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Durability of freshwater limestones *tenelija*, *miljevina* and *muljika* - Built-in factors as causes of changes in the stone

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Abstract: This paper presents the freshwater limestones, from *tenelija* and *(Mostar) miljevina*, which are intercalated in the Mukoša deposit near Mostar, and their "stone cousins," *Posušje miljevina* and *Tomislavgrad muljika*. In the process of diagenesis they acquired a specific orientation and structure (especially *tenelija*), which gave them specific physical properties (small bulk density, high porosity and permeability), which "classic" limestones used in construction do not have, and which were decisive for the choice of this stone for construction of the Old Bridge and other buildings in the wider area of Mostar and in the area of Posušje municipality, but also in other karst poljes of Herzegovina and southwestern Bosnia, in parts of Central Bosnia, and Miljevina near Foča. The second part of the paper presents the so-called built-in (internal) factors that the builders try to avoid in order for freshwater limestones that are built into numerous stone buildings and/or monuments to avoid complex processes of stone changes, or weathering (decay) of stone due to its interaction with various environmental conditions (external factors). It covers the problems and significance of the choice of stone, the method and (often too small) depth of its extraction from the deposit for the construction of significant buildings, insufficiently long aging (storage) after extraction, incorrect installation (stacking) of the stone in relation to its position in the deposit, as well as various errors in stone processing and execution, along with inadequate maintenance.

Key words: limestones (lim.), freshwater (lim.), lacustrine (lim.), tufaceous (lim.), lake chalk, oolitic (lim.), *tenelija*, *miljevina*, *muljika*, durability, internal factors

Trajnost slatkovodnih vapnenaca *tenelije, miljevine* i *muljike* - ugrađeni faktori kao uzroci promjena na kamenu

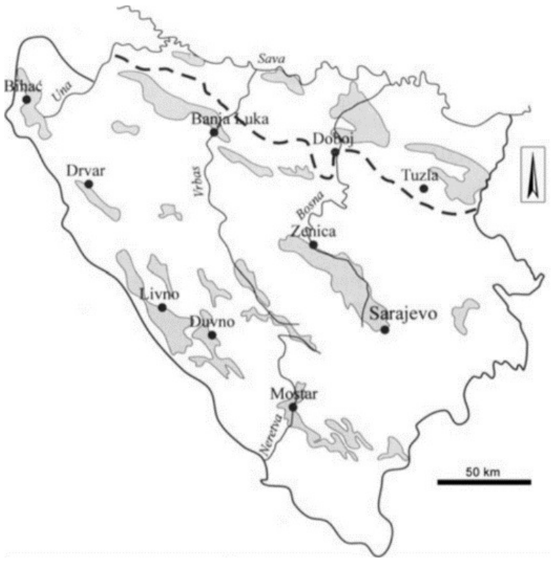
Sažetak: U radu su prikazani slatkovodni vapnenci, od *tenelije* i *(mostarske) miljevine*, koji su interkalirani u ležištu „Mukoša" kod Mostara, te njihovih „kamenih rođaka" *posuške miljevine* i *tomislavgradske muljike.* U procesu dijageneze zadobili su specifičnu orijentaciju i strukturu (posebno *tenelija*), što im je dalo specifična fizička svojstva (mala prostorna masa, visoka poroznost i permeabilnost), koja nemaju „klasični" vapnenci korišteni u građevinarstvu, a koja su bila odlučujuća za izbor ovog kamena za gradnju Starog mosta i drugih građevina na širem prostoru Mostara i na području općine Posušje, ali i u drugim krškim poljima Hercegovine i jugozapadne Bosne, u dijelovima Središnje Bosne, te Miljevini kod Foče. U drugom dijelu rada su prikazani tzv. ugrađeni (unutarnji) faktori koje su graditelji pokušavaju izbjeći da bi slatkovodni vapnenci koji su ugrađeni u mnogobrojne kamene građevine i/ili spomenike, izbjegli složene procese promjena kamena, odnosno trošenja (propadanja) kamena uslijed njegove interakcije s raznovrsnim uvjetima okoliša (vanjskim faktorima). Obrađeni su problemi i značenje izbora kamena, načina i (često premale) dubine vađenja iz ležišta za gradnju značajnih građevina, nedovoljno dugog odležavanja (skladištenja) nakon vađenja, neispravne ugradbe (slaganja) kamena u odnosu na njegov položaj u ležištu, kao i razne greške u obradi kamena i u izvedbi, uz neodgovarajuće održavanje.

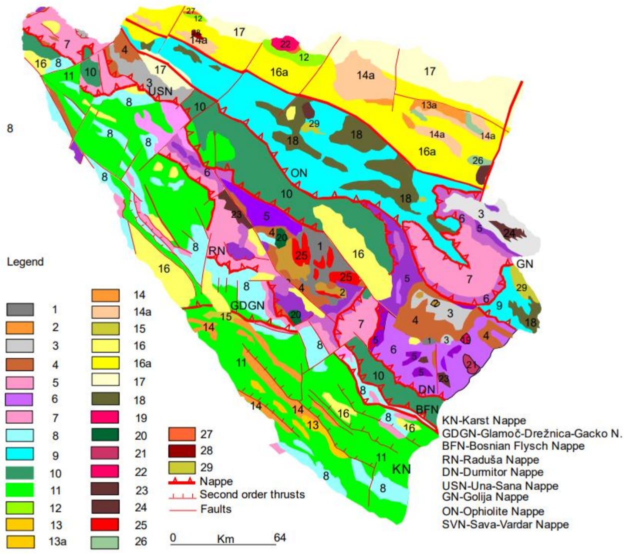
Ključne riječi: vapnenci, slatkovodni, jezerski, sedrasti, lakustrijski, jezerska kreda, oolitični, *tenelija, miljevina, muljika*, trajnost, unutarnji faktori

1. ABOUT FRESHWATER (LACUSTRINE/TUFACEOUS/...) LIMESTONES

According to Safet Čičić, approximately 65% of the terrain in BiH is composed of carbonate facies (limestones, dolomites and their transitional facies). Strong complexes of carbonate deposits sedimented in the Tertiary are found in the zone of the Outer Dinarides and in the Miocene of northern Bosnia. In the Central Dinarides, Tertiary marine carbonates are preserved in the vicinity of Gacko, and in the rest of the terrain they are found in Miocene complexes of geologically young freshwater lacustrine sediments in lakes in the tectonic depressions of the Dinarides, [1]. According to Hrvatović, in Bosnia and Herzegovina there are about 150 Neogene sedimentation basins [2] with freshwater limestones (lacustrine/tufaceous limestones, lacustrine chalk). These geologically young formations are characterized by considerable to high porosity, small bulk density, relatively low strengths and weak wear resistance.

In addition to *tenelija* and *miljevina* near Mostar, which are the subject of this paper, *bihacit* near Bihać, *plivit* near Jajce and *Bosnian mošćanica* near Zenica are very well known.

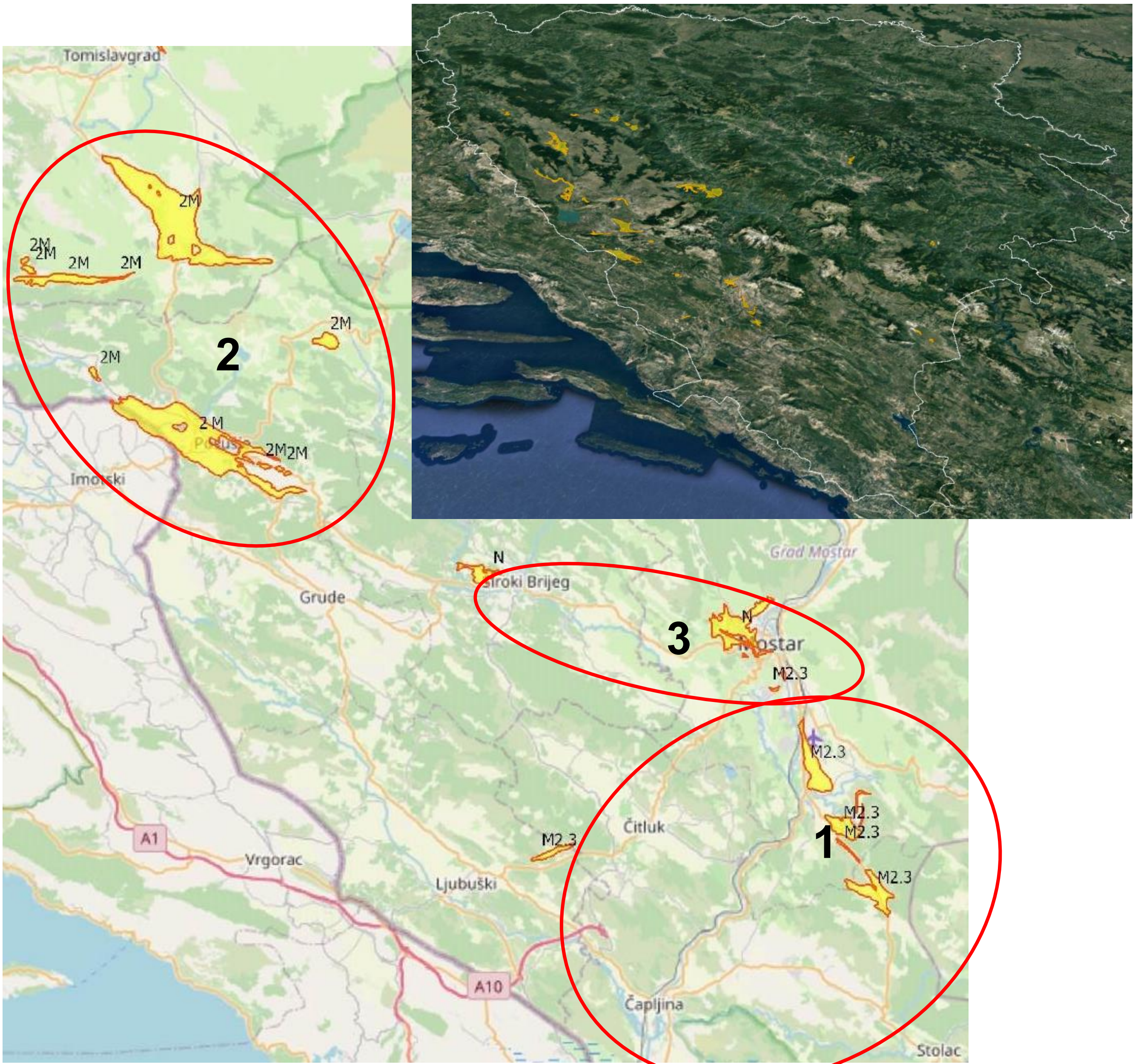




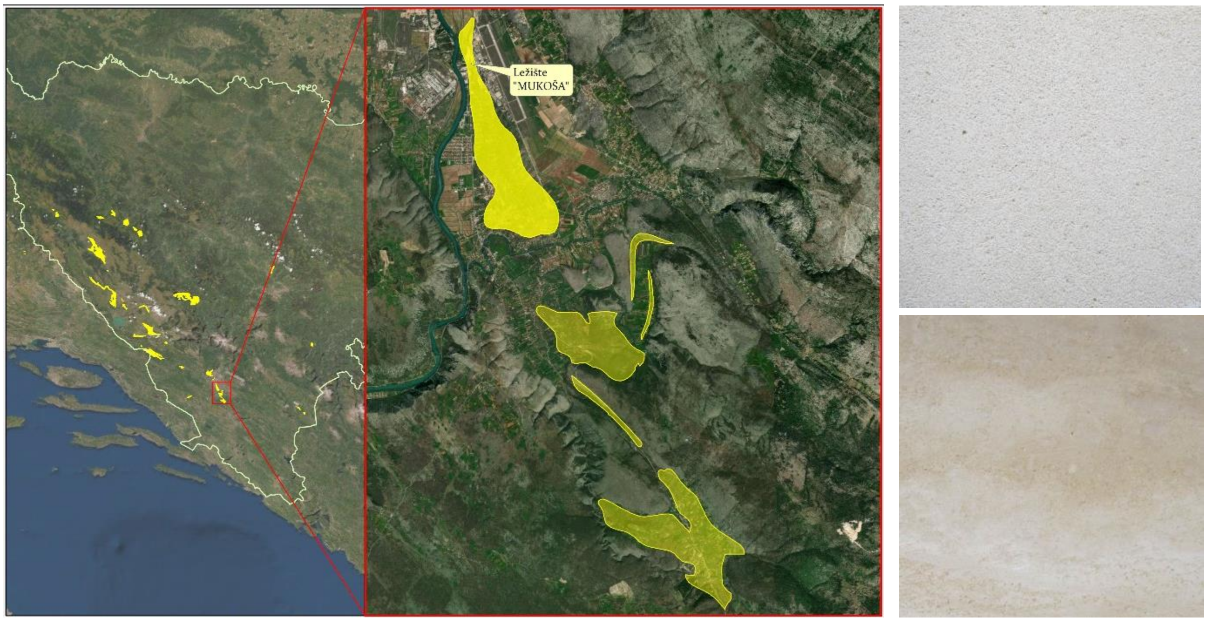
Figures 1-2. Location of the main Neogene sedimentation basins out of a total of 150 in BiH, (left; Hrvatović, 1999), [2]; Geological map of BiH, with Miocene intramontane freshwater sediments "16" and Miocene South Pannonian basin "16a", (right; Hrvatović, 2000), [3]

Three lithostratigraphic units that have a common marly-clayey and limestone component are identified within the Neogene deposits in Herzegovina. The first two units belong to the Miocene (^2M and $M_{2,3}$), while the third one is not analyzed in detail within the Neogene (N). The first unit is located in the wider area of Mostar, with two limestone subtypes locally called *tenelija* and *miljevina*, which differ from each other in grain size. [4] In the second unit, *miljevina* deposits are found in Posuško and Roško poljes, then in Vir, Rakitno and in larger areas of the southern part of Duvanjsko polje, [4]. Their Miocene age (2M) was determined on the basis of numerous fossil remains of shells and snails. Freshwater limestone, popularly called *muljika*, has long been used in Glamoč, Livno, Tomislavgrad and Bugojno. The third unit, with *miljevina* deposits, registered in Cim near Mostar and in Trn near Široki Brijeg, has little or no thickly stratified or banked oolitic limestones in its composition, so it was not interesting for dimension stone quarrying, [5].

In the process of diagenesis, these freshwater limestones, especially *tenelija*, acquired a specific orientation and structure, which gave them specific physical properties (small bulk density, high porosity and permeability), which "classic" limestones used in construction do not have, and which were decisive for the selection of this stone for construction of the Old Bridge and numerous other buildings and monuments since ancient times in a large number of locations in parts of Bosnia and Herzegovina where their deposits are located, from the karst poljes of Herzegovina and southwestern Bosnia (in the wider area of Mostar, Posušje, Tomislavgrad, Livno, Glamoč) to Central Bosnia (Gračanica near Bugojno, the lower basin of Trstionica near Haljinić and Ričica, in the vicinity of Kraljeva Sutjeska), Miljevina near Foča and Bihać. The quarry (pit or natural) moisture that they contain enabled easy and cheap extraction of blocks, easy processing and construction.



Figures 3-4. Simplified maps of parts of BiH with the locations of Neogene deposits (top, right), [6]; part of the map with 3 lithostratigraphic units with a common marly-clayey and calcareous component: in the wider area of Mostar ($M_{2,3}$ - tenelija and miljevina), in Posuško polje, along with traces in the areas of Roško and Rakitsko poljes, Vir, and the southern part of Duvanjsko polje (^{2}M - miljevina), and in Cim near Mostar and Trn near Široki Brijeg (N - miljevina), (author: K. Šaravanja)



Figures 5-7. 1. lithostratigraphic unit belonging to the Miocene in the wider area of Mostar: Ortiješ, Buna, Hodovo and Rodoč is mapped on the Basic Geological Map under the name marls and conglomerates with clivunellas ($M_{2,3}$) with tenelija and miljevina, the layers of which overlap in the "Mukoša" deposit, (left; author: K. Šaravanja), [6];
Photographs of cut samples of tenelija (right, above) and miljevina (right, below), (photo: I. Hajdarević)

They were used as masonry construction elements and decorative elements in construction (stone blocks that have their dimensions/volume within the building), and more recently as a decorative element (cladding) for vertical cladding on building facades, and as decorative stone plastic and decorative ornaments of the exteriors and interiors. Although the architectural and structural values of buildings made of Mostar *tenelija* (Old Bridge, and Karadjoz Bey's and other mosques and buildings in the area of Mostar, and beyond) have long been recognized and protected by UNESCO, or as national monuments of BiH, the architectural and constructive values of buildings made of the analyzed freshwater limestones, especially those outside Mostar, have not been sufficiently studied, or presented to expert and general public, from schools to the overall public, and some of them have not been put into operation, or in the tourist supply. In addition to the good functional solutions of these buildings, most of them were built individually in a way that their shape and structure protect them from decay. Unfortunately, after World War II, the value and quality of *miljevina* (and *muljika*) were disputed, so these freshwater limestones, and even tenelija, were completely neglected for decades. The reason was laboratory tests that showed the high absorption of stone and questionable resistance to frost, and other materials (bricks and concrete) began to be dominantly used.

The leading author wrote about the architectural and constructive values of these freshwater limestones in papers from 2017, [7], [8] as well as the doctoral thesis, [6].

Tenelija is a coarse-grained *oolitic* limestone, with a homogeneous (massive) texture and high porosity. Its strength and durability depend on the grain size (coarse and fine-grained ooids) and natural porosity ("*coarse*" and "*fine*" *tenelija*), [9]. It was used in various forms, in blocks weighing several tons (the arch of the Old Bridge), in smaller cubes and angle stones for building walls, in floor slabs several centimeters thick, for vertical cladding of the interior and exterior with cut panels of different formats, making columns and decorative fences, in various forms of tombstones and in sculpture, projecting sections of Austrian buildings, [10]. "*Masonry with tenelija is a tradition of the Mostar region. Where there was (tufa or) tenelija, or* *very similar miljevina, which can be easily processed, the buildings there are also more elegant, gentler and more refined*", [11]. Due to its instability to frost, the use of tenelija in the exterior is limited to the Mediterranean climate.

Figure 8. Part of the rich cultural and historical architectural heritage of Mostar, made of freshwater limestones tenelija and (Mostar) miljevina, (author: K. Šaravanja)

In contrast to the oolitic structure of *tenelija*, *miljevina* has a dense, fine-grained structure in which cementation and recrystallization of calcite has not occurred ("*dense limestone*"). It has weaker physical and mechanical properties compared to *tenelija*. The grains are supported by mud ("*mudstone*"), due to which it retains moisture for a long time, and the effect of temperature changes and ice causes surface loosening and deterioration of the stone, [12], [13]. It is unstable to frost and its use in the exterior is limited to the Mediterranean climate. *Miljevina* from the "Mukoša" deposit was determined as microcrystalline limestone with microcrystalline (to cryptocrystalline) structure ("Cerberus", Tuzla), and two samples from abandoned residential buildings in Mostar as crystalline porous limestone, with crystalline structure ("Cerberus"), or as dismicrite, with fine-grained structure and stratified structure ("IGH" Zagreb), [6]. Earlier, it was used as broken and cut stone for the construction of buildings of various purposes; today it is predominantly used for vertical cladding of interiors and exteriors with cut panels of different formats. Due to the high degree of porosity and slow release of moisture, it is preferable to be installed on surfaces that are not directly exposed to wetting (rain) and moisture and gusts of wind. The tested samples of *miljevina* from Tomića Brig and Ričina near Posušje were determined as crystalline porous limestones, with crystalline texture ("Cerberus"), or as biomicrite, with fine-grained structure ("IGH"), [6].

Muljika (miljuša) was formed by the deposition of silt that was cemented with oolitic calcium carbonate over thousands of years. It is similar in color and properties as *miljevina* and *tenelija*. It is sensitive to moisture, so it takes up to 10% moisture, which is not the case with any other type of stone. It is highly suitable for processing, [14]. In the literature, *muljika* or *milj(i)ka* is "*clay marl (Mergel), yellowish and soft stone, which can be easily and nicely dressed and cut, it just needs to be tested in the sun and snow, because one piece will remain for centuries, and the other will begin to flake and disintegrate in the first winter*", [8]. Stone samples from the abandoned building in the village of Kolo and from the stone stockpile near the church in Tomislavgrad were determined as crystalline impure limestone, with crystalline structure

("Cerberus"), and the sample near the church in Tomislavgrad was determined in "IGH" Zagreb as biopelsparite, with fine-grained structure, [6].

Tests conducted during the preparation of the doctoral thesis [6] confirmed significant differences in the properties of *miljevina* from the area of the City of Mostar (mapped on the Basic Geological Map as *marls and conglomerates with clivunellas* $M_{2,3}$) and *miljevina* from the area of Posušje Municipality (mapped as *marls and marly limestones with congerias* ^{2}M), so Šaravanja proposed adopting the names *Mostar miljevina* and *Posušje miljevina* in the future use of these types of natural stone. He proposed the name *Tomislavgrad muljika* for the only examined *muljika* from the area of Tomislavgrad municipality. In future research, it is necessary also to include *miljevina* from the area of the place of the same name in eastern Bosnia (Miljevina) and make a detailed comparison with *Mostar miljevina* and *Posušje miljevina*, as well as various *muljikas*/*miljevinas* from southwestern and central Bosnia, [6].

Analyzed freshwater limestones, are quite similar to each other, but still different from each other, from Mostar *tenelija* and *miljevina*, "stone twins" different from each other, which are intercalated in the "Mukoša" deposit near Mostar, and their "stone cousins" *Posušje miljevina* and *Tomislavgrad muljika*, to *muljika* and *miljevina* from other mentioned parts of Bosnia and Herzegovina.

In principle, the specified freshwater limestones correspond to the climatic characteristics of the area where their deposits are located, and have been used as such since ancient times, with all good and less good properties, [6].

2. BUILT-IN (INTERNAL) FACTORS, AS CAUSES OF CHANGES IN STONE/FRESHWATER LIMESTONES *TENELIJA*, *MILJEVINA* AND *MULJIKA*

On the natural stone built into stone buildings and/or monuments (hereinafter: buildings), the processes of changes, that is, weathering (degradation) of stone occur due to its interaction with various environmental conditions, the so-called external factors (effects of temperature, humidity and quality of air, winds, precipitation, acidic rain, exhaust gases, micro-particles and organisms in the air and water, harmful salts, radiation, soil, biological colonization), along with the destructive action of humans.

Therefore, stone durability (or its opposite, weathering) is a complex and key factor when selecting stone, which depends primarily on its physical properties, since it must withstand exposure to weather conditions, polluted atmosphere and environment, as consequences of anthropogenic action, and other agents of accelerated deterioration of stone incorporated in buildings and monuments. The distribution of various degradations in the building mainly depends on the lithological characteristics, on the composition, structure and texture of the stone (Charola, 2004), [15] but also on the position of different types of stone and the direction in which they are oriented, [16].

The durability of stone is affected by the processes to which the rock mass was subjected in the stone bed, or its textural and structural characteristics (exceptionally coarse-grained stone weathers faster), and porosity (the finer the pores, the greater the possibility of capillary moisture spreading, and thereby the possibility of damage). The durability of the built-in stone is particularly influenced by its mineral composition (and its possible transformations), [17].

In addition to the genetic and post-genetic processes undergone by the stone, its durability is also affected by the so-called built-in (internal) factors that we try to avoid, from the selection of stone, the method and depth (often too small) of extraction from the deposit (especially for the construction of significant buildings), insufficiently long aging (storage) after extraction, incorrect installation (stacking) of stone in relation to its position in the deposit, and we should also mention various mistakes in stone processing and execution, as well as inadequate maintenance.

In the end, the issue of durability of stone should also be placed in the context of its utility value, or whether it is incorporated into a valuable building of cultural heritage or a less significant commercial building.

2.1 The height of the building, its location and orientation/exposure

Changes in stone can be significantly influenced by various aspects of the building's location (climate, longitude and latitude), especially in northern areas with colder climate, as well as the altitude of the building (mountainous areas, at higher altitudes). On the other hand, buildings in more southern, warmer (and lower) regions are exposed to solar heating (insolation). The physical (mechanical) degradation of the built-in stone dominates in the mentioned cases. Although there is no change in the chemical composition, such fine-grained masses facilitate the process of chemical decomposition, especially in humid warm regions by the sea, which is a source of harmful, soluble salts (chlorides), which migrate with moisture through the stone, gradually destroying its structure.

Changes (and deterioration) of stone are contributed by the location of buildings near the sea, various industrial plants, roads with heavy traffic, as well as in urban areas with significant pollution. However, not only are there differences in the changes in the built-in stone in urban in relation to rural areas, as well as differences in the same type of stone in cities with different pollution, but there are also frequent differences within the same city, depending on the location of the building in relation to the main cities roads, location on high ground, proximity of a river, or prevailing local winds. All these factors can lead to not only the formation of a weaker/stronger concentration of polluting gases and dust, characteristic of the city center, but also, consequently, lesser/greater changes in the built-in stone in the buildings.

It is also necessary to mention the position/place and orientation of the building's surfaces in relation to the cardinal directions, which can result in the formation of various forms of deterioration and stone lithology on walls with different exposure, especially in urban areas, but also in rural areas.

Figure 9-10. The different appearance of the surface of the shaded parts on the west side of the reconstructed Koski Mehmed Pasha mosque in Mostar in relation to the sunnier south side; The stone facades are built of tenelija stone covered with surface deposits of dirt, the formation of which is caused by a combination of factors related to pollution and the effect of moisture on the stone (left); The different appearance of the surface of the stone facade of the shaded eastern and northern sides of the house in Tomića Brig-Vinjani near Posušje, built of miljevina, as a consequence of its location (right); The patina is also more pronounced in the parts closer to the ground, and around the gutters due to longer retention of water, (photo: K. Šaravanja), [6]

Figure 11-12. The lower part of the stone northwestern facade of the former SDK building in Mostar (left, www.cidom.org) is more markedly covered with surface deposits of dirt than the southwestern part of the facade (right); The formation of these deposits is caused by a combination of factors related to air pollution (from traffic, heating of households and industry) and the effect of moisture on stone, (photo: K. Šaravanja), [6]

Different soiling and blackening (patination) of facades on different sides of buildings will be discussed in more detail in another paper related to environmental (external) factors as causes of stone deterioration, where the different condition of the northern (upstream) and southern (downstream) sides of the Old Bridge in Mostar will be presented.

Here is especially emphasized exposure to the influence of insolation (parts of the building exposed to the sun heat up more, while those in the shade cool down faster by condensing atmospheric moisture, so differences in thermal expansion can lead to damage), more pronounced precipitation (on the west side a weak influence of precipitation, and on the north side high portion of precipitation) and dominant wind(s). In the process, seasonal temperature variations of the surface of the built-in stone are less significant than daily variations, which in the summer period in the continental climate area can be 40-50°C, depending on the position (exposure), where damage from thermal stress is usually increased on the south and west sides of the building, [18]. An example of exposure to the influence of insolation is given in the "Report on the conservation and restoration studies of the facade of the bell-tower and the western facade of the Franciscan Church of St. Peter and Paul, Gorica-Livno" (2011), which states that "*due to distinct daily thermal changes on the facade of the church, in the summer months there was damage to the lime joints and stresses of microcracks in the stone, which in winter allowed the penetration of water, leading to the present condition through daily cycles of freezing and thawing*", [19].

According to prof. Radnić et al., [20] "*on the reconstructed Old Bridge, in addition to vertical loads, temperature effects are the main cause of cracks in the original and reconstructed arch*".

The height of the structure is certainly also important (lower places are more prone to accumulate soluble compounds), and so is the morphology of the structure and its parts.

In the end, a (greater or lesser) shading of the building or a part of it by trees, or in general by higher vegetation (creepers,...) can have an additional effect.

Figures 13-14. Examples of the influence of the surrounding vegetation: a house in Tomića Brig-Vinjani near Posušje, with the influence of the nearby walnut tree on the east side of the building, whose leaves, when washed by rain, acidify the rainwater to some extent (left); The minaret of the mosque near the Bunur pedestrian bridge in Mostar with a more intense patination of the stone due to the proximity of the surrounding vegetation and the Neretva River (right), (photo: K. Šaravanja), [6]

In general, each stone building should be observed individually with regard to the climatic, atmospheric and other specified conditions of the microlocation where it is situated, and the conditions of the soil on which it was built, [17].

2.2 Wrong choice of stone or its inappropriate use

When choosing natural stone, one should take into account numerous aspects of its future use, above all possible ways of sawing and processing its surface. In addition to the physical and mechanical properties of the stone, its decorativeness, or stability of its color on external surfaces, is often important, which depends on its mineralogical and petrographic composition (and the presence of impurities) and on the exposure of the built-in stone to the effects of various atmospheric agents in an urban environment.

Due to the increased content of organic matter, many limestones fade on external surfaces and become full of bright spots, so knowing the process of stone discoloration due to the action of external factors is exceptionally important for the stone industry, as well as for restoration work on stone heritage, [21].

By proper selection of stone, we try to avoid potential problems with the durability of the built-in stone (changes to the stone in the form of damage, even disintegration), so the design requirements should be taken into account when constructing and using the building.

Since not a single factor should be ignored in the overall assessment of suitability in the selection of stone, an excellent knowledge of its physical and mechanical, as well as mineralogical and petrographic properties is required, considering that the stone must withstand exposure to weathering factors, polluted atmosphere and environment, as consequences of anthropogenic action.

It is difficult to answer the question of which limestones (petrographically) could be most susceptible to rapid deterioration because, according to Turkington [22], "*the durability of stone is difficult to define and measure*", especially where it is limited by complex process regimes, as well as in sites where there are no experiences related to the earlier use of the particular type of stone.

The stability of stone is primarily influenced by the genesis processes of the rock mass in the deposit, or its textural and structural properties (coarse-grained stone weathers faster), and porosity (the finer the pores, the greater the possibility of capillary moisture spreading, and thereby also damage). The durability of the built-in stone is particularly influenced by its mineralogical composition and its possible transformations, [23].

Many times, the restoration and reconstruction of cultural heritage buildings were faced with problems not only in identifying the petrographic type and establishing the properties of the stone, but also in finding the site from which the stone was extracted, or finding a replacement stone. Thus, for example, in the fresh state it is difficult to visually macroscopically distinguish between *tenelija* and *(Mostar) miljevina*, which are intercalated in the same layer of the deposit in several places. Only local stone masters can make the distinction, with the help of some tests, and the differences can be observed by different intensities of change in the quality of incorporated stone in buildings, as well as in abandoned quarry areas. Therefore, not only visual inspection, but also laboratory tests, are important for a good selection of stone, and experience in earlier applications of that stone in similar buildings, if such experience exists, is especially important.

Old builders used local types of freshwater limestones in construction, knowing exactly their possibilities and advantages related to the exceptionally easy processing and realization of more delicate buildings, but also limitations related to considerable to high porosity, small bulk density, high water absorption, relatively low strength, and poor resistance to wear and questionable resistance to frost.

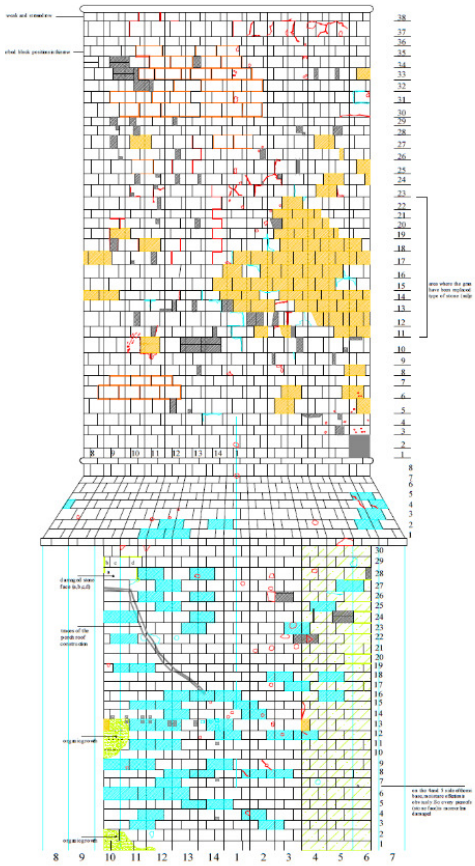
According to Frano Oreč, in the area of Posušje municipality, many tombstones in the Batin, Gradac and Kljenak-Broćanac cemeteries were made of *miljevina* from several quarries, mostly in the period from 1850 to 1930, without any motifs, some with motifs engraved on the tombstones (flowers, crosses, spirals,...), which are very rarely damaged. The height and width of the tombstones varied a lot. In terms of size, they range from 100 to 220 cm in height and from 80 to 120 cm in width, while the thickness is different and was not chosen, but was taken from the layer that was accessible, usually from 18 to 22 cm. The crosses in the Gradac, Batin and Kljenak-Broćanac cemeteries are made of stone of a poorer quality than the crosses in the Ričina, Matkovine, Martića Križ and Vinjani cemeteries. Due to their poorer quality, it can be observed that some of them are damaged by the weather effects, [6].

The importance of the proper selection of stone is evident from the occurrence of cracks on the arch of the reconstructed Old Bridge in Mostar, a monument under the protection of UNESCO. According to prof. Radnić et al., [20] "*the main cause of damage in the original and reconstructed stone arch is the inadequate quality of tenelija stone, with which the arch was built, and above all its low tensile strength*".

2.2.1 Wrong choice of stone that is unstable to frost in a particular climate

The reasons of the susceptibility of many freshwater limestones to deterioration can be found in the fact that they have not gone through intensive processes of deep diagenesis, so they are less crystalline and less dense, and therefore less durable, and more sensitive to the processes of chemical deterioration (dissolution and sulfation) and deterioration caused by crystallization (salts and frost) in relation to geologically older, compact (dense) limestones (Leary, 1983), [24]. Their durability is also affected by the method of cutting and installation of stone blocks, so stratification and secondary fracturing must be taken into account during processing.

During the renovation of the minaret of the Karadjoz Bey's Mosque (2003-2004), there were stone blocks of lower-quality surface stone (*miljevina*), which were replaced.

Figures 15-16. The minaret of the Karadjoz Bey's Mosque, a national monument of Bosnia and Herzegovina, the oldest building constructed with tenelija, before renovation, with visible traces of miljevina among the tenelija stones (left); detailed drawing showing cracks in red and various repairs in yellow and blue color, and all areas show replaced parts of surface stone (right), [25]

So, mistakes in the choice of stone that can be the cause of damage to buildings also occur in practice, from natural anomalies in the stone (veins, micro-cracks), to its inhomogeneity, or instability of the used stone to frost in a particular climate.

The changes especially affect the porous stone, the minerals of which are less resistant to deterioration. Knowing the limitations of the use of *tenelija* and *miljevina* related to high water absorption, builders in Mostar often used a different type of stone for the lower parts of buildings, and numerous buildings of various purposes from the Austro-Hungarian period (and somewhat later) that were built with thick walls of *miljevina*, prone to high water absorption, were covered with a facade for protection, [6].

When assessing the stability and general change of stone over time, of great importance is to know the behavior and condition of stone on already built buildings. Therefore, care should be taken with regard to the questionable resistance to frost of some freshwater limestones, especially in certain climates. Unfortunately, there were also examples of the wrong choice of freshwater limestone for gravestones and other monuments with a colder continental climate and frequent frosts. One of them is the original fountain next to the (Gazi Husrev) Bey Mosque in Sarajevo, made of Bosnian *miljevina* (1530). It was thoroughly renovated in 1772, however, at the end of the 19th century due to the strong Sarajevo winters and frequent freezing, it was almost completely damaged, so a new fountain was built from marble from Pučišće on the island of Brač., [6].

There was a similar problem with the use of *tenelija* for nišan tombstones in Bosnia, which collapsed due to frost during the first winter.

2.2.2 Insufficient depth of the deposit from which the stone is extracted

In order to obtain large blocks of high-quality stone without cracks, we need to extract limestone from the depth, where it was loaded by the stress of the upper layers. According to Tamara Plastić, [15] "*the reason for the difference in physical and mechanical properties of stone from the same deposit is the different depth of the deposit from which the stone is extracted. 'It's as if the stone gets decompression sickness when it comes to the surface.' Since there are considerable differences in the pressures to which the stone was subjected, it is logical to assume that the place of origin is reflected in its characteristics*". The stone that is extracted from deeper layers of the deposit loses smaller part of its moisture and it remains workable for longer.

From the stone quarrying and processing technology for the Süleymaniya Mosque in Istanbul in the mid-16th century, it is evident that limestone was extracted from a depth of 6.5 m to obtain large blocks of high-quality stone without any cracks. Faster degradation was also observed in stone from newer quarries where the stone is still extracted from "shallow" parts, [6].

2.2.3 Negative impact of modern technologies in quarries

Due to the faster degradation/deterioration of built-in stone in buildings, in recent decades it has been unreasonably doubted whether stone is acceptable for certain purposes, without taking into account the significantly accelerated technology of stone extraction with modern machines, along with the greater massiveness of the blocks, often pushing into the background surfaces and the dip of the stratification, which is an exceptionally important characteristic of limestones that defines their physical and mechanical properties, and can be one of the causes of faster deterioration of the stone after installation, [17].

Extraction of stone using explosives can cause internal fractures. If this is not taken into account, problems and deformations will be created on the architectural elements of buildings, and the stone will show signs of faster degradation/deterioration, or reduced durability.

2.2.4 Improper installation/stacking of stone in the building in relation to the position of the stone in the deposit

In a building, stone can have a constructive, constructive-decorative or decorative role. In the first two cases, the stone has dimensions and stone mass in the depth of the building, which takes on all the stresses after installation. In earlier buildings, the stone was properly laid, with a horizontally oriented planar anisotropy, with a layer. As a rule, the planes of textural anisotropy (layering, schistosity) should be perpendicular to the pressure. Proper installation has a positive effect on its durability, while improper installation can reduce durability to just a few years, [26].

The portion of degradation mainly depends on the lithological properties, on the composition, structure and texture of the stone (Charola, 2004), [27] but also on the position of different types of stone and the direction in which they are oriented, [28].

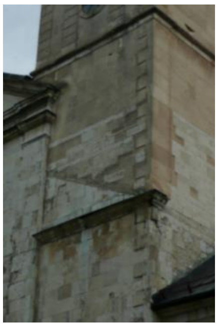
During construction, damage can occur if a stone block is installed in a building incorrectly in relation to its position in the deposit, especially in the case of some types of non-homogeneous stone that contain layers of different quality. As a rule, installation of stone blocks must be careful and similar to the natural position and direction as in the deposit. The layers should lie horizontally, in the way in which the stone was formed because the stone is stronger and less vulnerable to defects in that position. In such a case, if the stone is laid by the face (the layers are vertical), it is more vulnerable to damage from salt crystallization and/or the action of frost, because due to mechanical effects it is relatively easy to push away the embedded layers since there is no support on the adjacent stones. Therefore, the direction of load transfer in a building must always be perpendicular to the natural layers in stone, or to the layering of stone resulting from the sedimentation process of formation of such rocks. Otherwise, delamination and cracking of the stone occurs. When this rule is taken into account and the wall is constructed with cut platy blocks up to 30 cm thick, moisture very rarely penetrates the building, [6].

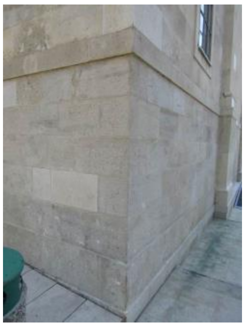
Practice has often shown that freshwater (porous) limestone as a building stone requires restoration and replacement, as in the cases of the famous church of St. Matijaš and the Parliament building in Budapest. In conservation practice, there are several ways of repairing damaged stone or preserving it in old buildings, depending on the nature of the mineral composition, structure and texture of the stone. In principle, built-in, damaged stone is repaired by replacing blocks/parts of blocks with selected stone on the front, visible sides of (bridges and other) structures.

Such a situation was with the walls of the Church of St. Michael the Archangel in Tomislavgrad and Church of St. Peter and Paul in Gorica-Livno, whose main facades are given special monumentality by dressed stone *muljika* from local quarries.

At the church in Tomislavgrad, stone blocks damaged by frost were replaced with newly made dressed stone elements from the same quarry. The damaged blocks had not been installed in the same position as in the bed, thus preventing the layers from coming to a vertical position and moisture from being drawn into them, which led to delamination and disintegration due to the action of ice, [6].


Figures 17-18. Church of St. Michael the Archangel in Tomislavgrad (above); frost-damaged blocks replaced with new cut elements of the same type of stone, (below; photo: K. Šaravanja), [6]





Figures 19.-21. An example of the construction of wall covering of the southern bell tower of the Church of St. Peter and Paul in Gorica in Livno with different types of dressed stone with regard to their color, size and surface processing (left), [29]; The muljika stone, which gives a special monumentality to the main facade H, it was restored on the facade and bell towers, (middle and right; photo: K. Šaravanja), [6]

On the church of St. Peter and Paul in Gorica in Livno, the national monument of BiH, the stone was restored on the facade and bell towers during the restoration due to the risk of collapse of the damaged stone. The proposers were the Croatian Restoration Institute from Zagreb and the Institute for Protection of Monuments of the Federal Ministry of Culture and Sports. Before choosing a replacement stone, it was recommended to leave a smaller block to overwinter unprotected in Livno, to make sure that the selected stone would be good for such conditions, [6], [29].

According to Frano Oreč, 660 residential and commercial buildings in Posušje municipality were built from *(Posušje) miljevina*. They were built in straight rows with a height determined by the thickness of the layer in the quarry (about 40 cm). The stacking of blocks into the building was always done in the same way as the block had its position in nature, to prevent the layers from coming to a vertical position and moisture from being drawn into them, which would lead to disintegration due to the action of ice. Since the building was made with dressed platy blocks up to 30 cm thick, moisture rarely penetrated the building itself, [6].

Some tombstones made of freshwater limestone were damaged due to mistakes in the choice of stone and failure to take into account its stratification, so moisture penetrated the stone layers, which led to partial or complete delamination of the tombstone due to frost.

Figures 22-25. Damaged tombstones in the Radoševina cemetery near Tomislavgrad, made of stone muljika, with visible delamination along the height (figures on the left) or on part of the height of the tombstone (figure on the right) due to failure to take into account the stratification of the stone, and long-term exposure to frost, (photo: K. Šaravanja), [6]

2.2.5 Improper handling of blocks after extraction and too short time from extraction to installation

Each stone contains a certain amount of quarry (pit) moisture, which is constant in the deeper layers, and in the layers closer to the surface it depends on atmospheric conditions. In the extracted samples, the total moisture is quarry moisture, and wet stone is softer and easier to process.

If the stored samples were exposed to rain, in addition to quarry moisture, precipitation moisture is also present.

In addition to the technology of stone extraction, nowadays the way of handling blocks after extraction has also changed significantly due to different market dynamics, so there is no traditional aging (storing) of extracted stone blocks (and finished stone products), i.e. after extraction, they should have gone through all stages of production so that the final product has the desired properties, [17]. Thus, the stone was not used immediately after extraction, but later, in different stages of aging and releasing of quarry moisture, which made it more resistant to weathering factors.

Back in ancient Rome, it was a practice, especially in underground mines, to process the stone immediately, while it still contains its natural moisture. After extraction to the surface, the stone begins to dry, moisture comes out of the pores, and the color of the stone becomes lighter. The famous Roman architect and builder Marcus Vitruvius Pollio in the book "*De architectura libri decem*" or, in the Croatian translation, "*Deset knjiga o arhitekturi (Ten Books on Architecture)*", [30] wrote how to treat stone if you want to build well "*Stone should be extracted two years before starting to build, and so in the summer, not in the winter, then it should be left lying in an open place. The stones that were damaged by the elements during those two years should be laid in the foundations. The rest that remains undamaged will be able to withstand, if built in above the ground, because nature has tried it. This should be taken care of not only with cut stone, but also with masonry construction with broken stone*", [6].

In the case of stone for the construction of the Süleymaniya Mosque in Istanbul, in the middle of the 16th century, the stone blocks that were initially processed in the quarry were not transported for installation until 4 years later, with fine finishing, [6].

That is exactly how the stone extracted in the Brač quarries was handled until the 1980s, but over time this procedure was set aside, [17].

The book "Building with natural stone" graphically presents the influential factors on which the (long) durability of stone depends. In addition to genetic and postgenetic processes, the durability of stone is also affected by the method of quarrying, the method of processing, installation and maintenance of stone, as well as exposure to atmospheric agents. The figure shows the stresses to which the stone is exposed from extraction to installation, which individually and collectively affect the durability of the stone. Tamara Plastić made a correction that takes into account the storage of stone after extraction, [17].

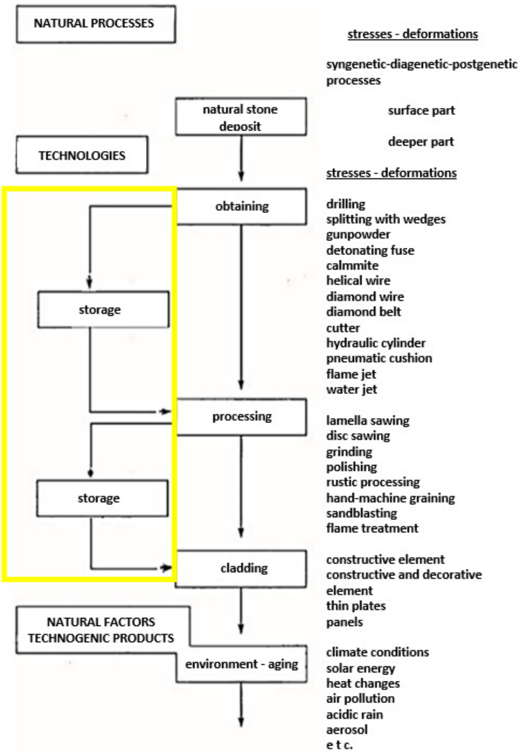


Figure 26. Stresses caused by natural and technogenetic factors to which stone is exposed from extraction to installation, which individually and collectively affect the durability of the stone (left); 4.3 Correction that takes into account the storage of stone after extraction, [17]

According to Frano Oreč, the "picking" of the *miljevina* stone from the quarry in Posušje was conducted at the end of summer or in autumn (also even earlier, in spring). It was arranged in a free area and left outside, in the sun and snow before use, in order to remove bad stone from future use, so if it had not undergone changes (especially in winter) it would be used for further processing and installation, because, as the people say, "*one piece will remain for centuries, and the other will begin to flake and disintegrate in the first winter*". Over time, this practice was abandoned for economic reasons, so the builder does not wait for this entire period to pass because he needs the stone, [9].

Aging of the extracted stone contributed to a faster loss (drying) of quarry moisture, thus reducing the specific gravity, which indirectly indicates a decrease in absolute porosity, or an increase in the compactness of the minerals, or of the stone which they form, [17]. It has been empirically observed that the specific gravity and bulk density, as well as porosity and density of the "mature stone" are generally improved, and the mechanical properties of the stone are also improved, as well as the resistance to the influence of atmospheric agents, [29]. Moisture loss depends on the size of the extracted block, the type of porosity and generally on the structure of the pore system, but also on the environment in which the stone is located, [17].

Due to their porosity, porous limestones have a high coefficient of water absorption. Despite this, they are resistant to frost because, due to the favorable sizes and interconnectedness of the pores and holes, water does not stay in the pores, so even if freezing occurs, due to the size of the pores, the ice in them has enough room to develop, and it does not press the walls. This does not apply to extracted blocks, they must not be kept outdoors at negative temperatures.

Nataša Plastić wondered on behalf of all of us, "*is it possible to postpone or slow down the aging of stone, or to extend the durability of stone, by proper maturation?*", so she performed tests of some physical and mechanical properties of stone relevant for application in construction in different stages of maturation and release of quarry moisture, after which she concluded "*that the physical properties such as specific gravity and bulk density, as well as porosity and density of the stone of the mature material are generally improved*", and that "*the absence of the phase of adaptation to the surface (external) conditions in stone production is one of the most influential factors of its accelerated deterioration*", [17].

2.2.6 Mistakes in stone processing

In order to avoid damage to stone, it is important to use the appropriate mason's tool for a specific stone, to change it when it becomes dull, and to temper the tips in the evening, as a way of preparing for tomorrow's working day, in order to have greater work efficiency. In addition to the stonemason's tools, the stonemason's own knowledge and experience in processing a particular type of stone is especially important, because using the same type of tool for certain phases of dressing, different masons can achieve different processing finenesses and dressing methods. In some cases, as a result of inappropriate dressing techniques, excessive processing of the stone surface creates some surface irregularities or holes that retain water, or can accumulate salts, with all possible consequences. The appearance of the built-in stone can be spoiled by scratches, scrapings and other damages in the final treatment. An important fact is also that numerous larger buildings, like the Old Bridge, were constructed over the years, with changes in master masons, and the different subsequent alterations and repairs are a special story.

2.3 Mistakes in the construction and renovation of buildings

In the construction and renovation of a stone building, various mistakes are possible, such as incorrect structural solutions, since the shape and method of construction can protect it from deterioration. It is known that most stones have a good bearing capacity for compression, but not for tension, bending and shear stresses. Walls with two faces and infill with crushed stone are less resistant to earthquakes in the case when these faces are thin and the infill is of lower quality. There are also mistakes due to improper foundation, foundation in soils with poor bearing capacity, even different bearing capacity of the soil under parts of the building. Objects made of iron embedded in stone are problematic due to iron corrosion and swelling, which causes the stone to crack and also pollute its surface. The mentioned mistakes in the construction and renovation of buildings can result in disturbance of the bearing capacity of the entire building, even its collapse, [26].

An example of a mistake in the construction of a stone building was established during the renovation of the minaret of the Karadjoz Bey's Mosque (2003-2004), 30 m high, made of perfectly square stones 30 cm thick, connected by iron cramps sealed with lead. Since not all of them were connected to each other, a considerable "protrusion" of the axis appeared (Figures 15-16), [6].

On the church of St. Peter and Paul in Gorica in Livno, it was observed that, due to swelling, the corroded iron connections inside the dressed blocks press the stone and cause its destruction, which leads to its breaking off and formation of large holes in the wall coverings.

According to the professional paper of prof. Radnić and associates from 2011, the following deviations of the restored Old Bridge compared to the original were observed:

- *"Large hollow spaces, with reinforced-concrete bearing structure, in which archaeological museums are located, were left in the zones immediately behind both abutments. The bottom of the hollow space is at the arch spring level. Compared to the original situation, this has reduced favorable action of the permanent vertical load behind the arch springs, and has increased horizontal deformability of the arch;*
- *The restored bridge is probably globally stiffer than the original (it has a higher average modulus of elasticity) because the stone blocks are more precisely cut, the joints between the blocks are generally narrower and more regular, the mortar in joints is probably better compacted and less deformable, In the crown, the arch is braced (prestressed) with hydraulic jacks, metal connections between stone blocks are of better quality, the arch scaffold was dismantled only after completion of the spandrel structure, the stiffness of the abutment and spandrel structure was increased by subsequent grouting, and after scaffold dismantling, the arch deflection at the crown level was less than one millimeter. Greater arch stiffness is less favorable with regard to temperature effects.*
- *At the original bridge, the arch thickening at the spring was realized using a hard crushed limestone bound with a special mortar (mixture of quicklime, terra rossa, sand, gravel, and water). At that, stone blocks situated in between external frontal walls were more than 0.8 m in thickness, and were rounded or slit at the top, with very rough extrados surface. In the case of the reconstructed bridge, a lower strength mortar was used for arch thickening at the spring level, and stone blocks are of similar thickness (0.8 m), with a relatively flat extrados surface. Thus the initial shear bearing capacity, at the connection between the arch extrados and arch thickening at spring, was reduced, i.e. the resistance of the composite structure was reduced.*
- *The arch geometry does not correspond to the geometry of the original bridge, but has imperfections (depression) at the south side, between the crown and side of arch toward the west (real arch geometry before destruction). This is more unfavorable from the aspect of stresses in arch;*
- *The construction of the initial bridge lasted nine years, while its renovation lasted less than two years. Consequently, the tenelija stone strength on the day the scaffold was dismantled from the renovated bridge was lower than the strength of stone in the original arch upon its completion.*

According to the conclusions of the paper "*great damage to the renovated arch over a short period of time is probably due to deviations from some solutions that had been used for the original bridge*.", [20].

It has been 12 years since these conclusions.

In recent years, experts from the Commission for Preservation of National Monuments and experts from the German institute LGA Nürnberg have studied the Old Bridge. Unfortunately, there is still no exact diagnosis.

3. CONCLUSIONS

The analyzed freshwater limestones are similar to each other, but still different, from the "stone twins" tenelija and *(Mostar) miljevina*, which are different from each other, their "stone cousins" *Posušje miljevina* and *Tomislavgrad muljika*, to *muljika* and *miljevina* from other parts of BiH. In the process of diagenesis they acquired a specific orientation and structure (especially *tenelija*), which gave them specific physical properties (small bulk density, high porosity and permeability), which "classic" limestones used in construction do not have, and which were decisive for the choice of this stone for construction of the Old Bridge and other buildings in the wider area of Mostar and in the area of Posušje municipality, but also in other karst poljes of Herzegovina and southwestern Bosnia (Tomislavgrad, Livno, Glamoč), parts of Central Bosnia (Jajce, Bugojno, Gračanica and Travnik), and Miljevina near Foča.

Freshwater limestones are incorporated in numerous stone buildings and/or monuments, where complex processes of changes, or weathering (degradation) of stone occur as a result of its interaction with various environmental conditions (external factors).

In addition to the genetic and postgenetic processes that freshwater limestones have undergone, their durability is also affected by the so-called incorporated (internal) factors that the builders try to avoid, from those in the choice of stone, the method and (often too small) depth of its extraction from the deposit for construction of significant buildings, insufficiently long aging (storage) after extraction, improper installation (stacking) of stone in relation to its position in the deposit, to various mistakes in stone processing and execution, with inadequate maintenance.

Old builders used local types of freshwater limestones in construction, knowing exactly their possibilities and advantages related to the exceptionally easy processing and realization of more delicate buildings, but also limitations related to considerable to high porosity, small bulk density, high water absorption, relatively low strength, poor resistance to wear and questionable resistance to frost. In principle, they correspond to the climatic characteristics of the area where their deposits are located, and have been used as such since ancient times, with all good and less good properties.

We conclude with Tamara Plastić's brilliant thoughts that "*building with stone requires a special sensibility in its application, to which the stone responds by lasting for centuries*", and that "*there is a perception of stone as being eternal, maybe because buildings from the distant past leave us such an image, but stone is such only when due attention and respect are devoted to it*", [17].

REFERENCES

1. Čičić, S. (1998): „Karbonatne facije u geološkoj građi terena Bosne i Hercegovine“, „Naš krš“, XVIII, broj 31, str. 3-37
2. Hrvatović, H, Dragičević, I. (2010): „Zeničko-sarajevski neogenski bazen - Lašvanski konglomerati“, 4. Hrvatski geološki kongres, Šibenik

3. Hrvatović, H. (2006): "Geological guidebook through Bosnia and Herzegovina", Geological Survey of Federation Bosnia and Herzegovina, Sarajevo
4. Bilopavlović, V. (2017): "Ukrasni kamen u Hercegovini/popularizacija poduzetništva i obrade kamena", Građevinski fakultet Sveučilišta u Mostaru
5. „Elaborat o klasifikaciji, kategorizaciji i proračunu zaliha arhitektonsko-građevnog kamena oolitičnog vapnenca (tenelije i miljevine) na istražnom prostoru „Mukoša" u Mostarskom polju", „DENT" Istraživanje, eksploatacija i obrada kamena, Mostar, 1998
6. Šaravanja, K. (2020): „Slatkovodni vapnenci neogene starosti, s posebnim osvrtom na arhitektonsko-građevinsku vrijednost i trajnost kamena miljevina (muljika)", Doktorska disertacija, str. 1-253, Građevinski fakultet Univerziteta u Sarajevu, XII. 2020
7. Šaravanja, K., Hajdarević, I., Kurtović, A., Šerifović, E. (2017): „Građenje bosanskim slatkovodnim vapnencima - Bihacit, Plivit i (Bosanska) Mošćanica", Zbornik broj 4 Udruge „Zvuk kamena", str. 46-58, Posušje, XII. 2017
8. Šaravanja, K. (2017): „Gradnja kamenom u BiH s posebnim osvrtom na arhitektonsko-konstruktivne vrijednosti kamena tenelija i miljevina/muljika", „e-Zbornik" Elektronički zbornik Građevinskog fakulteta Sveučilišta u Mostaru, broj 13, str. 12-29, VI. 2017. Reprint:http://www.cidom.org/wp-content/uploads/2017/07/Kre%C5%A1imir-%C5%A0aravanja-Gradnja-kamenom-u-BiH-s-posebnim-osvrtom.pdf
9. „Pilot Cultural Heritage Project: Reconstruction of the Old Bridge over the Neretva in Mostar, Laboratory testing of ancient and new building materials; Sampling and testing of Stones (Ancient and new Stones)", LGA - Geotechnical Institute - Historical Bridges Group, Nürnberg, 26.01.2001
10. Zvonić, Z. (2000): „Tenelija - kamen Mostara", Časopis „Most", godina XXVI., broj 130 (41 - nova serija), Mostar, IX. 2000
11. Nametak, A. (1939): „Islamski kulturni spomenici turskog perioda u Bosni i Hercegovini", Sarajevo
12. Mandžić, K. (2006): „Inžinjerskogeološka i geotehnička svojstva kamena Tenelija", magistarski rad, Rudarsko-geološko-građevinski fakultet u Tuzli, IV. 2006.
13. Oreč, F., Bilopavlović, V. (2011): „Arhitektonske vrijednosti miljevine", Zbornik 1 Udruge „Zvuk kamena", str. 46-55, Posušje, XII. 2011
14. Aladuz, V. (2019): „Stari bosanski nišani općine Hadžići", Hadžići, II. 2019
15. Cultrone, G., Luque, A., Sebastián, E. (2012): „Petrophysical and durability tests on sedimentary stones to evaluate their quality as building materials", Quarterly Journal of Engineering Geology and Hydrogeology, Vol. 45, pp. 415-422
16. Stambolou, T. (1970): „Conservation of Stone", pp. 119-124, in reference 19. „Conservation of New Stone and Wooden Objects", New York Conference, VI. 1970 (The International Institute for Conservation of Historic and Artistic Works, London)
17. Plastić, T. (2019): „Utjecaj sazrijevanja kamena na njegove fizičko-mehaničke karakteristike i dugotrajnost nakon ugradnje", „Klesarstvo i graditeljstvo", str. 109-126
18. Sunara, S. M., Barišić, M. (2009): „Utjecaj okoliša i drugi utjecaji na žbuke i kamen", „IN SITU" on line časopis za konzervaciju i restauraciju, Umjetnička akademija Sveučilišta u Splitu, Split, http://www.e-insitu.com/images/stories/Pdf/s_b-okolis.pdf
19. „Elaborat konzervatorsko-restauratorskih istraživanja pročelja zvonika i zapadnog pročelja franjevačke crkve sv. Petra i Pavla, Gorica - Livno", Hrvatski restauratorski zavod Služba za nepokretnu baštinu, Zagreb, 2011
20. Radnić, J., Harapin, A., Smilović, M., Grgić, N., Glibić, M.: „Statička i dinamička analiza Starog kamenog mosta u Mostaru", „Građevinar", Vol. 64, No. 08, Zagreb, 2012
21. Kršinić, A., Tomašić, I. (2009): „Utjecaj pigmenata i primjesa na postojanost boje i dekorativnost prirodnog kamena", Časopis Klesarstvo i graditeljstvo, str. 77-86
22. Turkington, A.V. (1996): "Stone durability", In: Smith, B.J., Warke, P.A. (Eds.), Processes of Urban Stone Decay, Donhead Publishers, London, pp. 19-31

23. Pletikosi, L. „Primjena kamena u graditeljstvu“, https://bib.irb.hr/datoteka/
24. Smith, B.J., Viles, H. (2006): „Rapid, catastrophic decay of building limestones: Thoughts on causes, effects and consequences“, In: Fort, R., M. Alvarez de Buego, M. Gomez-Heras, C. VazquezCalvo (Eds): Heritage weathering and conservation
25. Idrizbegović Zgonić, A. (2011): „Mostar city icons - an insider's view paper for: TTEM Technics Technologies Education Management Mostar city icons - an insider's view Karadjozbeg mosque and Old bridge complex“, Technics Technologies Education Management-TTEM, Vol. 6, Issue 1, p. 40-51
26. Crnković, B., Šarić, Lj. (2003): „Građenje prirodnim kamenom“, „IGH“, Zagreb
27. Cultrone, G., Luque, A., Sebastián, E. (2012): „Petrophysical and durability tests on sedimentary stones to evaluate their quality as building materials“, Quarterly Journal of Engineering Geology and Hydrogeology, Vol. 45, pp. 415-422
28. Stambolou, T. (1970): „Conservation of Stone“, pp. 119-124, in reference 19. „Conservation of New Stone and Wooden Objects“, New York Conference, VI. 1970 (The International Institute for Conservation of Historic and Artistic Works, London)
29. „Livno Gorica, elaborat konzervatorsko-restauratorskih istraživanja pročelja zvonika i zapadnog pročelja franjevačke crkve sv. Petra i Pavla“, Hrvatski restauratorski zavod, Zagreb, 2011
30. Marcus Vitruvius Pollio: “De architectura libri decem” ili na hrvatskom prijevodu “Deset knjiga o arhitekturi”, Golden marketing i Institut građevinarstva Hrvatske, Zagreb, 1999