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Provenance and characteristics of the pavement stone from the courtyard of the Ljubljana Castle

Izvor in značilnosti kamna v tlakovcih na osrednjem dvorišču Ljubljanskega gradu

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Abstract

The pavement stone used in the central courtyard of Ljubljana Castle originates from the Kukul area northeast of the town of Prilep in Republic of Macedonia. Several pavers were badly damaged and partly replaced by two other natural stones, because the original stone from Kukul is no longer available on the market. The natural stone that is recently used as a replacement is commercially named “Bianco Sardo” and differs from original rock from Kukul in both, structure and composition. The advancement of the replacement of original pavers with “Bianco Sardo” is resulting in extremely uneven and disturbing appearance of the courtyard. The original Kukul stone used in the central courtyard of Ljubljana Castle is of metamorphic origin and belongs to gneisses. Two types of pavers were identified, the light coloured and the dark coloured varieties. They have similar mineral composition consisting of quartz, feldspars (orthoclase, microcline and plagioclases), minerals of the epidote group, micas (muscovite and biotite), titanite, zircon, clinopyroxene, kyanite, pyrite and calcite. Light coloured pavers have porphyroclastic, protomylonitic to mylonitic structures. Dark coloured pavers display gneissic structure, contain more quartz and epidote, less feldspars, and no clinopyroxene. They show intensive recrystallization and granoblastic textures. Both analysed rock types belong to the same rock massif, only that the blocks were extracted from various parts of the rock massif. The variations are due to the process of metamorphic differentiation, which resulted in segregation and separation of light and dark coloured minerals. In the past, the natural stone that was coming from Kukul, was known and classifyed as a type of granite. The rock that is used in the central courtyard of Ljubljana Castle is not granite but granitic gneiss, therefore, we assume that in the last stages of quarrying in the Prilep area, they were extracting also the metamorphic country rocks for some time. The broader area of Prilep belongs to the Pelagonian massif. Its thick metamorphic complex contains also granitoid (granodiorite) intrusives, which crop out in the Prilep anticline and used to be quarried at the locality of Kukul. According to national regulations of the Republic of Macedonia the area is now protected as a natural monument and further exploitation was no longer possible. Today, there is only one open granite exploitation field in the wider surroundings of Prilep, the locality of Lozjanska Reka–Kruševica and a few localities of gneiss-granites of high potential. It would be necessary to consider these solutions for the conservation-restoration of the Ljubljana Castle central courtyard instead of using an inappropriate stone replacement.

Izvleček

Naravni kamen, s katerim je tlakovano osrednje dvorišče Ljubljanskega gradu, izvira iz območja Kukula, severovzhodno od mesta Prilep v Republiki Makedoniji. Ker prvotni kamen iz Kukula ni več na voljo na tržišču, so več poškodovanih tlakovcev nadomestili z dvema nadomestnima vrstama naravnega kamna. Naravni kamen "Bianco Sardo", ki so ga nedavno pričeli uporabljati kot nadomestek, se močno razlikuje od prvotne kamnine iz Kukula, tako po teksturi kot tudi po sestavi. Z napredovanjem menjave originalnih tlakovcev s kamnino "Bianco Sardo" postaja videz osrednjega dvorišča Ljubljanskega gradu izrazito neenoten. Izvirni kamen iz Kukula, ki je bil uporabljen v osrednjem dvorišču Ljubljanskega gradu, je metamorfnega izvora in pripada gnajsom. Ločili smo dve vrsti tlakovcev, tlakovce svetle in temne barve. Imajo podobno mineralno sestavo, ki jo sestavljajo kremen, glinenci (ortoklaz, mikroklin in plagioklazi), minerali iz epidotove skupine, sljude (muskovit in biotit), titanit, cirkon, klinopiroksen, kianit, pirit in kalcit. Svetli tlakovci so porfiroklastični, s protomilonitno do milonitno strukturo. Temno obarvani tlakovci imajo gnajsno strukturo, vsebujejo več kremena in epidota, manj glinencev in nič klinopiroksenov. Zanje je značilna intenzivna rekristalizacija in granoblastična struktura. Obe analizirani kamnini pripadata istemu kamninskemu masivu, le da so bili bloki med izkopom očitno odvzeti iz različnih delov kamnoloma. Razlike v teksturi in strukturi so posledica procesa metamorfne diferenciacije, ki je povzročila segregacijo in ločitev svetlih in temnih mineralov. V preteklosti je bil naravni kamen, ki je prišel iz Kukula, znan in klasificiran kot vrsta granita. Kamnina, ki se uporablja v osrednjem dvorišču Ljubljanskega gradu ni granit ampak granitni gnajs, zato predpostavljamo, da so v zadnji fazi obratovanja kamnoloma pri Prilepu zajeli tudi metamorfne prikamnine. Širše območje Prilepa pripada Pelagonskemu masivu. Njegov debeli metamorfni kompleks vsebuje tudi granitoidne (granodioritne) intruzije, ki izdanjajo v Prilepski antiklinali in so jih lomili v kamnolomu Kukul. V skladu z nacionalnimi predpisi Republike Makedonije je območje zdaj zaščiteno kot naravni spomenik in nadaljnje izkoriščanje ni več mogoče. Danes je v širši okolici Prilepa samo eno pridobivalno omočje granita v Lozjanski Reki-Kruševici in nekaj območij granitnih gnajsov z velikim potencialom. Te rešitve bi bilo treba pretehtati tudi za rekonstrukcijo osrednjega dvorišča Ljubljanskega gradu, namesto da se uporabljajo že na pogled neprimerni nadomestni naravni kamni.

Introduction

The appearance and the purpose of the Ljubljana Castle, located above the Ljubljana city center, have been changed several times since 1120, when Ljubljana and its medieval fortress were mentioned for the first time. Today the Ljubljana Castle is regularly visited by national and foreign tourists, as it has become a cultural and social center where numerous events are organized (Kralj, 2005).

Within the castle walls and towers there is an inner courtyard, which is in central part paved with natural stone originating from Kukul area near Prilep in Republic of Macedonia (Žiga Miklavc, personal communication, October 17, 2017). Many factors influence the degradation of natural stone when used as pavers, and at Ljubljana Castle one of the main reasons are mechanical damages. Some of the pavers were damaged to the extent that they had to be replaced. To the knowledge of the authors, this has been done without professional conservation-restoration guidance, but rather as individual repair works. As the original natural stone from Kukul is not available since 2017, they started to use two different stone replacements. Unfortunately, one of them ("Bianco Sardo"; Žiga Miklavc, personal communication, October 17, 2017) differs substantially in both, composition and structure from the original rock and is greatly disrupting the look of the courtyard itself (fig. 1). So far, from 10 to 15 pavers have been replaced, but the number of damaged pavers waiting for a replacement is still large and their number is increasing over time.

The Kukul natural stone was known commercially as granite and obviously they are replacing Kukul granite with another type of granite named "Bianco Sardo". The problem is that the rock from Kukul, which is used in the central courtyard in Ljubljana Castle, is not an igneous rock (granite) but displays obvious metamorphic structure.

In this paper, we present detailed mineralogical and petrographic, textural and structural characteristics of original natural stone used

Fig. 1. (a) View of the central courtyard of the Ljubljana Castle in moist weather conditions. The replaced stones in the central part are easy recognizable. They are significantly lighter and disturb the uniform appearance of the courtyard. (b) Typical mechanical damages on the pavers in form of cracks along the edges. (c) Example of inappropriate replacemets in the central courtyard of Ljubljana Castle.

in pavers. Precise macroscopic observations in the field and microscopic analysis of 13 polished thin sections were performed and correct petrographic classification of rocks used in pavers at the central courtyard of the Ljubljana Castle is defined. In order to compare these rocks with the original Kukul stone, the literature on the provenance, geological setting and petrology of the latter been studied.

Materials and methods

The macroscopic characteristics were observed on site. Original rock types as well as their macroscopic composition and structure were described and photo-documented. Types of damages and the current practice of repair works were listed and photographed.

In the central courtyard of Ljubljana Castle, several pavers were already replaced and stored in the Castle cellar. From the individual replaced pavers we cut the representative samples that were used for further petrographic analysis. The collected samples were first cut perpendicular to the observed structures. From the rock chips, 13 polished thin sections were prepared. Six thin sections from six samples of light coloured pavers (labelled as 1a, 2a, 4a, 5a, 6a, and 7a), and seven thin sections (labelled as 1b, 2b, 3b, 4b, 5b, 6b and 7b) from seven different samples belonging to a darker variation of Kukul stone were made. Petrographic analyses were carried out using the Nikon Eclipse E200 optical microscope in the plane polarized light. The thin sections were photographed using the Nikon DS-Fil camera and the NIS Elements Basic Research program.

Results

Observed damages of the pavers and current state of repair

Numerous mechanical damages of the pavers are clearly visible. In most cases, they are expressed as thin cracks along the edges and of the corners of pavers (fig. 2). Weathering along the cracks is commonly marked with intensive discoloration (fig. 2c). Some cracks only started to form, cutting only the surface of the pavers, while others cut deep into the pavers or even all the way through. In the latter case, the pavers will have to be replaced.

In several places, individual pavers were already replaced by two other rock types (fig. 3). Since the natural stone from the original source Kukul is no longer available, they choose two different types of natural stones that are used as a replacement for the damaged pavers. At first, the natural stones of unknown origin was used which is similar in appearance to the original rock from Kukul (fig. 3a – marked with a square). Recently, natural stone with a commercial name “Bianco Sardo” was applied as a replacement. It has a completely different appearance from the primary paving stone from Kukul, as well as to the previously used replacement rock of unknown origin, and is disrupting the uniform appearance of the central courtyard of the Ljubljana Castle (fig. 3a – marked with a circle and fig. 3b). “Bianco Sardo” which is quarried in Italy is noticeably brighter, without coloration, and has different compositional and structural characteristics compared to original paving stones. It has typical igneous holocrystalline structure, is homogeneous and medium-grained with sizes ranging from one millimeter to two centimeters. Macroscopically recognizable minerals are grayish quartz, white and brownish feldspars, muscovite, biotite, amphiboles and/or pyroxenes. Petrographic classification of rock with the commercial name “Bianco Sardo” is granite.

Macroscopic characteristics of the original pavement stone

From the macroscopic observation, original pavement stone may be divided into two groups, light coloured (fig. 4) and dark coloured pavers (fig. 5). Most rocks in this group display medium-grained porphyroclastic and protomylonitic to mylonitic structure (e.g. Trouw et al., 2010) (fig. 4b, c). Minor concentrations of femic minerals in forms of seams or bands are commonly observable (fig. 4c). Occasionally, primary phaneritic structure may still be recognized (fig. 4d), although quartz is obviously recrystallized and porphyroclasts of potassium feldspar show signs of rounding on the edges at closer inspection. In the light coloured variations, potassium feldspars and quartz prevail, and are responsible for the bright appearance and lighter colour of the rock (fig. 4a). Potassium feldspars form idiomorphic to hipidiomorphic crystals with sizes ranging from 5 cm to small crystals of only few mm in diameter. Other distinguishable minerals are quartz, forming nests or sometimes ribbons or just evenly distributed crystals in the matrix, minerals of epidote group, and minor amounts of pyrite and garnets.

In the dark varieties of pavement stone, the femic minerals are concentrated and segregated into lenses and bands resulting in a darker ap-

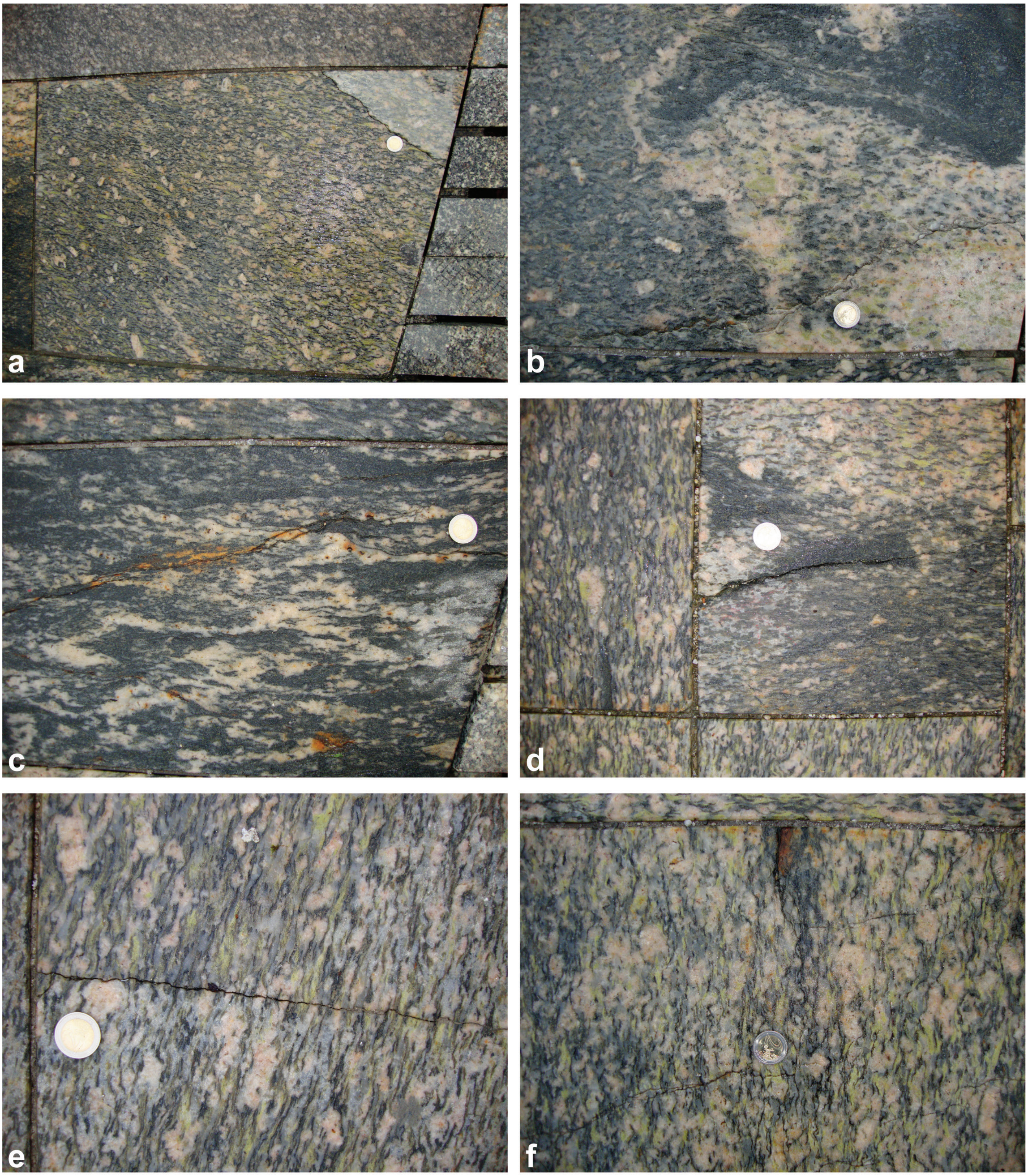

Fig. 2. Damages on original paving stones in form of cracks along the corners (a–b) or edges of the pavers (c–e). In several cases, cracks propagate deep into the body of the pavers (d).

pearance of the pavers (fig. 5). The segregation of femic minerals is forming gneissic structure, where bands formed during metamorphic differentiation often display complex deformation (figs. 5a–b). Most minerals are macroscopically indistinguishable (fig. 5c), apart from minerals in larger felsic bands and lenses, where pink potassium feldspars, greyish quartz, minor grains of pyrite and garnet may be recognized (fig. 5d).

Microscopic characteristics of original pavement stone

Light coloured pavers

All samples have heterogeneous texture and contain approximately 36 % of quartz, 35 % of potassium feldspars represented by microcline and orthoclase, 11 % of minerals from epidote group (epidote, clinozoisite, and allanite), 4 %

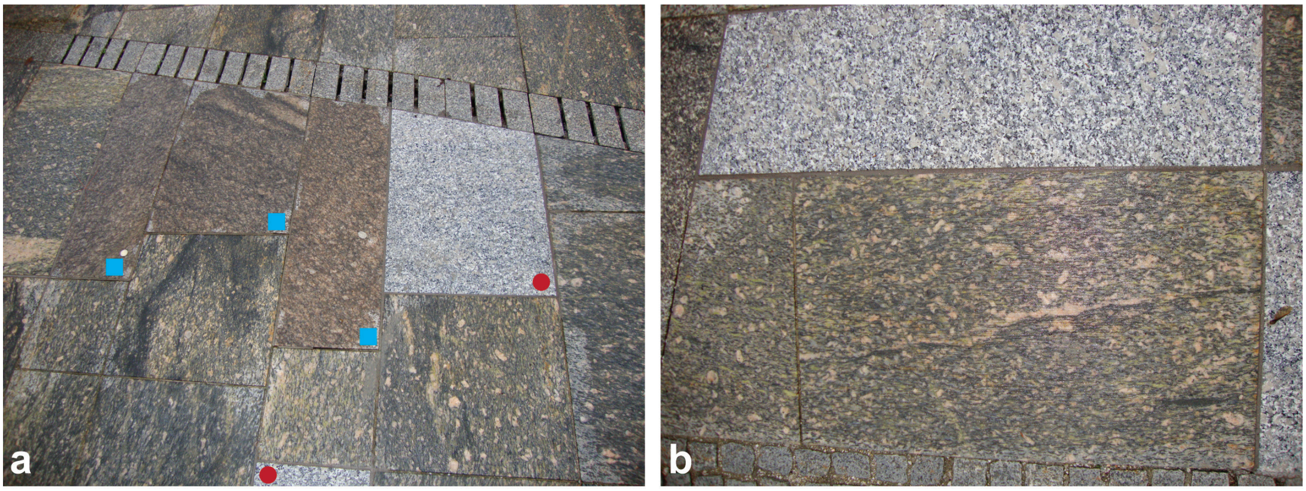

Fig. 3. Replaced pavers in the central courtyard of the Ljubljana Castle. (a) A natural stone with the commercial name "Bianco Sardo" (marked with a circle) and another natural stone of unknown origin (marked with a square). (b) The bright greyish appearance and the apparent magmatic texture of the natural stone "Bianco Sardo" are in strong contrast with the original coloured rock from Kukul.

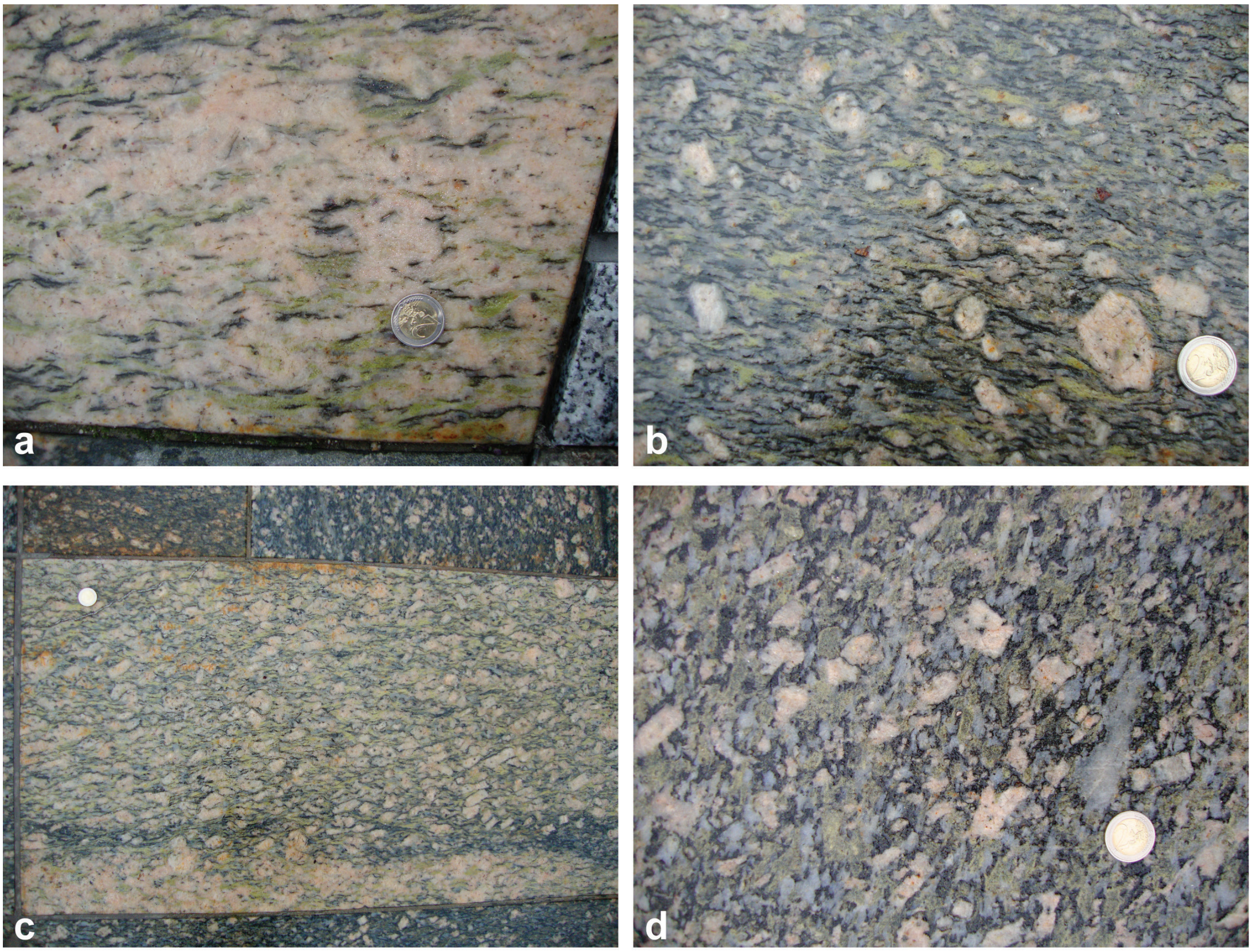

Fig. 4. Light coloured pavers used in central courtyard of Ljubljana Castle. (a) Potassium feldspars are giving the unique pinkish tint to the matrix of the rock, yellowish green colour is mostly from minerals of epidote group and thin black seams are due to minor femic minerals. (b) Mylonitic structure composed of porphyroclasts of potassium feldspar in the matrix of epidote, some femic minerals, and recrystallized quartz. Perfect delta clast of potassium feldspar is nicely visible on the right side, below the centre of the figure. (c) In some pavers, femic minerals are concentrated in seams or bands (lover part of the figure). (d) Igneous phaneritic structure is still clearly visible.

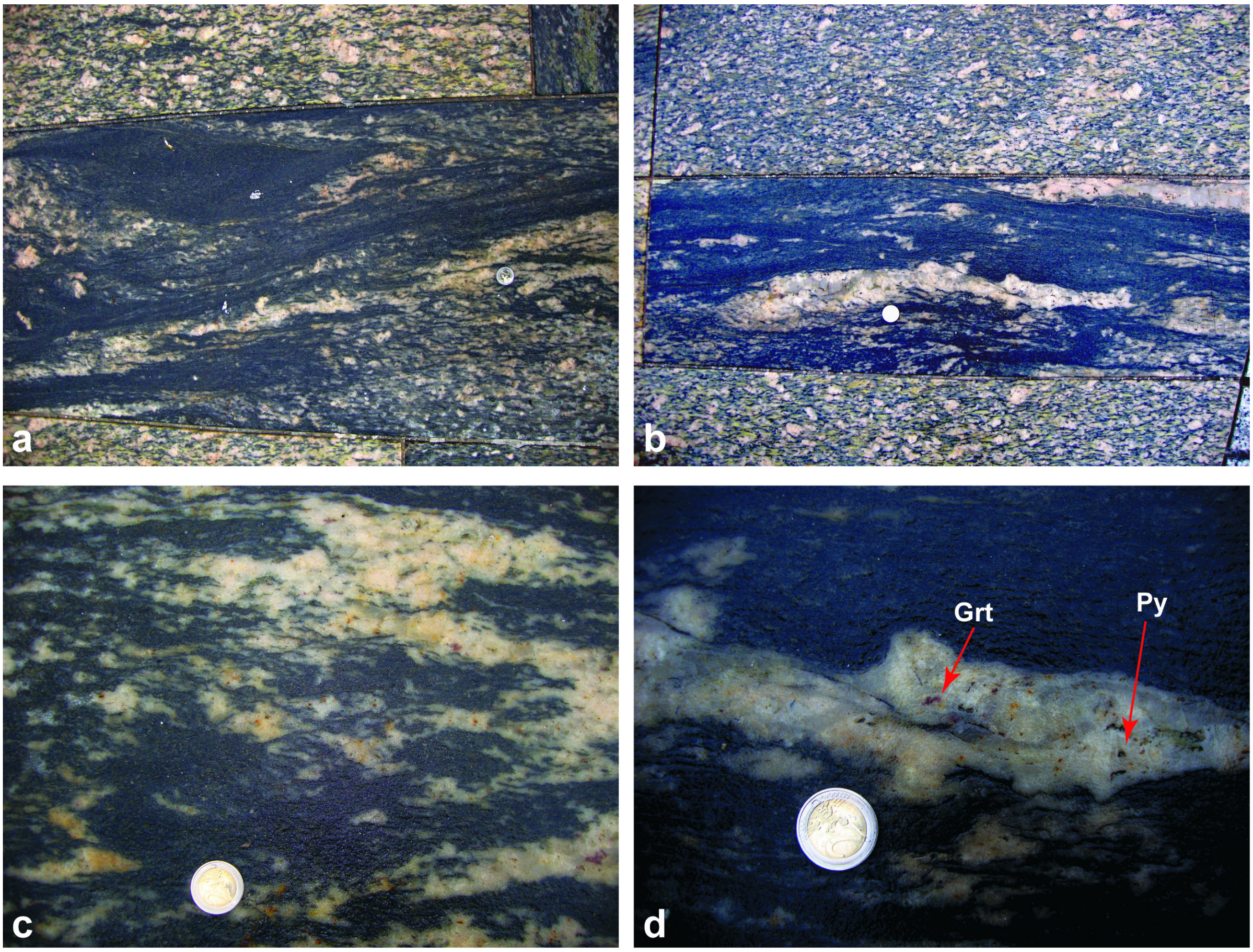

Fig. 5. Dark coloured pavers used in central courtyard of Ljubljana Castle. (a–b) Typical gneissic structure and contrast of dark pavers in contact with light coloured varieties (top and bottom border). (c) Most minerals in dark coloured pavers are macroscopically indistinguishable. (d) Reddish minerals in the felsic lens composed of white feldspars and quartz correspond to garnets (Grt), dark spots are pyrite (Py).

of plagioclase, 4 % of muscovite, 2 % of biotite which is partly chloritized and/or epidotized, 2 % of titanite, 2 % of calcite, and 1 % of each of minerals: clinopyroxene, zircon, kyanite, and pyrite.

Predominant polycrystalline and minor monocrystalline quartz is xenomorphic to hipidiomorphic and have uniform or undulatory extinction (fig. 6a). The latter is a result of recovery processes, which in places progressed all the way to the dynamic recrystallization (fig. 6a). Quartz either appears in recrystallized bands or surrounds feldspar and clinopyroxene porphyroclasts. In places, granoblastic texture is observable (fig. 6b). Among feldspars, microcline forms the largest crystals in all six thin sections, reaching 0.2 to 4.3 cm in length. They are xenomorphic and rounded on the edges due to the process of dynamic recrystallization (fig. 6c). Microcline is frequently twinned representing a rigid porphyroclast in an intensively recrystallized quartz matrix forming a protomylonitic to mylonitic texture (fig. 6c). Orthoclase also forms porphyroclasts, which are mostly xenomorphic and often twinned, with sizes ranging from 0.1 to 2 cm (fig. 6d). In some parts, orthoclase crystals show albite exolution lamellae and correspond to orthoclase perthite (fig. 6d). Plagioclases are smaller, reaching 0.02–0.1 cm in average. They are present as individual xenomorphic crystals randomly distributed within the recrystallized quartz matrix (fig. 6e), together with muscovite and minerals from epidote group. As bigger crystals, they appear in the role of porphyroblasts or poikiloblasts (fig. 6e).

Epidote group minerals are common and most typically occur in green, brown or mustard yellow colours. Epidote and clinozoisite form needle like and prismatic minerals in the matrix (figs. 6e, f), with sizes from 0.02 to 0.75 mm. Another epidote representative occurs in bigger isolated minerals with deep brown colour and distinct zoning, which are up to 1 cm long and most probably correspond to allanite (fig. 6f). Micas show strong parallel orientation and segregation in seams and bands

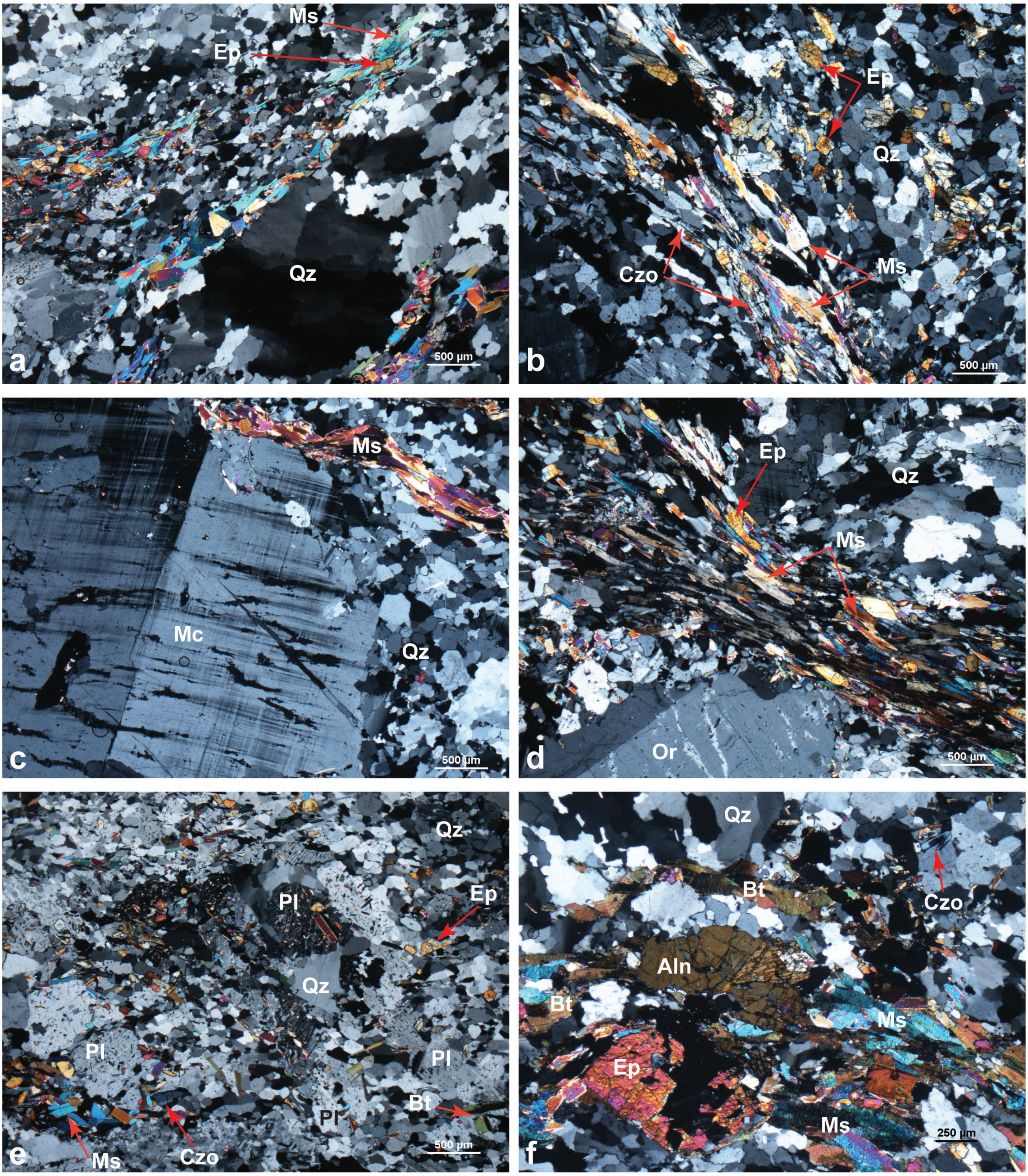

Fig. 6. Microphotographs of light coloured pavers. (a) Mono and polycrystalline quartz showing signs of recovery and recrystallization together with small elongated muscovite and minerals from epidote group. (b) Oriented muscovite is forming foliation. Quartz on the right-hand side is mostly idiomorphic, recrystallized and forming granoblastic texture. Higher relief prismatic minerals belong to epidote and clinozoisite. (c) Twinned microcline is forming a porphyroclast in intensively recrystallized quartz matrix forming protomylonitic to mylonitic texture. Microcline is rounded due to the recrystallization along the edges. (d) Porphyroclast of orthoclase-microperthite lies bellow the segregation of muscovite and some epidote group minerals defining foliation of the rock. (e) Individual plagioclase crystal in quartz matrix together with muscovite, biotites and epidote group minerals. Plagioclase poikiloblasts are full of small mineral inclusions. (f) Prismatic epidote group minerals in matrix and isolated crystal of allanite, in the centre of the figure. All figures were taken under crossed polars. Mineral abbreviations are according to Whitney & Evans (2010).

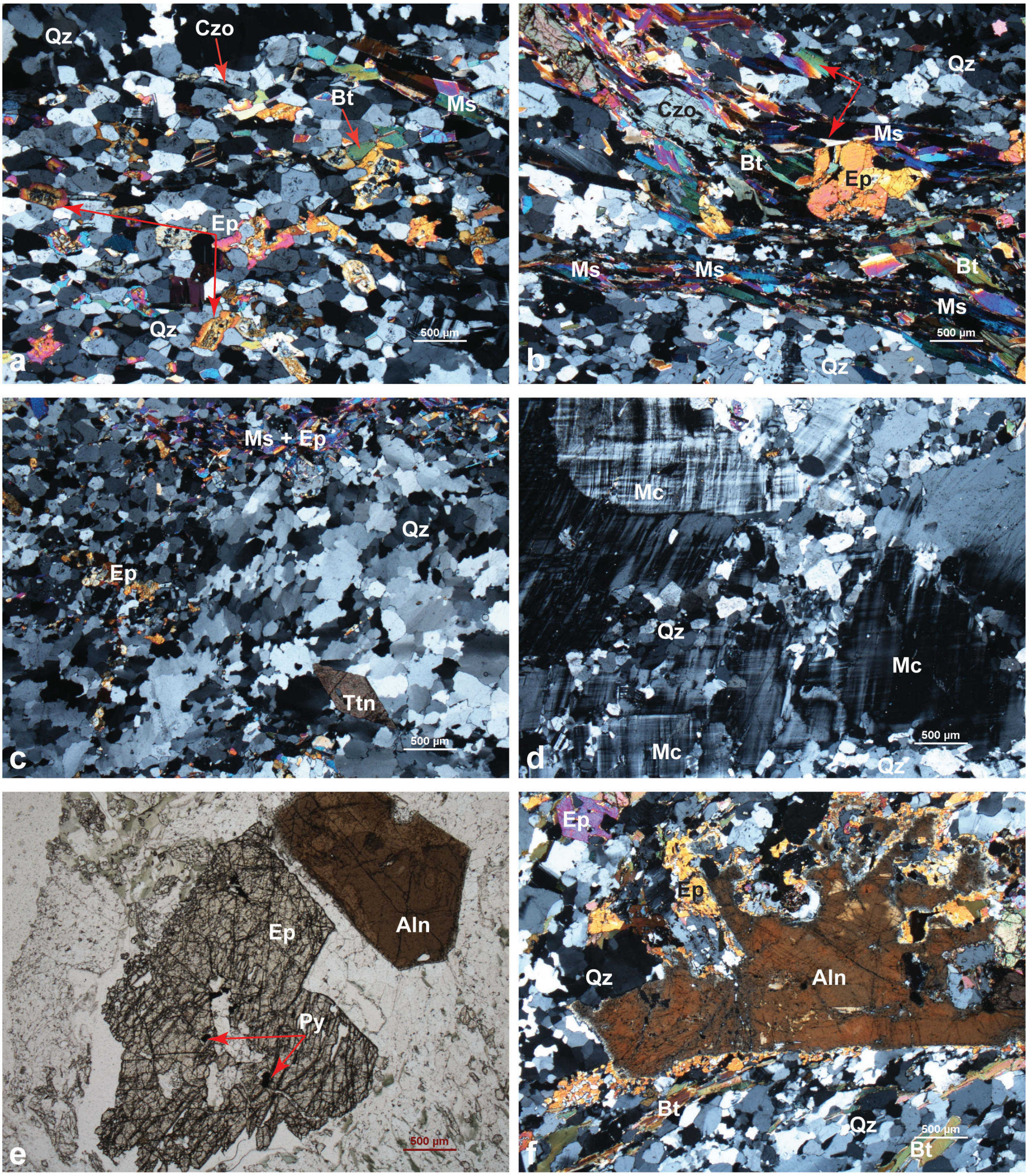

Fig. 7. Microphotographs of dark coloured pavers. Quartz is a predominant mineral. Intensive dynamic recrystallization resulted in granoblastic texture. (a) Granoblastic polygonal texture where the equidimensional quartz has well developed crystal faces resulting in straight grain boundaries; the triple junctions are common. Minerals with higher interference colors belong to muscovite, biotites, clinozoisite, and epidote (note the zoning). (b) Granoblastic interlobate texture where quartz grain boundaries are mostly irregular (lover left-hand side of the figure). The segregation of muscovite and biotite in the central part of the figure is forming foliation. (c) Idiomorphic titanite in quartz with granoblastic amoeboid texture, the rest of the minerals are xenomorphic. The dynamic recrystallization is not complete and in several places, signs of recovery are still visible. Minerals with higher interference colours are muscovite and epidote. (d) Deformed microcline porphyroclasts are replaced by dynamically recrystallized quartz along the edges. (e) Large epidote grains with small pyrite inclusions next to idiomorphic brown coloured allanite with slight zoning. The rock is composed mostly of dynamically recrystallized quartz with rare small micas and epidote group minerals. (f) Xenomorphic zoned allanite partly altered along the rim. Slightly chloritized biotite (lower part of figure) and epidote are also recognizable. Figures (a–d and f), were taken under crossed polars. Figure (e) was taken under plane polarized light. Mineral abbreviations are according to Whitney & Evans (2010).

resulting in pronounced foliation (figs. 6b, d). Muscovite has typical flaky appearance with sizes ranging from 0.10 to 0.8 mm. Biotites are often replaced by chlorite and/or epidote; therefore, they are unusually green, rarely brown, in colour. Biotites are a bit less common and smaller in size compared to muscovite, reaching maximal size of 0.6 mm, but they are mostly much smaller.

Titanite is hipidiomorphic to idiomorphic, frequently with rhombic form and 0.02 to 1 mm in size. It can occur as individual crystals in matrix or as inclusions in feldspars, epidote, and kyanite. Clinopyroxenes are hipidiomorphic and 0.02 to 0.75 mm in size. They occur as individual matrix minerals (fig. 6f). Small zircons do not exceed 0.08 mm in diameter, are mostly rounded and are heterogeneously distributed in the matrix or as inclusions in biotite. Rare kyanite minerals are present in hipidiomorphic form and are full of inclusions, mostly belonging to titanite. Their average size is 0.8 mm. Pyrite occurs in xenomorphic crystals, only seldom it is found in idiomorphic forms with well-developed crystal faces of a cube. Pyrite crystal size ranges from 0.05 to 0.45 mm. Pyrite is often limonitized and display partly transparent red coloured edges. Calcite occurs as secondary mineral phase, is xenomorphic and is reaching 0.10 to 1.25 mm in size. It is found in form of filling in thin veins or as accompanying mineral together with quartz in matrix around bigger feldspar porphyroclasts.

Dark coloured pavers

All samples display inhomogeneous texture, which show signs of intensive dynamic recrystallization processes. Quartz is the most abundant mineral in all samples, making up to 50 % of the rock. The other constituents are represented by epidote group minerals (18 %), feldspars (17 %), micas (at 8 %), and the remaining 7 % belong to titanite, calcite, zircon, kyanite, and pyrite.

Quartz is predominant mineral in all samples. Its extinction is mostly uniform and rarely undulatory. It shows signs of intensive dynamic recrystallization that resulted in different types of granoblastic texture (figs. 7a–c). Feldspars belong to orthoclase, microcline, and plagioclase series and have average size of 0.70 to 2.5 mm. Orthoclase and microcline porphyroclasts are usually deformed and appear rounded or with irregular boundaries due to the replacement by unstrained dynamically recrystallized quartz grains (fig. 7d). Plagioclases are mostly smaller, up to 0.7 mm, contain numerous small mineral inclusions and represent poikiloblasts. Minerals of epidote group belong to epidote, allanite and clinozoisite. Clinozoisite mainly forms individual elongated prismatic crystals in the matrix. Epidote size ranges from 0.02 to 3.5 mm and frequently shows zoning (fig. 7b). Allanite forms big distinctive brown coloured porphyroblasts, frequently with idiomorphic forms. They are reaching up to 3 mm in length and display distinctive zoning (fig. 7e–f).

Micas occur as elongated flaky crystals, 0.1 to 0.75 mm in size, and are heterogeneously distributed thorough the rock. Often they are segregated and concentrated in lenses and layers and are forming gneissic foliation (fig. 7b). Micas are represented by muscovite and minor biotites. Biotites are inferior and commonly replaced by epidote and chlorite. They contain inclusions of small zircon. Titanite is hipidiomorphic to idiomorphic with well-developed rhombic cross-sections (fig. 7c). Individual titanite crystals range in size from 0.10 to 1 mm and occur in matrix or as inclusions in other minerals, mainly kyanite. Zircon was found as small idiomorphic inclusions in biotite or as dispersed crystals in the matrix. Zircon size ranges from 0.05 to 0.1 mm. Rare xenomorphic kyanite crystals do not exceed 0.8 mm. Pyrite is mostly idiomorphic and 0.08 to 0.1 mm in size. Rare xenomorphic grains of calcite occur and are up to 0.5 mm in size. They are found in parts composed of plagioclase and quartz.

Discussion

Petrografic characterization of "Kukul granite" used in the central courtyard of Ljubljana Castle

The stone used in pavers displays macroscopically recognizable gneissic structure, which is a result of metamorphic differentiation. During the metamorphic processes, the dark coloured minerals become segregated into distinct bands, which may be straight or bent. The intensive dynamic recrystallization of the matrix in porphyroclastic parts of the rock resulted in the formation of protomylonitic to mylonitic texture.

The average mineral composition of the rock used for pavers in the central courtyard of Ljubljana Castle is 43 % of quartz, 28 % of feldspars, 14 % of minerals from the epidote group, 7 % of micas and 8 % of other minerals (Table 1). Based on mineral composition and texture characteristics, the investigated specimens of original rock are classified as gneisses (Winter, 2014).

For the purpose of possible future restoration-conservation works, we distinguished two rock varieties: the light coloured and the dark

Table 1. Mineral composition of the rocks used in the pavement stone of the central courtyard of the Ljubljana Castle. Mineral abbreviations are according to Whitney & Evans (2010).

Mineral	Qtz	Kfs	Pl	Ep	Ms	Bt	Ttn	Zr	Cpx	Ky	Py	Cal
Average composition (%)	43	25	3	14	5	2	2	1	1	1	1	2
Light colored pavers (%)	36	35	4	11	4	2	2	1	1	1	1	2
Dark colored pavers (%)	50	15	2	18	6	2	2	1	0	1	1	2

coloured pavers. Both have similar mineral composition, but the proportions between individual minerals are different (Table 1). In light coloured pavers, porphyroclastic, protomylonitic to mylonitic structures are present, while in dark coloured pavers gneissic structure is predominant. Samples of dark coloured pavers with regard to light coloured varieties contain more quartz and epidote and less feldspars, and have no clinopyroxene. They also display more intensive recrystallization that is obvious from common triple junctions, polygonal quartz and frequent granoblastic textures.

In several pavers the transitions between the light and dark variation of natural stone are displayed. These transitions are either sharp or gradual and mostly correspond to the transition between light coloured and undifferentiated to dark coloured and intensively metamorphically differentiated rock. Therefore, even though we considered paving stones as two varieties of rocks, we have to bear in mind that this is the same rock, except that the blocks were obviously taken from various parts of the rock massif during the extraction. The variations within the rock massif are the result of the metamorphic differentiation, which resulted in the formation of various textures due to the segregation and separation of light and dark coloured minerals.

Osojnik (2016) studied the radioactivity of 69 samples of the most used natural stone in the Republic of Slovenia, including samples of Kukul granite. Based on his petrographic observations the Kukul granite is uniform with igneous texture and containes 55 % feldspars, 30 % quartz, 13 % micas, 1 % of epidote minerals and 1 % hornblende, and was classified as monzogranite (Osojnik, 2016). Compared to the samples of "Kukul granite" taken from the Ljubljana Castle courtyard, the proportions of minerals are different, the texture of the rock is obviously metamorphic and the variability of the used natural stone is high.

It is obvious, that the rock described by Osojnik (2016) and rock type used for pavers in the central courtyard of Ljubljana Castle are different, although both have the same commercial name (Kukul granite) and are classified as granite in the market. Although manufacturers of finished products are obliged to demonstrate and ensure the consistency of their products, in the case of Kukul stone, they clearly failed. We assume that in the process of stone extraction in the quarry area, they started to extract not only the granite/granodiorite massif but also the country rocks, which are gneisses with completely different physical, mechanical and aesthetic characteristics.

The provenance of the pavement stone in the central courtyard of Ljubljana Castle

Locality Kukul is situated northeast of the town of Prilep in Rebublic of Macedonia in the direction of Drenova and towards Prisad and Dolneni, at an altitude of 953 m. The stone that has been quarried there under the commercial name Kukul granite is also known as Kukulj or Prilep granite.

According to national regulations of the Republic of Macedonia (the Law on Protection of the natural values since 1965), the Kukul area as part of the Prilep granite complex has been protected as an area of exceptional natural phenomena so that the state nullified the previous concession for the exploitation of the architectural stone (Kurtović, 2018).

The area of Kukul belongs to the Pelagonian massif, a relic of the Precambrian Earth crust in this part of the Dinaric-Helenic belt, also known under the name Pelagonian horst anticlinorium. This large NW–SE-trending, NW-plunging anticlinorium with high-grade metamorphic core consisting of amphibolite grade gneiss, augen gneiss, and schist formed from protoliths of Precambrian metasedimentary rocks. The complex is characterized by a thick section of marble in the upper part that partly frames the anticlinorium, and abundant granitic plutons, and is separated from its neighbouring tectonic units by deep regional faults (Rakičević et al., 1965a; Dumurdzanov et al., 2005). The metamorphic complex of the Pelagonian Massif in general (according to Arsovski, 1960 and Stojanov, 1960, 1974), can be subdivided into: a) the lower metamorphic complex composed of the lowest series of gneiss and granites-granodiorites and the superpositioned series of micaschists; and b) the upper metamorphic complex composed of the so-called mixed series and series of massive marbles. The mixed series, in general, is built from the albite-augen gneiss, white marbles and meta-rhyolites, while the series of the massive marbles is composed of dolomite, dolomite-calcite, and calcite marbles.

In the lower complex, that is, in the series of gneisses, granitoid intrusions are found around Prilep, while in the surrounding region (for example at the contacts of these granitoids and micashists), amphibolites and amphibolite-eclogites occur. The upper metamorphic complex lies concordant on the lower metamorphic complex with a sharp boundary between them (Jancev & Anastasovski, 2004).

It is believed that the metamorphic crystalline rocks (gneisses, micaschists, marbles and other regional metamorphic complexes) are about 1,500–720 million years old continental basement (Upper Proterozoic-Cambrian). These rocks have been intruded by granitoid magma probably about 250–300 million years ago during the Variscan orogeny (Jancev & Anastasovski, 2004; Schenker et al., 2014). Thus, the basic structural characteristics of the metamorphic phase in the Pelagonian massif are the result of syngenetic processes of high regional metamorphism and folding with plastic flow mechanism and contemporaneous intrusion of granodiorites of the first phase when large fold structures were formed (Arsovski, 1997; Spasovski & Dambov, 2011; Schenker et al., 2014).

Granitoid complex of Prilep is structurally a part of Prilep anticline, which covers about 65 km² in the territory north of Prilep (Arsovski, 1960; Rakičević et al., 1965a, b) (fig. 8). A large part of this structure is composed of massive coarse-grained or locally porphyroid granodiorite-adamelite (quartz monzonite). In between are rare occurrences of enclaves of various old schists in the granite. The length of the Prilep

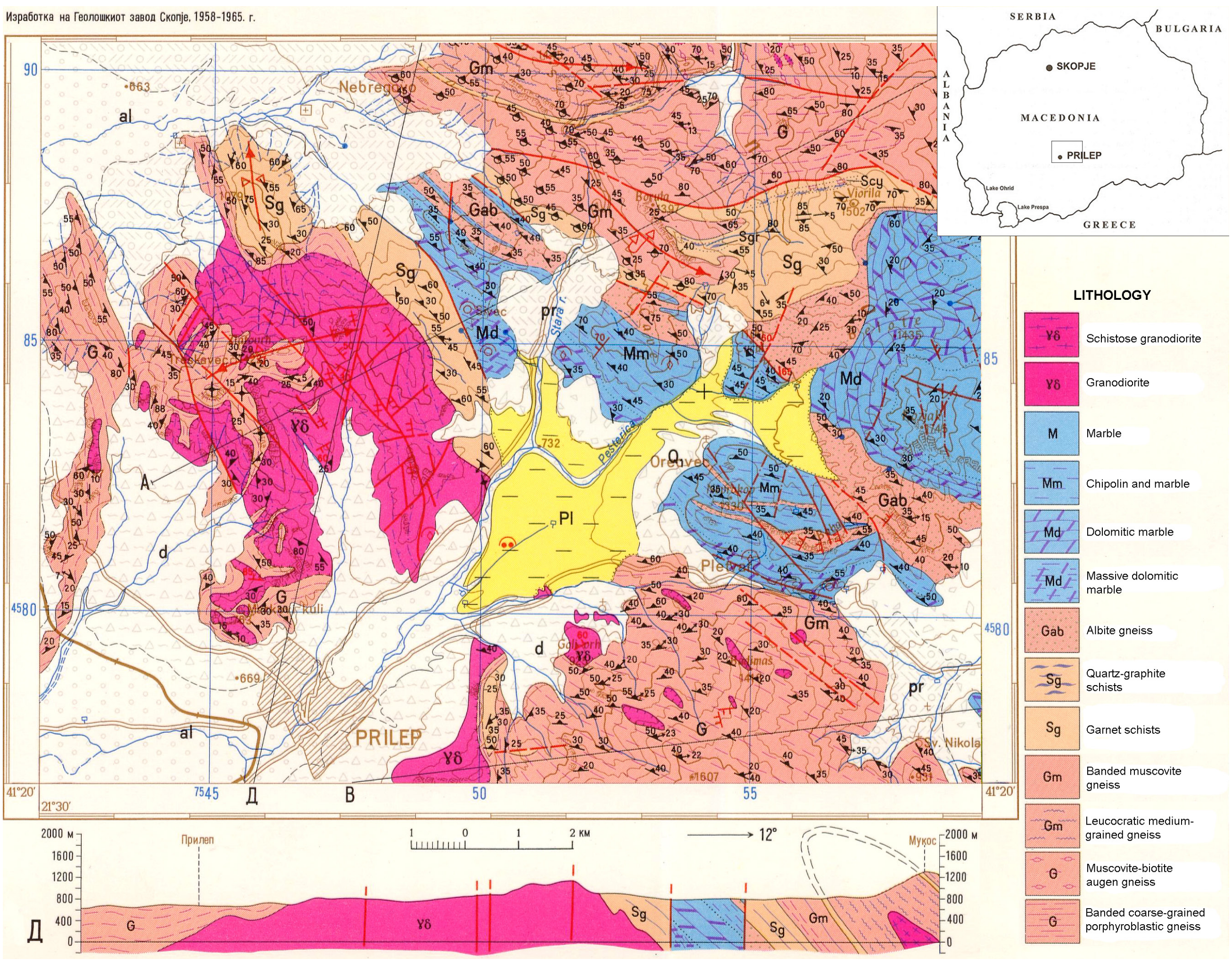

Fig. 8. Geological map and cross-section of the area of Prilep granitoids. Crop out from the Sheet Prilep of the Basic Geological Map 1: 100 000 (Rakičević et al., 1965a).

granodiorit-adamelite massif is about 8–9 km while the width is about 8 km. The contacts of the granite with the surrounding metamorphic rocks are accompanied by the granodiorite-adamelite sills and dykes. These contact zones are from about 10 to a few tens of meters wide and characterized by severe feldspatization in the surrounding rocks as well as other mineralogical manifestations (e.g. quartzites, epidotization, etc.) (Stojanov, 1974).

Suitable replacment pavement stone for conservation-restoration

The natural stones used for pavers in the important areas, like in the central courtyard of the Ljubljana Castle, should be durable and available for longer period, because only in this way the uniform appearance of the area can be maintained. This should be taken into account when important buildings and/or their parts are exposed to extensive conservation-restoration works in modern times.

When the stone from original quarry is not available on the market anymore, suitable replacement must be provided. It is suggested to first check the areas nearby the original quarry. In case that geological setting of the broader area is uniform, there is a great possibility to find a proper replacement stone in the vicinity in the quarry that is situated in the same geological unit (even if it is across the state border). If we have to find a replacement stone for conservation-restoration from the set of foreign rocks, then we must find a rock that will mimic the original rock in its composition and structure as much as possible. Therefore, basic mineralogical and petrological analyses and proper petrographic classification should be the rule and not the exception. Unfortunately, in most cases, the repair works are carried out without proper conservation-restoration guidance or any geological support and the result is what we can see in the central courtyard of Ljubljana Castle. A different type of granite ("Bianco Sardo") replaces the commercially named "Kukul granite", which is not a granite but gneiss. Because these two rock types differ much in the texture and in the quantitative mineral composition, it is not a surprise that the advancement of the replacement very much disrupts the uniform appearance of the central courtyard of the Ljubljana Castle (fig. 1).

The Faculty of Civil Engineering of the University of Sarajevo faced the same problem preparing the requirements for conservation-restoration of the prominent Square of Bosnia and Herzegovina in front of the Bosnia and Herzegovina Parliament building in Sarajevo (Kurtović, 2018). There, the pale rose to light brown paving tiles of Kukul granite were originally used in combination with dark Jablanica gabbro. Based on the detailed petrographic analysis of the pavers, the stone was identified as granite with the remark that due to the small amount of plagioclase, it could also be determined as granodiorite, but only after its chemical examination (Kurtović, 2018).

The only open granite-granitic gneiss exploitation field in the wider surroundings of Prilep is the locality of Lozjanska Reka–Kruševica in the area of Mariovo, south-east of Prilep. There, the surface exploitation of granite/granodiorite is producing stone commercially called Mariovo-Krin. The field investigation of the area showed that Kukul-Prilep and Mariovo-Krin represent quarries within the same geological unit. After the physical-mechanical analyses of the Mariovo-Krin stone has shown its high quality, this stone was approved for use as a replacement stone of on the Bosna and Hercegovina Square (Stojkov & Spasovski, 2014; Spasovski & Spasovski, 2015; Kurtović, 2018).

This solution is necessary to be considered also for the replacement of the pavers in the central courtyard of Ljubljana Castle, however it might prove not to be applicable, due to our results that the "Kukul granite" there is in fact gneiss.

According to the descriptions of other natural stones in the area of Prilep (in the Pelagonian massif) (Boev, 2006), the granitic gneiss from the locality of Mramorani is very promising. The locality is situated some 6 km north-west of Prilep in close proximity to the village of Mažučiste. Macroscopically this gneiss-granite possesses ornamental look with white-creamy-greenish color. The mineralogy of the rocks consists of quartz, potassium feldspars (orthoclase, anorthoclase, microcline), acid plagioclases (albite to andesine), muscovite, biotite, apatite, rutile, titanite, ilmenite, zircon and epidote (Boev, 2006).

Conclusions

Based on mineralogical, petrographic, textural and structural characteristics of original natural stone used in pavers as well as literature data on provenance and geological setting we can make the following conclusions:

1. Present appearance of the central courtyard of Ljubljana Castle is uneven and disrupted because the original pavement stone, from the Kukul area northeast of the town of

Prilep, is not available any more for conservation-restoration works. They are replacing it, without professional conservation-restoration guidance, with inappropriate replacement granitic rock with commercial name "Bianco Sardo" originating from Italy, which is completely different in colour, structural and compositional characteristics.

2. The original pavement stone contains on average 43 % of quartz, 28 % of feldspars, 14 % of minerals from the epidote group, 7 % of micas and 8 % of other accessory minerals. Based on the composition and structural characteristics it belongs to granitic gneiss.
3. Two types of pavers are recognized, the light and the dark rock types. They have similar mineral composition, only the proportions of the minerals are different; dark coloured pavers contain more quartz and epidote, less feldspars, and no clinopyroxene. Light coloured pavers have porphyroclastic, protomylonitic to mylonitic structures and dark coloured pavers display gneissic structure. The processes of dynamic recrystallization are more intensive in the dark coloured rock. Since in several pavers transitions between the light and dark rock types are displayed, we assume that this is in fact the same rock, but extracted from various parts of the structurally uneven rock massif. The obtained variations are the result of metamorphic differentiation, which produced the segregation and separation of light and dark coloured minerals.
4. Natural stone coming from Kukul (Republic of Macedonia) was known as a type of granite and/or granodiorite on the market. The rock that is used in the central courtyard of Ljubljana Castle is obviously gneiss, therefore, we assume that in the last stages of quarrying in the Prilep area, parts of the metamorphic counrty rocks were also exposed to quarrying activities.
5. Today, the only open granitic gneiss exploitation field in the wider surroundings of Prilep is the locality of Lozjanska Reka–Kruševica and there are a few localities of granitic gneiss of high potential. It would be necessary to consider these solutions for conservation-restoration of the Ljubljana Castle central courtyard instead of using an inappropriate stone substitutes.

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