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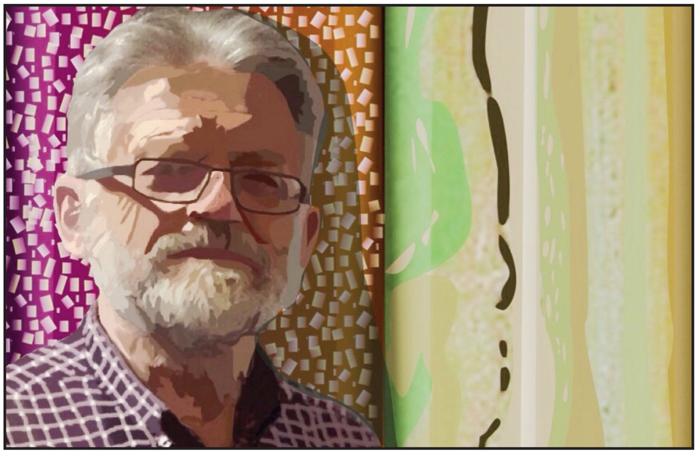

Heritage Stone 7. Pohorje Granodiorite – One of the Most Significant Slovenian Natural Stones*

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SUMMARY

Granodiorite from the Pohorje Mountains (northeastern Slovenia) is considered the highest quality natural stone in Slovenia. *Pohorje granodiorite* is a grey, calc-alkaline igneous rock of Miocene age (18.7 Ma) that is distinguished by thick white aplite−pegmatite veins. It mainly consists of plagioclase, quartz, and K-feldspar, subsidiary biotite and a small amount of hornblende. It is characterized by high density, low water absorption, and low porosity, so that it exhibits high frost and salt resistance, as well as a high compressive strength and a very high flexural strength. It is widely recognized throughout the country for its durability and decorative white veins, and is the most frequently used natural stone in Slovenia today. It is mainly used as paving and cladding material for residential buildings, churches, and other structures, as well as in public areas, where it adds special character to many of the larger towns and cities. Several important buildings, some of which have been declared cultural monuments of national importance, are also decorated with this stone, including the Slovenian Parliament, the Republic Square business complex, and the Faculty of Law of the University of Ljubljana, all of which are located in Ljubljana. Since 1940, Pohorje granodiorite has also been widely used by sculptors in various monuments and fountains.

RÉSUMÉ

Le granodiorite des montagnes de Pohorje (nord de la Slovénie) est considéré comme la meilleure pierre naturelle de Slovénie. Le granodiorite de Pohorje est une roche ignée grise, calco-alcaline du Miocène (18,7 Ma) qui se distingue par la présence d'épais filons de pegmatites d'aplite blanche. Il se compose principalement de plagioclase, de quartz et de feldspath potassique, de biotite accessoire et d'une petite quantité d'amphibole. Elle est caractérisée par une densité élevée, un faible coefficient d'imbibition, et une porosité faible, de sorte qu'elle présente une haute résistance au gel et au sel, ainsi qu'une résistance élevée à la compression et une résistance très élevée à la flexion. Elle est très connue dans tout le pays pour

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sa durabilité et ses filons décoratifs blancs, et c'est la pierre naturelle la plus fréquemment utilisée en Slovénie de nos jours. Elle est principalement utilisée comme matériau de pavage et de revêtement pour les bâtiments résidentiels, les églises et autres constructions, ainsi que dans les espaces publics, où elle donne un caractère distinctif aux grands villages et aux villes. Plusieurs bâtiments importants, dont certains ont été déclarés monuments culturels d'importance nationale, sont également décorées avec cette pierre, y compris le Parlement slovène, le complexe d'affaires Place de la République, et la Faculté de droit de l'Université de Ljubljana, lesquels sont tous situés à Ljubljana. Depuis 1940, le granodiorite de Pohorje a aussi été beaucoup utilisé par les sculpteurs dans divers monuments et fontaines.

Traduit par le Traducteur

INTRODUCTION

This contribution proposes *Pohorje granodiorite*, a calc-alkaline igneous rock of Miocene age from Slovenia, as a candidate for international recognition as a Global Heritage Stone Resource, following the Terms of Reference of the Heritage Stone Task Group of the International Union of Geological Sciences (IUGS) (www.globalheritagestone.org; see also Cooper 2010; Pereira 2012; Cooper et al. 2013; Marker 2015). In required support of the nomination of Pohorje granodiorite as a Global Heritage Stone Resource (GHSR), this paper provides a comprehensive listing of the defining geological characteristics of the stone and its associated terminology. In addition, source quarries and petrophysical characteristics of Pohorje granodiorite are provided, as well as documentation of its use as a building stone.

GLOBAL HERITAGE STONE RESOURCE CANDIDACY REQUIREMENTS

Origin of Name

In Slovene, the Pohorje granodiorite is written as 'Pohorski granodiorit.' The name originates from the Pohorje Mountains (north-northeastern Slovenia), where the granodiorite crops out. The granodiorite has moderate quartz content (20–60%) and plagioclase predominates over K-feldspar by a factor of 2:1 or more. Biotite is relatively abundant, whereas hornblende is less common and augite is rare. The name 'granodiorite' originates from two geologically related rocks: granite and diorite, to which granodiorite is intermediate. The 'grano' root comes from the Latin word 'granum' meaning 'grain.' Diorite is named from the Greek verb 'diorizein' (διοριζειν) meaning 'to distinguish' (Le Maitre 2002). Commercial designations are also Tonalite, Pohorje tonalite, Pohorje granite.

In the past, the Pohorje igneous rock was named Pohorje granite (Benesch 1918) because of its mineral composition: quartz, feldspars and biotite. Later, the stone was classified as tonalite (Dolar-Mantuani 1938). According to the IUGS classification, the rock is a granodiorite, though local transitions to tonalite can be found (Zupančič 1994a). Despite apparent spatial relations, Faninger (1970, 1976) stressed that Pohorje granodiorite cannot be considered an eastern prolongation of the Železna Kapla (Eisenkappel) tonalite. Granodiorite differs from tonalite in its higher content of alkali feldspars – in this case, K-feldspar.

Principal Location of Extraction Sites

Pohorje granodiorite represents the largest occurrence of igneous rocks in Slovenia by area. It crops out in the Pohorje Mountains in the northern part of the country (Fig. 1). Two quarries are located in Pohorje granodiorite, both protected as valuable natural geological features. The only operating granodiorite quarry at present, and the largest igneous rock quarry in Slovenia, is situated at Cezlak near Oplotnica (Fig. 2). A second quarry at Josipdol (Fig. 3) is currently inactive.

Production Details and Manufacturing Information

In recent years, the total annual production of stone blocks at the Cezlak Quarry has varied greatly from 25,000 tonnes to 67,000 tonnes, depending on market demand. The stone is obtained by surface quarrying methods in 6 m-high benches, using a diamond wire for cutting. Raw blocks, approximately 1.6 x 1.8 x 2.9 m in size, are transported to a plant at Podpeč, near Ljubljana, for further processing. Using modern technology, raw blocks are then either cut into slabs of standard thickness and processed with different surface finishes, or manufactured into other products. Irregularly shaped large pieces that remain after removal of the raw blocks are processed into armour stone or paving setts (brick-sized dressed blocks of stone) at a production plant located at the quarry. The producer has plans to recycle part of the current quarry waste into an aggregate for asphalt course layers. The largest quarried block measured 1.9 m in width, 1.2 m in height and 6.6 m in length, and weighed about 40 tonnes.

Geological Age and Geological Setting

The area of Pohorje represents the south-easternmost exposed part of the Eastern Austroalpine metamorphic complex at the southwestern margin of the Pannonian Basin. The Pohorje tectonic block consists of polymetamorphic rocks, which were (in the central part) intruded by calc-alkaline magma at around 18.7 Ma (Trajanova et al. 2005, 2008; Fodor et al. 2008). The igneous body represents a strongly tilted batholith (Trajanova 2013), which extends continuously over more than 30 km in a northwest–southeast direction close to the Labot fault, north of the Periadriatic fault zone. The Pohorje pluton is surrounded by presumably Precambrian metamorphic rocks of the Pohorje Series (Mioč and Žnidarčič 1977, 1989; Mioč 1978). Gneisses and mica schists dominate, and contain numerous lenses of amphibolite, marble, quartzite, sparser pegmatite gneiss, eclogite, and serpentinite; their mineral paragenesis shows polyphase metamorphism (Hinterlechner-Ravnik 1971, 1973, 1982). The deepest easternmost part of the Pohorje metamorphic rocks (peridotites, eclogites, gneisses) were subjected to Cretaceous ultrahigh-pressure metamorphism (e.g. Janák et al. 2004, 2015a, b). The protolith radiometric age of these rocks has not been determined because they have been strongly rejuvenated in the Alpine orogenic cycle (e.g. Fodor et al. 2008). The northwestern part of the Pohorje tectonic block features a thrust and a partly imbricated structure; the primary overriding plate is the Remschnig thrust block (Mioč 1978), which consists of Ordovician to Carboniferous low-grade metamorphic sedimentary (lower part) and pyroclastic (upper part) rocks belonging to slates of the Magdalensberg Formation. Biostratigraphic investigation of lenses of marmorized limestone in this for-

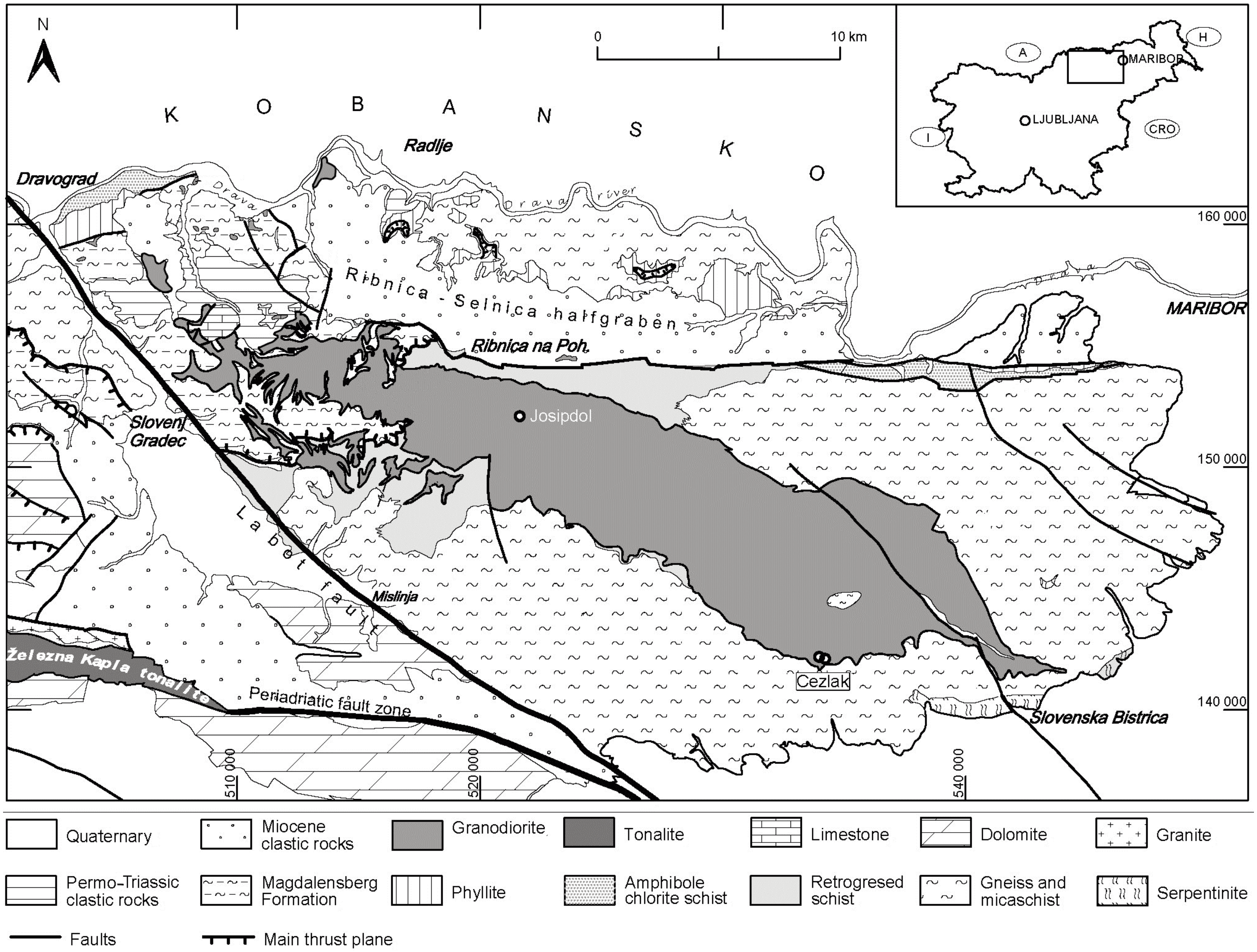

Figure 1. Simplified geological map the of Pohorje area (modified from Trajanova et al. 2008). Inset is a contour of Slovenia with the Pohorje area outlined.

Figure 2. Active quarry in granodiorite near the village of Cezlak. Photo: Samo Jenčič.

Figure 3. Josipdol granodiorite quarry during a period of active exploitation. Photo: Samo Jenčič.

mation has yielded sparse fossils indicating an Early Devonian age (Mioč and Ramovš 1973; Kolar-Jurkovšek and Jurkovšek 1996). The Magdalensberg Formation is discordantly overlain by, from oldest to youngest, Permo–Triassic clastic rocks, some patches of Triassic dolomite, relics of the Cretaceous Gosau Group rocks, and mid-Miocene sedimentary rocks. Granodiorite magma intruded the entire rock sequence, except for the mid-Miocene rocks, thus constraining its upper age limit. The northwestern part of the massif is considered to represent an apical part of the intrusion and of the entire Pohorje tectonic block lithological succession (Trajanova 2013).

Pohorje magmatic activity seems to be connected to the Miocene evolution of the Pannonian Basin (Trajanova and Pécskay 2006; Trajanova et al. 2008; Trajanova 2013) and not to the Oligocene Periadriatic intrusions, as believed by earlier researchers. Mid- to late-Miocene deformation, uplift and rapid unroofing affected the entire pluton and the host rocks, due to which they are tectonically and locally hydrothermally altered.

Petrographic Name and Characteristics

From an international perspective, the Pohorje granodiorite represents a classic calc-alkaline igneous rock. It forms a single, continuous, batholithic intrusion (Trajanova and Pécskay 2006; Trajanova et al. 2008; Trajanova 2013) of granodiorite and subordinate tonalite. Because of its petrographic similarities to the Periadriatic Železna Kapla tonalite, it was named tonalite, and this name remains in common use today. As reported by Zupančič (1994a), primary tonalite was altered to granodiorite as a result of strong potassic metasomatism. Later investigations confirmed metasomatic processes only for a limited area connected to the Remschnig thrust zone (Trajanova 2013).

The granodiorite is coarse- to medium-grained in the deeper, eastern part, and grades to fine-grained and porphyritic in the shallower, northwestern part of the pluton. Locally, gradual transitions to more mafic rocks of subvolcanic, andesitic composition can be observed. Their origin is considered a product of magma mixing (Trajanova 2013), which is indicated by geochemical parameters (Zupančič 1994b). Somewhat younger (about 18 Ma) are mafic dykes of basalt and andesite composition found in metamorphic host rocks near the south-southwestern margin of the pluton. They were previously identified as lamprophyres (e.g. Mioč and Žnidarčič 1977, 1989; Mioč 1978), but this determination has been rejected on petrographical and geochemical grounds. The youngest K–Ar cooling ages of about 16.5–16.0 Ma are associated with undeformed subvolcanic dacitic dykes of the same composition as the batholith. Their emplacement age is not confirmed yet, but geological evidence indicates that they are younger than the main igneous body.

The central part of the granodiorite commonly contains mafic inclusions. In addition, it is crosscut by white to very light grey aplite–pegmatite veins that are 1–50 cm thick. Syn-cooling tectonic activity has produced a fabric in the granodiorite, indicating ductile deformation. In addition to the foliation, a lineation is observed as a preferred orientation of phyllosilicates and sparse hornblende, and stretched, degraded, and recrystallized quartz. In the jargon of quarrymen in the Cezlak Quarry, the first is called *rast* ('growth') and the second *kolnost* ('splitting') (Vesel and Senegačnik 2004). Mylonitic to cataclastic shear bands formed locally. The upper part of the granodiorite body is strongly degraded, i.e. sub-horizontally brittle sheared and, therefore, unusable as natural stone.

The major mineral components of the granodiorite are plagioclase, quartz, K-feldspar, and biotite (Figs. 4 and 5). Hornblende occurs locally in the granodiorite, but is the dominant mafic mineral in subvolcanic andesitic and basaltic dykes. Opaque minerals, allanite, epidote, titanite, zircon, apatite, and traces of garnet and pyroxene are accessories. In places, the concentration of opaque minerals, garnet, and epidote is significantly higher, e.g. where the pluton intruded low-grade metamorphic rocks in the Remschnig thrust zone (Mioč 1978). The contact aureole is characterized by the presence of garnet, epidote, hornblende hornfels, and skarn. Magnetite–hematite mineralization in the contact aureole was discovered and exploited in the first half of the 20th century. Iron ore is accompanied by Fe-sulphides, predominantly pyrite, and some Pb and Zn mineralization; pyrite is sparser in the eastern parts of the granodiorite body. The Remschnig thrust zone is characterized by slight hydrothermal alteration, which is reflected as K-metasomatism, chloritization, sericitization and calcitization.

A peculiarity of the granodiorite is a large altered mafic xenolith (Trajanova 2013), locally called cizlakite (Nikitin 1939), included within the granodiorite on the southern rim of the pluton, close to the village of Cezlak. Cizlakite has been regarded as a mafic differentiate of granodiorite or as a prod-

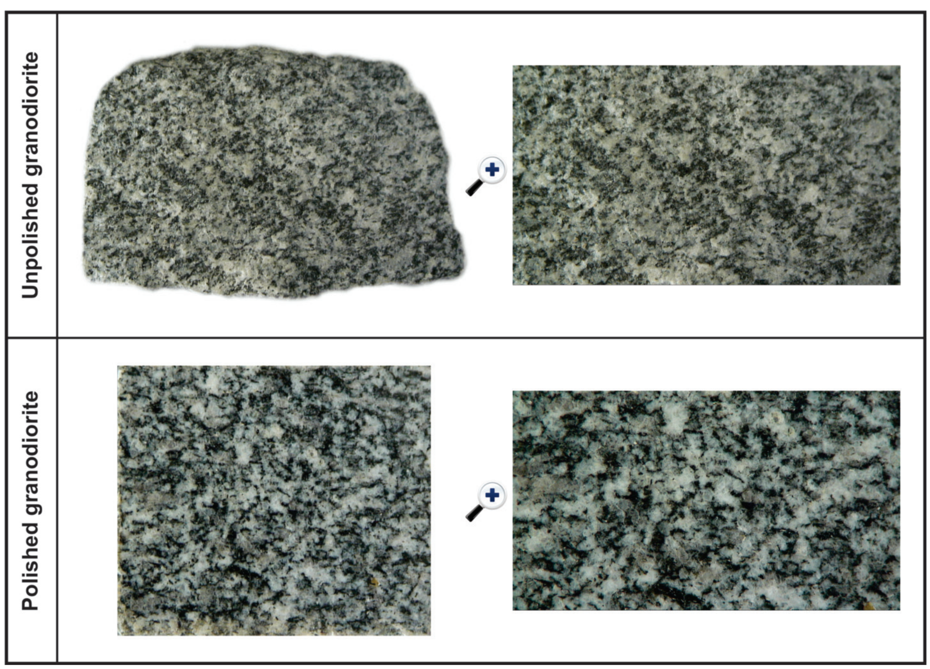

Figure 4. Unpolished and polished samples of granodiorite (left) with a magnified view (right). White – plagioclase, light grey – quartz, pale yellowish and pinkish grey – K-feldspar, black – biotite and amphibole. The width of the unpolished sample is 11 cm, and the width of the polished sample is 5.5 cm. Photo: Matej Dolenec.

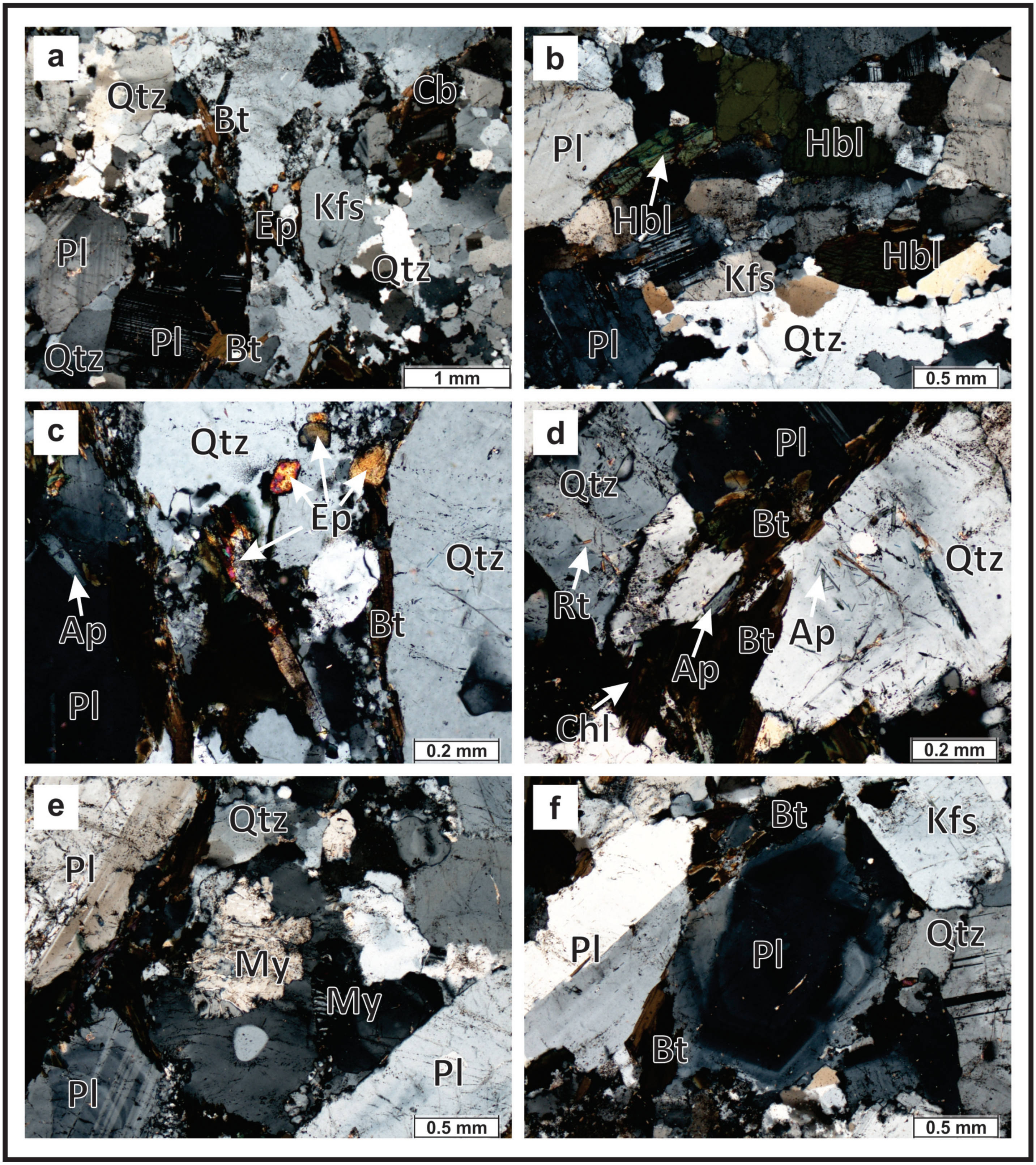

Figure 5. Photomicrographs of holocrystalline, hypidiomorphic, fine- to medium-grained Pohorje granodiorite (cross-polarized view). a) Granodiorite composed of euhedral to subhedral polysynthetic plagioclase, anhedral polycrystalline quartz grains, subhedral prismatic biotite, anhedral K-feldspar, idiomorphic accessory epidote and carbonate grains; b) euhedral hornblende twinned on Carlsbad law showing pronounced colour variations visible in plane-polarized light; twinned plagioclase; and polycrystalline quartz; c) accessory grains of epidote; poikilitic texture of small grains of apatite completely enclosed in large plagioclase; and anhedral grains of quartz with undulose extinction; d) chlorite replacing subhedral biotite at the rim and along cleavage planes, accessory grains of euhedral rutile in anhedral quartz, and prismatic euhedral laths of apatite in subhedral plagioclase grains; e) subhedral polysynthetic twinned and oscillatory zoned plagioclase grains, and myrmekitic textures of wormlike quartz at the boundary with subhedral plagioclase; f) oscillatory-zoned and polysynthetic-twinned euhedral to subhedral plagioclase with prismatic subhedral interstitial biotite, and anhedral grains of K-feldspar. Photo: Matej Dolenec. Ap – apatite, Bt – biotite, Cb – carbonate grain, Chl – chlorite, Ep – epidote, Hbl – hornblende, Kfs – K-feldspar, My – myrmeketic texture, Pl – plagioclase, Qtz – quartz, Rt – rutile.

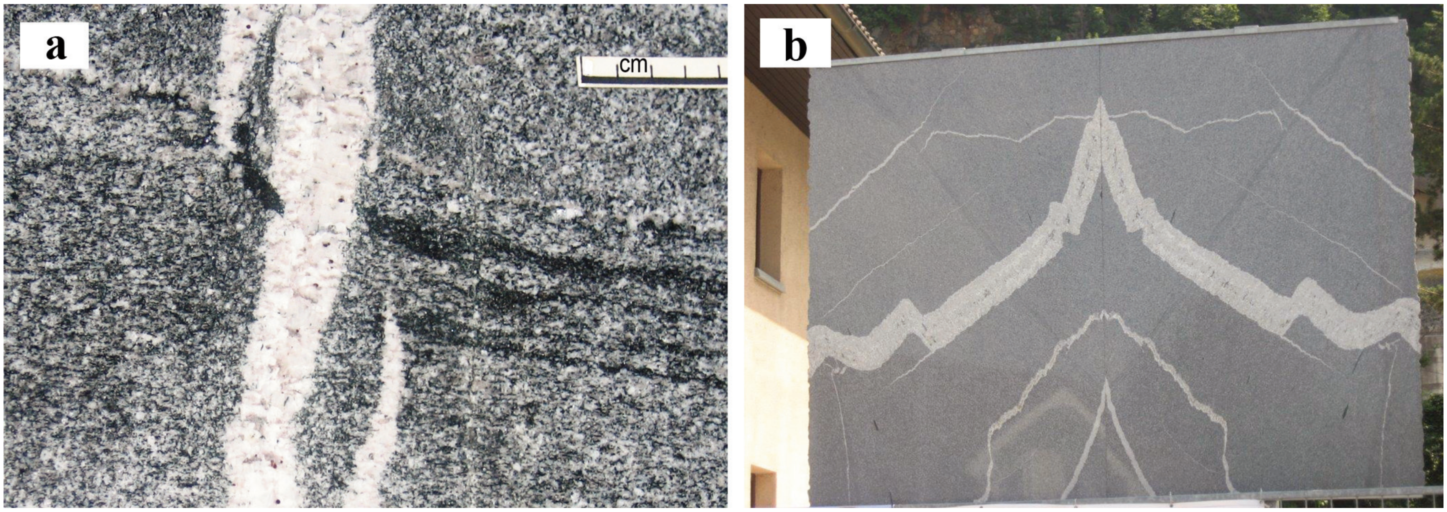

Figure 6. a) Foliated granodiorite with black schlieren and aplite–pegmatite veins at the Cezlak (active) Quarry. Photo: M. Trajanova. b) polished granodiorite panels in front of the company Mineral d.d. (Archive Mineral d.d.).

uct of stratification in the magma chamber (e.g. Zupančič 1994a, b), but most often has been referred to as diorite or gabbro, corresponding, respectively, to quartz monzogabbro and transitional diorite–pyroxenite (Trajanova et al. 2009) according to the classification of Le Maitre (2002). Faninger (1976) expressed doubt that cizlakite is a mafic differentiate of granodiorite, interpreting it instead as an older mafic to ultramafic rock that was partly assimilated by more felsic magma. This interpretation is supported by field and petrographic evidence (Trajanova 2013). The cizlakite lens is also crosscut by aplite–pegmatite veins.

The massive structure, coarse-grained texture, and variegated dark green and white colour of cizlakite were much admired in the past, and the rock was frequently used as an architectural stone. However, because of the small size of the lens, the reserves were limited and quarrying eventually ceased.

Primary Colour(s) and Aesthetics of Stone

Generally, Pohorje granodiorite is characterized by its grey colour and thick white aplite–pegmatite veins (Fig. 6). Major colours of the granodiorite mineral assemblage, as defined by the Munsell geological rock-colour chart, are as follows: N9 (white) for plagioclase, N8 (very light grey) and N7 (light grey) for quartz and K-feldspar, and N3 (dark grey) and N1 (black) for biotite and hornblende. Aplite–pegmatite veins are recognized as N9 (white). Aplite–pegmatite veins are up to 50 cm thick, but most do not exceed 25 cm. The veins mostly crosscut foliation, but are locally sheared together with the host rock. Foliation is developed unevenly, and is more pronounced in peripheral and shallower parts of the pluton.

Natural Variability

The Pohorje granodiorite and its porphyritic phases define the main textural varieties: equigranular granodiorite is a medium- to fine-grained rock, whereas porphyritic granodiorite comprises larger phenocrysts in a medium- to fine-grained groundmass. White veins consist of fine-grained aplite in the middle and coarse-grained pegmatite at the edge. Pohorje granodiorite has a relatively uniform structure, based on its appearance in active and abandoned quarries. Nevertheless, grain size and texture varies along the strike of the body from medium- to coarse-grained in eastern and central parts to porphyritic in its northwestern part. Aplite–pegmatite veins are more abundant in the central part of the granodiorite body and become sparser toward the east and west-northwest. Sporadic black schlieren and mafic inclusions impart a streaky appearance to the rock.

Technical Properties

Pohorje granodiorite is considered to be the highest quality natural stone in Slovenia. It is characterized by its high density, low water absorption, and low porosity, so that it exhibits high frost and salt resistance, as well as a high compressive strength and a very high flexural strength (Table 1).

Table 1. Physical properties of Pohorje granodiorite.

Parameter	Procedure	Result
Water absorption	EN 13755:2008	0.1 – 0.2% by mass
Real density	EN 1936:2007	2700 Mg/m$^{32700\ Mg/m3}$
Apparent density		2670 Mg/m$^{32670\ Mg/m3}$
Porosity (open)	EN 1936:2007	0.60%
Porosity (total)		0.90%
Compressive strength – dry	EN 1926:2007	190 MPa
Flexural strength – dry	EN 13161:2008	20 MPa
Resistance to salt crystallization	EN 12370:2000	0.00%
Frost resistance	EN 12371:2000	0.00%
Slip resistance		
Brushed surface		
SRV dry		63
SRV wet	SIST EN 14231:2003	39
Polished surface		
SRV dry		55
SRV wet		14
Thermal Expansion Coefficient	SIST EN 14581:2005	8.4 x 10^{-8}/K

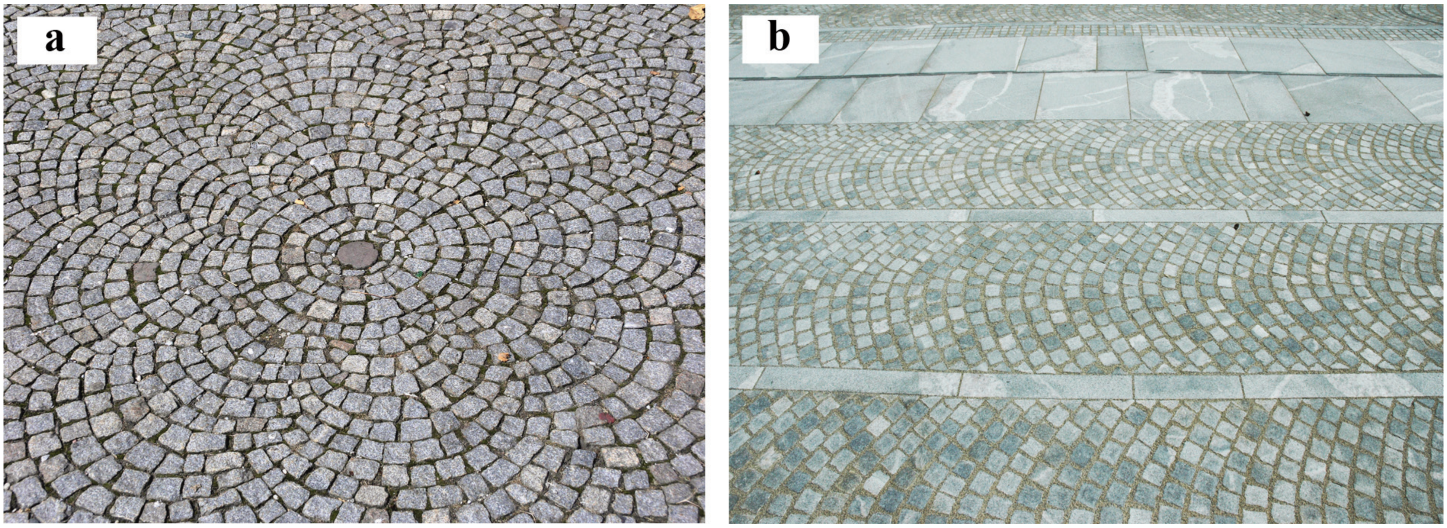

Figure 7. a) Pavement of granodiorite cobblestones. Photo: Samo Jenčič. b) pavement of granodiorite cobblestones and paving slabs. Photo: Miran Uddovč.

Suitability

Pohorje granodiorite is widely known throughout Slovenia for its durability and decorative white veins, and is currently the most frequently used natural stone in the country. It is mainly used as paving and cladding material for the interiors and exteriors of residential buildings, churches, and other structures, as well as for paving public squares, thus giving many of Slovenia's largest towns a unique character. Due to its high durability and artistic workability, this type of stone is excellent for various monuments and sculptures, which is shown by the existence of numerous historical and contemporary works. Pavements made of small cobblestones (Fig. 7) are common in the public squares of some towns. Until the recent past, many streets were entirely paved with cobblestones; some are still well-preserved and maintained. This type of paving was also common on some regional and local roads, where steep slopes can cause loss of traction in winter.

An unusual type of degradation of granodiorite cladding panels occurs in the form of bowing (Fig. 8). Despite being a common phenomenon with other natural stones, it was first detected with Pohorje granodiorite on the façades of the Maximarket department store in Ljubljana, which was constructed in 1971 (Mauko et al. 2006). This phenomenon is one of the very few documented cases of bowing of igneous rocks.

Pyrite has been considered to be a potentially problematic accessory mineral because of the possibility of limonitization. However, the presence of a small amount of arsenic in the pyrite makes it quite stable and not prone to alteration, hence minimizing its negative impact. Depending on exposure conditions, a slight limonitization may occur, but this phenomenon is much less extensive than in many other rocks containing pyrite.

Figure 8. Bowing of granodiorite on a building façade. Photo: Ana Mladenović.

Vulnerability and Maintenance of Supply

In the area of Pohorje, two localities are protected as valuable natural geological features, based on typicality, rarity, scientific research and evidential importance (decree on the designation and protection of valuable natural features; official gazette of the Republic of Slovenia, No. 111/04, 70/60, 58/09 in 93/10). The one-remaining operating quarry at Cezlak (Oplotnica, southern outskirts of Pohorje), is a valuable natural resource of national importance. Granodiorite in the non-active quarry in Josipdol (Ribnica na Pohorju, central Pohorje) was also

Figure 9. In the Cezlak granodiorite quarry, women also worked before World War II (Archive Mineral d.d.).

declared a valuable natural feature of local importance. Relevant data can be found on http://www.naravovarstveni-atlas.si/nvajavni/profile.aspx?id=NV@ZRSVNJ, under the identification numbers 4399 and 121. Stone reserves are estimated to be sufficient for future needs, and there is no question of the long-term availability of this valued material for cultural monument restoration.

Historic Use, Geographic Area of Utilization, Commercial Diffusion

According to historic records, exploitation of 'Pohorje granite,' the common name for the granodiorite among the general public, was started in 1891 by a farmer living in nearby Cezlak. This farmer began exploiting the resource with the permission of the landowner (Count Windischgrätz), cleaned up the hillside and started to cut the stone into smaller pieces. From 1905 to 1919, the quarry was operated by the owner. The following decades were marked by progress and expansion of the quarry (Fig. 9). Detailed geological exploration carried out to determine reserves of natural stone have been used as a base of production for several decades. From 1919 to 1941, the owner of the quarry was German Erlich (Vrečko 2012). In 1941, the quarry was nationalized by the Germans and handed over to the Austrian company SS Graz. After World War II, the quarry was managed and operated by Granite Industry Oplotnica (Vrečko 2012). During this period, setts of different sizes and blocks for building bridges were produced. The excellent quality of manual processing of the stone was recognized well beyond the borders of Slovenia, and much product was sold in Austria, Switzerland and Germany. In 1945, around 500 people were employed in the quarry (Curk 2004). The quarry also began co-ordinating with surrounding quarries in 1962, and until 1976 operated under the name INGMAG (Vrečko 2012). After 1975, new machinery and technologies allowed more rapid exploitation with a smaller work force. In 1984, the quarry was taken over by the company Mineral d.d. (Mineral podjetje za pridobivanje, predelavo in montažo naravnega kamna, delniška družba). Today, granodiorite is extracted by modern methods, including a diamond cutting wire. Granodiorite from the Cezlak Quarry is currently exported to Austria, Croatia, Italy, Serbia and Hungary. The second granodiorite quarry is at Josipdol (no longer active), located on the northern side of Pohorje. It is named after the village of Josipdol in the municipality of Ribnica on Pohorje. The quarry was opened in the second half of the 19th century and produced cobblestones. Five quarries, having 250 employees, were active between World Wars I and II (Vrečko 2012).

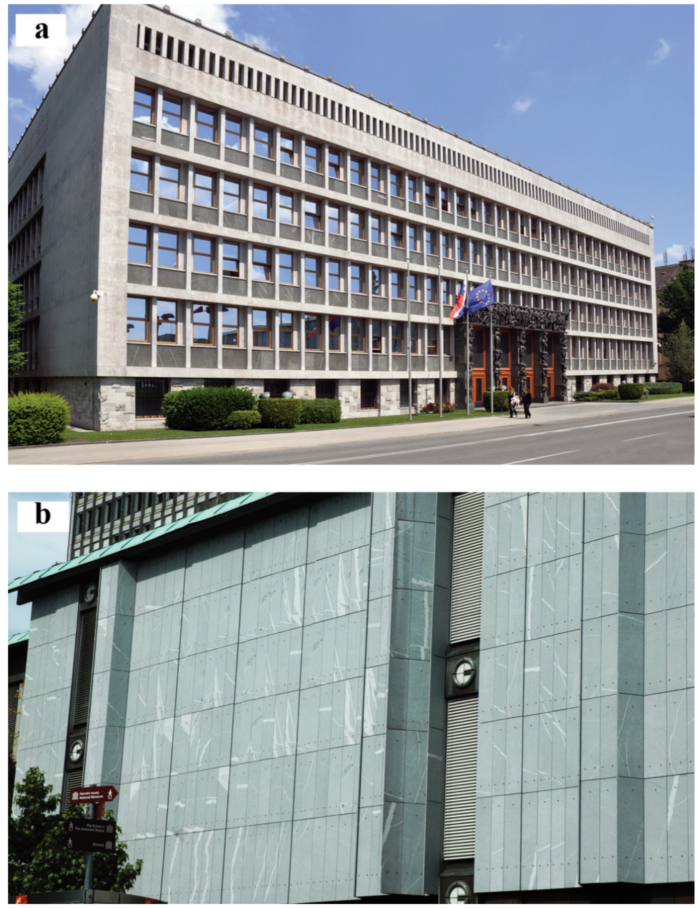

Figure 10. a) Granodiorite is used in the staircase of the Slovenian Parliament. Dark grey panels of the façade are made of cizlakite. Photo: Matjaž Zupanc. b) Maximarket department store with granodiorite façade. Photo: Miran Udovč.

Buildings

The major part of current production is used as paving and cladding material for residential buildings, churches, outdoor steps, and public squares, thus giving a unique character to many Slovenian towns and cities. Several important buildings are decorated with the stone, including the Slovenian Parliament (Fig. 10a), the Republic Square business complex (1962–1984), which houses the Maximarket department store (1971) (Fig. 10b), and the Faculty of Law of the University of Ljubljana (2000); all of the above are located in Ljubljana, and some have been declared cultural monuments of national importance.

Other significant buildings in Slovenia in which the stone has been used (listed chronologically) include:

- Old Bridge, Maribor, renovated with granodiorite during WWII

- hydro power plant Mariborski otok, during WWII
- business building Konus, Slovenske Konjice, 1985–1987
- Grajski Square, Maribor, 1993
- business building HIT, Nova Gorica, 1997
- Faculty of Social Sciences, University of Ljubljana, Ljubljana, 1999
- business skyscraper BTC-CITY, 2000
- business building, VO-KA, Ljubljana, 2001
- business building PKMG, Ljubljana, 2001
- congress hall – Hotel Habakuk, Maribor, 2002
- pavement of the old city centre, Kranj, 2012/2013
- pavement of the old city centre, Celje, 2013
- Faculty of Medicine, University of Maribor, Maribor, 2013

Since 1940, granodiorite has also been widely used by sculptors for various monuments, fountains, and sculptures exhibited throughout Slovenia (Brate et al. 2004). Among them:

- monument of Boris Kidrič, Maribor, 1961
- monument to the victims of fascism, Rogatec, 1964
- monument to the victims of WWII, Ormož, 1994
- monument of Rudolf Maister, Ljubljana, 1999
- monument to the victims of Frankolovo, Frankolovo, 2000
- Mobitel fountain, Ljubljana, 2001
- fountain in Postojna, 2009

Monuments abroad:

- monument to the victims of fascism, Graz, Austria 1961

One of the important Slovenian architects who used this stone was Edvard Ravnikar (1907–1993), who was a student of architect Jože Plečnik. Later, he led the new generation of Slovene architects, who are notable for developing the Slovene architecture field infrastructure.

Related Heritage Issues

Both granodiorite quarries lie within the Ecologically Important Areas, Pohorje (ID 41200) and Natura 2000, on the Pohorje site (ID 3000270). The largest square in Ljubljana, The Republic's Square, has been declared a cultural monument of national importance (Official Gazette RS, No. 44/2014-1813). The business complex in the square includes a central platform, two high buildings and a department store, Maximarket. Granodiorite has also been used for the façade and staircase of the Slovenian Parliament, a cultural monument of local importance (Official Gazette RS, No. 60/93-2193, 105/2008-4510).

Related Dimension Stones

Pohorje granodiorite is visually similar to the Železna Kapla/Eisenkappel tonalite. However, they are related geographically, not geologically. The main distinguishing characteristic of the granodiorite is its transition to porphyritic type and the presence of numerous aplite–pegmatite veins in the central part of the massif, where major exploitation is located. The veins are much sparser and thinner in the tonalite. Another specific feature related to the Pohorje granodiorite massif is the transitional diorite to pyroxenite lens referred to as cizlakite, located at the southern margin of the pluton. A small quarry operated there for a short period. Cizlakite is crosscut by aplite–pegmatite veins, which form a striking contrast to the dark green cizlakite. As reserves of this unique stone are very limited, exploitation has been stopped. At present, only Pohorje granodiorite is exploited as a natural stone resource from the Cezlak Quarry.

CONCLUSIONS

Pohorje granodiorite is a classic calc-alkaline igneous rock of Miocene age (18.7 Ma). It is spatially, but not geologically, related to other calc-alkaline intrusions along the Periadriatic fault zone and in the Pannonian Basin. It is medium- to fine-grained, and locally transitional to porphyritic granodiorite. The major mineral components and geochemical parameters identify the stone as a granodiorite rather than tonalite. Accessory minerals have no significant impact to the quality of the stone. White veins crosscutting the granodiorite consist of fine-grained aplite in the middle and coarse-grained pegmatite at the edges, adding a special character to the stone. The two localities in the Pohorje area are protected as valuable natural geological features.

Pohorje granodiorite is the only igneous rock exploited in Slovenia and is considered to be the highest quality natural stone, explaining its widespread use. It provides a special character to many of the larger towns and cities in Slovenia. Pohorje granodiorite is characterized by its high density, low water absorption, and low porosity. It exhibits high frost and salt resistance, as well as a high compressive strength and a very high flexural strength. These features facilitate a wide array of applications, mainly as paving and cladding material for the interiors and exteriors of residential buildings, churches, and other structures. Some buildings decorated with granodiorite have been declared cultural monuments of national importance, indicating the high regard in which the stone is held. The stone is also suitable and widely used by sculptors for various monuments and fountains.

The information given in this work will contribute to the international knowledge and recognition of Pohorje granodiorite as a natural stone that is part of our heritage. The authors believe that the granodiorite fulfils at least five of the criteria for a Global Heritage Stone Resource.

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