidly deteriorating and the monument was also losing its stability. In addition to climatic conditions, the urban environment and overly aggressive past interventions, the durability of the natural stone is also greatly affected by the properties of the stone itself, which are not the most suitable for the outdoor environment, hence why these monuments weather faster. Salt weathering is, however, observed outdoors as well as indoors (Kramar *et al.*, 2010b; Kramar *et al.*, 2011a; Kramar *et al.*, 2011b).

6.8. Limestones of the Classical Karst (Kras limestones)

One of the first associations with the Kras (Karst) is undoubtedly stone, which naturally creates the landscape (Figure 13a) and upon which man has left his mark with various stone products. The limestones of the Kras have played, and continue to play, an important role as a building, architectural, and decorative material (Kramar *et al.*, 2015b). Limestone was used for the construction of dry stone walls (Figure 13b) typical of Kras walls and shepherd's huts, for classical limestone construction with carvings, for gutters, roofing, fountains, technical elements (drainpipes, manhole covers, grinding wheels, etc.), for various vessels and troughs and for all the classic stonemasonry products. The art of dry stone walling, along with the knowledge and techniques of Kras, were listed by UNESCO in 2018 (together with those of Istria) as Intangible Cultural Heritage of Humanity. This rich heritage is still preserved in many places throughout the area, and villages and hamlets as a whole are listed in the Register of Intangible Heritage (Štanjel, Kopriva, Povir, etc.).

Its use has also spread elsewhere in Slovenia, but not to the same extent. In Ljubljana, two karstic limestones from Kopriva and Vrhovlje can be found on the outer surfaces of the Parliament building. In addition to the two types already mentioned, a darker Kras limestone from Kazlje is used in the interior (Fatur & Kunaver, 2000).

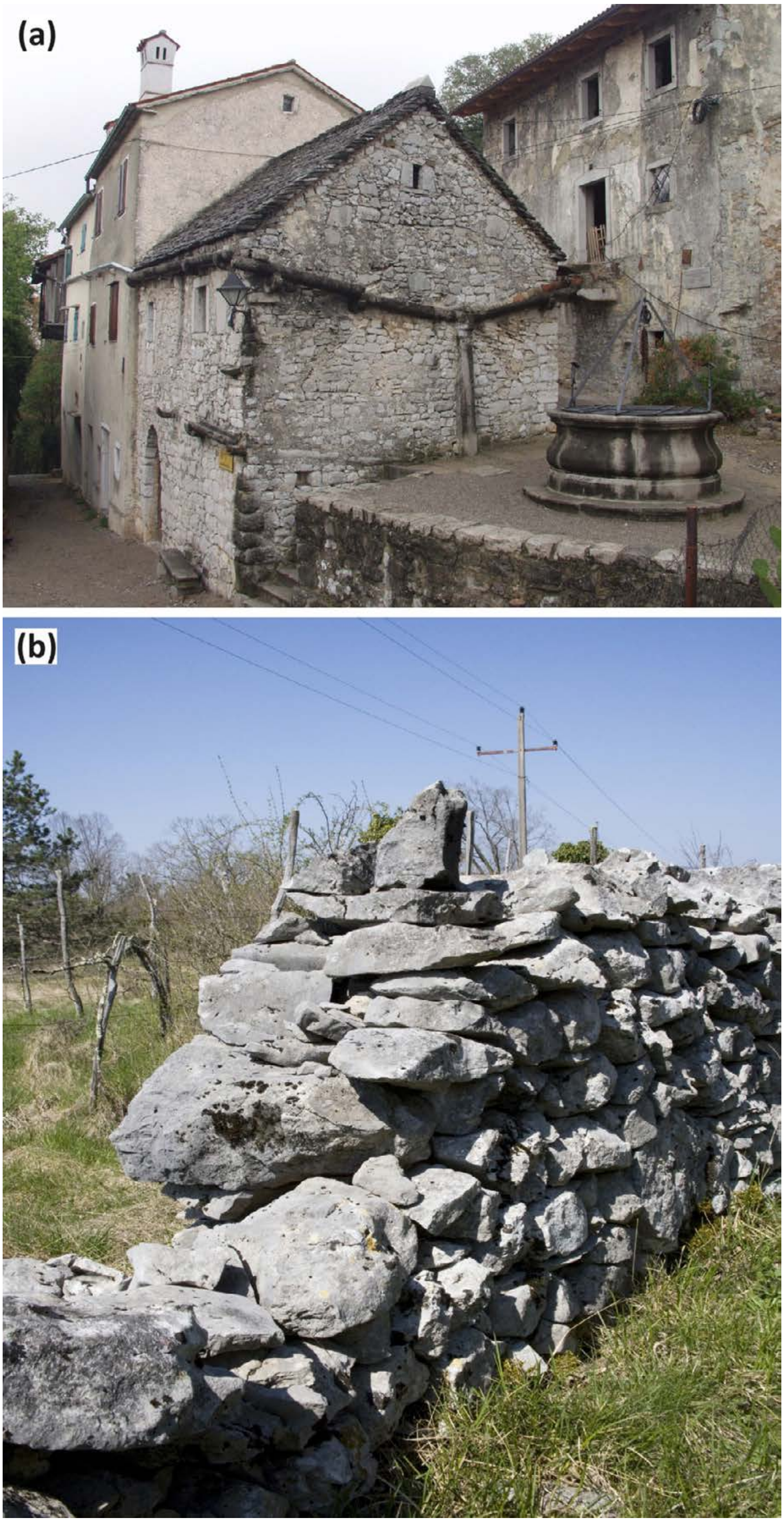


Figure 13. (a) Kras village Štanjel—examples of the traditional use of limestone in the Classical Karst: stone gutters, fountain, construction material, stone roofing, window frame and stairs (photo Valentin Benedik), (b) Archaeological site Debela Griža-Volčji Grad in Kras; dry-walled construction.

Figura 13. (a) Pueblo de la region de Kras, Štanjel: ejemplos de uso tradicional de calizas de Classical: canales de piedra, fuentes, material de construcción, tejados, marcos de ventana y escaleras (foto Valentin Benedik), (b) Sitio arqueológico Debela Griža, construcción en piedra seca.

6.9. Lithothamnion limestone

This rock of eastern Slovenia has been used as a building and architectural material in heritage monuments such as Negova Castle, Podčetrtek Castle and the lower part of the Monument commemorating plague - plague marker "Kužno znamenje" in Maribor. The blocks in the foundation of the Abbey Church in Celje, the Church of St. Daniel, are also made of Lithothamnion limestone. The construction of the 12th-century Žiče Carthusian Monastery, an important monument of cultural heritage in the wider European area, also made extensive use of this rock (Golež, 1999).

Research conducted a few years ago has shown that the Graz sculptor F. J. Straub used white Lithothamnion limestone to create the Baroque sculptures of Dornava Manor (Figure 6b). The manor house, which is listed in the Register of Immovable Heritage as a monument of national importance, contains the richest collection of garden stone sculptures in the country, and research has so far confirmed the use of Lithotamnian limestone in three of the sculptures (Gutman Levstik, 2021). The Lithothamnion limestone is one of a few natural stones that was exported and widely used abroad. It was used in several prominent buildings, such as the Parliament Building in Budapest and the Natural History Museum in Vienna (Fatur & Kunaver, 2000).

Despite extensive conservation-restoration work in the 1990s, the garden sculptures of the Dornava Manor were preserved in such poor condition that they were dismantled at the beginning of the 2000s. The preserved originals will be replaced at their original locations with copies made of artificial and natural stone. There are also numerous decorative sculptures and other elements in the manor area, and, due to continued exposure, new damage and the loss of material are being recorded. The condition of outdoor sculptures is similar elsewhere. In some cases, the originals can be kept outdoors even after conservation-restoration work, but, in addition to appropriate conoslidation, additional protection is necessary, e.g., with a sacrificial paint layer or through the application of hydrophobic coatings. Remnants of paint layers can be found on some sculptures, which indicates that the sculptures were most likely painted or gilded in the past, which contributed to their protection. Remnants of paint coatings are also present on portals, window frames and other architectural elements, and they also most likely served as protection. Regular maintenance in the past allowed for a longer lifespan, but in Slovenia the time after World War II was not exactly favorable towards this type of heritage, as is evident in the preservation of mansions and their furnishings.

6.10. Jezersko tufa

Jezersko tufa is typically used as an architectural stone for façade cladding and various decorative details in buildings, gardens and parks. Center of the capital offers a very good example of this type of use, on the façade of the late nineteenth-century house Prešernova 5, where the ground-floor part of the façade is entirely clad in stone. Because of the rare number of economically interesting deposits in the world, the Jezersko tufa is highly sought after both at home and abroad (for example, the tufa is used for the decorative arch at the top of the slope in the old part of the city and the cladding of the new part of the municipality building in Kranj, the façade of a hotel in Sant Moritz in Switzerland, a fountain in Berlin, etc.). Jezersko is the only working quarry in our country and probably also the only one in Central Europe (Herlec & Vidrih, 2006). Compared to other natural stones used for similar purposes, it has poorer mechanical properties. Due to its low load-bearing strength, it is not useful as a load-bearing structural element. Therefore, blocks and smaller pieces are sawn into panels for cladding external walls and other façade elements (non-load-bearing arches, columns, shelves) and decorative objects. When installed in this way, it is quite resistant to various weather conditions. Due to its pronounced porosity, it is difficult to clean, which is especially evident in urban and industrial environments (Mirtič *et al.*, 1999). When restoring façade cladding, the most problematic areas are those in the immediate vicinity of the ground, especially in urban environments, where salt is still sprinkled heavily on roads and sidewalks in the winter to prevent frost. Fortunately, the extraction of this stone is still alive and the most damaged panels can be replaced with new ones.

6.11. Škofja Loka conglomerate

Gray, reddish, and greenish limestone conglomerates were used as building stones in the wider area of extraction and were also very popular for making millstones. The reddish and yellowish variants are abundantly represented among the monuments in Škofja Loka. It can be found on the plague marker as well as on numerous portals, vaults and sacral buildings, such as St George's Church, and elsewhere.

In the capital, the architect J. Plečnik also erected six columns with capitels made of Škofja Loka conglomerate as part of the Roman wall in Mirje (the monument is inscribed on the UNESCO World Heritage List) (Figure 8b). Most often, selective weathering with the matrix eroded is observed in monuments made of this natural stone.

6.12. Želebej breccia

Due to its advantageous physical properties (good workability, can be polished etc.) breccia is suitable for stone cladding, appropriate for both internal and outdoor use, and is especially suitable for paving (Vesel & Senegačnik, 2000). Due to its physical properties, breccia is also suitable for outdoor use, such as wall cladding (Miletić & Novak, 2021). Parts of the rock that contain clay mineral admixtures as a binder are particularly suitable for indoor products, such as flooring and stairs (Mirtič *et al.*, 1999; Miletić & Novak, 2021).

This stone was mostly used locally and we can still find some repairs or reconstructions on stone monuments carried out with grayish breccia, such as the renovated staircase of the Church of the Holy Spirit (1487) in Črnomelj (Miletić & Novak, 2021).

6.13. Vundušek Sandstone

This stone has been used as a building, architectural and decorative material. In Maribor, we can find it on the railway and road bridges, on the base of St. Florian's statue, and on many other monuments in the city. The columns, pavements, portals and staircases in the famous pilgrimage church of Our Lady of Protection at Ptujska Gora are made of sandstone (Figure 8d). The stone is also found in many castles, such as the castles of Goričko, Ravno polje, Vurberg and Štatenberg.

6.14. Elerji sandstone

Throughout history, the area of Slovenian Istria has recorded the use of sandstone for various construction, architectural and decorative purposes. Thick slabs of sandstone have decorated the old pavements of coastal towns and the interior of Istria, secular and sacred buildings have been built, urban furniture has been created and buildings have been adorned with detailed stonemasonry.

In Koper's main square, the former 12th-century city tower, now the bell tower of the Cathedral Church of the Assumption, reveals a sandstone construction, as does the 17th-century salt storehouse of St Mark. In addition to limestone, which is also a local stone in Istria and typically used in the construction of major buildings, sandstone has often found its place, as in the cylindrical defensive tower at Punta in Piran, which dates from the 16th/17th centuries (Figure 14). We can also find some pavements and other minor architectural uses for this sandstone in the capital city, but it is more abundantly present in the cultural heritage of nearby Trieste, Italy. Sandstone is mostly used in the coastal zone, where the climate is milder, being used for both interior and exterior elements. On historic buildings, where exposed stone dominates today, the effects of weathering are visible even to the naked eye. More exposed stone blocks lose material and, between the recessed surfaces, the harder material usually stands out at the joints. Probably, as with the other stones, the fact that the façades were painted helped considerably, giving the stone a sacrificial layer, which, with regular maintenance, prevented direct contact with any factors causing the deterioration of natural stone. Damage was also common as a result of the presence of salt near the ground and due to erosion, especially on walking surfaces.

Throughout history, it has been used in the area mentioned for various paving purposes. Due to its favorable mineral composition and structure, its surface remains rough even after prolonged use and it is therefore non-slip. It is important, however, that it does not contain marl. This, even in small quantities, significantly reduces the quality of the products (Mirtič *et al.*, 1999).

Figure 14. Coastal lighthouse on the defensive tower on the Venetian city walls, made of Elerji sandstone, the edge of the peninsula in Piran (photo Nina Žbona).

Figura 14. Faro en el límite de la Península en Pira, hecho de arenisca Elarji en la torre defensiva de las murallas venecianas (foto Nina Žbona).

6.15. Shales

The tradition of covering roofs with shale in Slovenia probably originated in Podgora, west of Dolsko (Ramovš, 1987). It was common practice to cover the roof with shales throughout the wider area from where it was extracted (Figure 9b). We still also have some examples of stone roofing in Bohinj, and in the past they exported the stone to neighboring Austria. Slabs were found as paving stones in cellars and halls in some houses and even in some smaller streets in the old city of Ljubljana.

7. CONCLUSIONS

The geological diversity of Slovene territory results in a variety of natural stones being used in architectural heritage, which also gives the landscape special character. While some natural stones, such as granodiorite, cizlakite, Lesno Brdo and Kras limestones are widely used across Slovenia in important buildings, a different variety of rocks, such as sandstones, conglomerate, breccia, shale and tuff give character to local vernacular architecture. The Cezlak quarry is the only known site of cizlakite, a Slovenian endemic. Podpeč limestone is designated as a Global Heritage Stone Resource (GHSR). Podpeč limestone and Hotavlje limestones are used in the works of the architect Jože Plečnik that are included in the UNESCO World Heritage List. Most of the quarries presented are declared as valuable natural feature of local importance, protected as geological valuable features of national importance or protected as natural monument. Due to low reserves, many quarries are today abandoned. Depending on the natural conservation status, under certain conditions it is possible to extract small quantities of stone for the renovation of monuments of great importance.

Especially in the past, the choice of natural stone was often limited primarily to availability or due to the existence of a local source, regardless of its physical-mechanical properties. Stone heritage therefore gives special character to the landscape of Slovenia, which is primarily identified through the application of various types of natural stone.

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Authorship contribution statement

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The authors of this article declare that they have no financial, professional, or personal conflicts of interest that could have inappropriately influenced this work.

Statement on the use of Artificial Intelligence

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