Krisztina FEHÉR, Imre TAKÁCS, Ákos TÖRÖK*

STONE MATERIALS OF THE LATE TWELFTH-CENTURY INCRUSTATION WORKS OF ESZTERGOM

Abstract: The paper deals with the material analysis of four emblematic stone fragments from Saint Adalbert Cathedral and the Royal Palace of Esztergom from King Béla III's era. All of the four examined objects (two fragments from the *Porta speciosa* and two throne arm-rests) have incrustations with red limestone basement and other colourful stone pieces. As red limestone is a well-known material in Hungarian art history with a rich historiography, the paper focuses on the findings of the analyses of other stone materials of the incrustations. The research contains several non-destructive analytical methods, such as relative humidity measurement, macroscopic and microscopic photography and X-ray fluorescence with lithologic description. Besides the comparative analysis of the stone materials, archive documents, the current state and the impacts of subsequent restorations of the four stone artefacts were also studied.
Keywords: Esztergom, *Porta speciosa,* incrustation, opus sectile, mineral analysis, stone material

I. INTRODUCTION

Saint Adalbert Cathedral and the medieval Royal Castle of Esztergom were undoubtedly the most prestigious buildings in medieval Hungary at their time, especially at the end of the twelfth century after King Béla III's constructions.

These buildings were particularly characterised by the use of local cemented red limestone referred to as marble in medieval texts and often in modern parlance, which had begun to be quarried at that time. The first known mention of the red marble covering of the cathedral walls comes from the description of the siege of Esztergom in 1543.[1] Remains of similar "marble" coverings – i.e. the application of thin polished red marble slabs on grey limestone walls – can still be seen in the side room of the late twelfth-century chapel connected to the royal palace.[2]

From the last decades of the twelfth century an especially elegant stone decoration technic was applied: the polychrome or bichrome incrustation and the opus sectile. Both technics were popular for ornamental surface (wall, floor, furniture, etc.) covering in the ancient Roman Empire and later in the Byzantium, where Béla III spent his early years, but were also known, especially from the twelfth century in Italy and Provence.[3] Works produced by incrustation are decorative (geometric or figural) compositions of stone or glass pieces of different colours placed in carved recesses. The plastic filling of carved recesses in different colours was also widely used to decorate

* Krisztina Fehér, Department of History of Architecture and Monument Preservation, Faculty of Architecture, Budapest University of Technology and Economics; Műegyetem rkp. 3, H-1111 Budapest, Hungary; feher.krisztina@epk.bme.hu, https://orcid.org/0000-0001-9739-2159
Imre Takács, Institute of Art History, Faculty of Humaities. Eötvös Loránd University, Múzeum krt. 6–8, H-1088 Budapest, Hungary; takacs.imre.2014@gmail.com
Ákos Török, Department of Engineering Geology and Geotechnics, Faculty of Civil Engineering, Budapest University of Technology and Economics; Műegyetem rkp. 3, H-1111 Budapest, Hungary; torok.akos@emk.bme.hu, https://orcid.org/0000-0002-5394-4510
Received: 14 October 2022 • Accepted: 29 October 2022

stone carvings. In Esztergom, several details from the *Porta speciosa* and two arms of a throne, as well as several fragments of unidentified origin, have survived that show the technique of stone incrustation. Each has a red limestone base with carved recesses for the stone inlays. The opus sectile technique is represented mainly by the remains of colour floor coverings composed of geometric elements.

In the current paper four incrusted monuments are to be examined with material analysis. The incrusted pieces are the so-called Deësis tympanum presumably from the *Porta speciosa* (PS-1), the fragment with Daniel the Prophet's head from the *Porta speciosa* (PS-2), the two throne arm-rests with figurative decoration (T-1 and T-2) (*Fig. 1 a–d*). The iconographical aspect and historical significance of these artefacts have been described earlier.[4] There is no doubt that the western gate of the cathedral, with its inlaid images, was built in the last decade of the twelfth century. The art-historical evaluation of its images is influenced not only by their closest antecedents in northern Italy, but also by considerations that, in the context of certain iconographic formulas, such as the Deësis tympanum, have raised the possibility of direct Byzantine connections.[5] The style of the images of the throne, made of the same materials as the gate and technically close, is characteristically different. The difference can certainly be explained by the fact that the technical knowledge of the workshop became an integral part of the artistic tradition of Esztergom after the completion of the gate, around 1200 and later in the first decades of the thirteenth century.[6]

The role of 'red marble' in Esztergom and Hungarian history of art and architecture were examined by Pál Lővei, with a special interdisciplinary approach towards the stone material and the historical stone quarries.[7] The high standard petrological analysis of medieval red limestone monuments, including one fragment from the *Porta speciosa* of Esztergom, was also

Fig. 1. The four examined incrusted monuments: a) Deësis tympanum (PS-1), b) the fragment with Daniel the Prophet's head from the Porta Speciosa (PS-2), c) throne arm-rest with man pruning grape (T-2), d) throne arm-rest with Hermes's silhouette (T-2)

carried out some years ago.[8] Lővei has emphasised the importance of such scientific analyses in the historical research of stone monuments, adding that “It would be similarly interesting to learn more about the not red materials of inlaid carvings in Esztergom.”[9] and “Besides the examination of stone materials it would be necessary to analyse such »subsidiary« materials as various pastes intensifying stone colours for filling engraved lines, or the adhesive and filling materials for inlaying coloured stones in the basement.”[10]

In accordance with Lővei’s remark, the aim of the current paper is the material analysis of the various stone inlays applied in the selected monuments of Esztergom. The purpose is to identify, describe and compare the petrological features of the different stone types, and to outline their possible provenance. Besides this, the scientific description of the artefacts’ technical state was also a part of the study in order to identify signs and materials applied at prior restorations.[11]

II. RESEARCH METHODOLOGY

As the examined objects are precious and unique remains from the incrustations of the archiepiscopal and royal centre of Esztergom, their destructive analysis was not possible. All the objects have so delicate features (reduced dimensions, sophisticated details), that no sample could be collected without the fatal deterioration. Without sample collection, the range of results were certainly limited, but significant results could be achieved with a series of non-destructive examination technics.

The four examined elements are exhibited in the Castle Museum of Esztergom, where the stone materials were analysed. They were described according to *MSZ EN 12670:2001*[12] and *MSZ EN 12407:2000*[13] standards. On the site macroscopic and microscopic photographs were taken for identifying the texture features of the stone inlays. For the microscopic images a portable [TOOLCRAFT USB] microscope with a magnifying rate of 200 was applied. As another non-destructive method the relative humidity of the objects was measured with a GANN Hydromette UNI-1 type tool equipped with B 50 probe *(Fig. 2 a)*. Relative humidity of the different stone materials provides information about their physical features. For a more exact result relative humidity values were measured on several points of material surfaces. For mineralogical composition analysis, a portable Olympus Delta X equipment was used *(Fig. 2 b)*. This tool works by X-ray fluores-

a) b)

Fig. 2. Non-destructive measurement tools applied for the research.
a) relative humidity, b) portable elemental composition analysis with Olympus Delta XRF

cence (XRF) measurement principle, which allows to identify elemental composition of materials. Before the measurements, the equipment was calibrated with a standard. The measured data was subsequently processed and evaluated with regards of the results of the other analysing tools. Finally, for a more precise understanding of the history of the incrusted monuments, the evaluation of the scientific measurement results was complemented with the study of archive photographs as well.

III. ANALYSED OBJECTS

PS-1: Deësis tympanum

The Deësis tympanum is a well-known object of medieval Hungarian art history.[14] It is a red limestone tympanum of segment circle form, representing the Deësis *(Fig. 1 a)*. Originally it was located at the back of the *Porta speciosa*, facing the interior of the church.[15] In 1759, György Széless found it lying face down by the western wall of the cathedral.[16] According to a description by János Mathes in 1827, the tympanum was rediscovered in 1822 in the foundations of the Calvary built in the second half of the eighteenth century on the site of the choir of St Adalbert's Cathedral.[17] Before its present position in the Esztergom Castle Museum interior, it has been stocked in the castle courtyard exposed to weather and humidity for a long time. As far as we know, no restoration works have been done so far. It is currently exhibited on wooden stands in the longue of the Castle Museum. The monolith red limestone represents the basement with 1-3 cm deep

Table 1. Basic data of the four examined fragments

Object code	Short description	Technic	Materials and state	Location
PS-1	Deësis tympanum, presumably from the Porta Speciosa	incrustation	Basement: red limestone, segmented circle basement (subsequently modified) Inlays: three types of white stone: skin surfaces, Christ's throne seat and book, the seraphim's underwings, Saint John the Baptist's tunic; black stone for the background: only two tiny pieces remained among the seraphim's wings	Esztergom Castle Museum interior, lounge, on wooden stand
PS-2	Fragment from the Porta Speciosa representing Daniel the Prophet's face	incrustation	Basement: red limestone (fragmented) Inlays: white marble (the Prophet's face); green stone (tefillin)	Esztergom Castle Museum interior, exhibition room, on the wall by metal hangs
T-1	Throne arm-rest fragment with man pruning grape	incrustation	Basement: red limestone (fragmented) Inlays: white stone (skin surfaces, parts of the grape); black stone for the background (some pieces are missing)	Esztergom Castle Museum interior, gallery of the festive hall, framed in a reconstructed artificial stone throne
T-2	Throne arm-rest fragment with Hermes's silhouette	incrustation	Basement: red limestone (fragmented) with the engraved silhouette of a standing figure Inlays: white rhombus shape decoration on the front edge	Esztergom Castle Museum interior, gallery of the festive hall, framed in a reconstructed artificial stone throne

engraved cells for the stone inlays. The plasticity of the figures was expressed with carefully drawn lines deepened in the flat upper surface. The tympanum had a rich and colourful incrusted composition of various stone inlays. In its present state, most of the inlays have been lost, but at the time of Széless's descriptions of 1759 and 1761, it was less incomplete. In the Deësis composition, the faces, arms and hands of the figures (Christ, the Virgin Mary, John the Baptist and the seraphs) are made of white stones. The seraphs' lower wings, Christ's throne and the book are also inlaid in white. The figure of John the Baptist has two white insets from his tunic: one on his chest and one on the sleeve of his dress. The latter has a greyer colour. The background of the composition is made of black stone, according to the two tiny fragments remaining between the two seraphs' wings (see *Table 1*).

PS-2: Fragment from the jamb of the Porta speciosa representing Daniel the Prophet's face[18]

The fragment depicting the prophet Daniel was in the right-hand niche of the *Porta speciosa*. Since the nineteenth century it has been kept in the Cathedral collection.[19] The basement for the inlays is red limestone *(Fig 1 b)*. Now, only the Prophet's face and the kipa covering his head remain from the original full-length portrait. According to Farkas Pintér and Bernadett Bajnóczi's results,[20] who examined another jamb fragment of the *Porta speciosa* (the one representing John the Apostle), it can be stated with no doubt that the red limestone is from the Tardos stone quarry near to Esztergom.[21] Daniel's face is made of white marble, the inlay of the tefillin worn on top of the kipa is green stone. The whole composition is completely flat, carefully sculpted and marked with lines. The fragment is exhibited in the heated inner hall of the Castle Museum (see *Table 1*).

T-1: Throne arm-rest fragment with man pruning grape

Similarly to PS-1 and PS-2 objects, the basement of the arm-rest is a red limestone plate with engraved cells. The fragmentary composition consists of a tree, a vine rich in tendrils and bunches, a standing man pruning the vine, and a small detail of another figure holding a bow in his hand. All the grapevine and the parts of the men's body are white stone inlays. The tree, the standing man's clothe, the fragmented bow and the frame of the composition are carved from the basement's red limestone *(Fig. 1 c, Table 1)*. The background is made of black stone pieces. The engraved recesses of the basement are cca. 10-15 mm deep. The inlays are cca. 5 mm thick. According to György Széless's description from 1759, that time the arm-rest fragment used to be in the castle walls near to the Cat-gateway (*Macskakapu*).[22] According to the oldest known photograph of the arm-rest from 1901, there used to be more inlays at the lower part representing more grape tendrils and clusters, and another man (or centaur[23]) stretching a bow with one of his arms.[24] The fragment is currently framed in an artificial stone throne reconstruction, together with the arm-rest fragment T-2.

T-2: Throne arm-rest fragment with the silhouette of a standing figure

Arm-rest fragment of red limestone basement framed in an artificial stone throne reconstruction together with fragment T-1. For the main figure a cca. 15 mm deep cell is engraved in the basement with the form of a standing man carrying a wand with badges.[25] The cell of the latter is only a few mm deep. It probably could have paste filling. Stone or metal inlays here are less likely.[26] The Roman abbreviation GPR is carved below the man's feet, who can be identified as a Roman signifier or Hermes.[27] All these inlays are lost, but a significant amount of original adhesive has remained in their cells. After János Mathes's description, the fragment was found in the area of the castle before 1827.[28] The upper circular edge of the arm-rest is carved with profile. The front edge has polygonal profile decorated with white rhombus shaped stone inlays *(Fig. 1 d)*. The majority of these inlays are also lost, only some of them have remained (see *Table 1*).

IV. RESULTS

PS-1

The microcrystalline, prevailingly micritic limestone of the Deësis tympanum is very similar to the Tardos red limestone from Gerecse Mountains, traditionally called 'red marble'.[29] The dark inlays are black coloured microcrystalline cemented limestone with very low porosity. Typical feature of this lithotype is the presence of thin white-to yellowish calcite veins. The majority of the inlays are light coloured marbles. After the X-ray fluorescence measurements *(Fig. 3)*, several types could be distinguished by their textural characteristics and element composition. Three types are identified:

- White marble 1: coarse grained greyish white marble with non-uniform crystal size and xenoblastic micro-fabric,
- White marble 2: fine crystalline slightly yellowish, greyish white marble with colour bands, and
- White marble 3: greyish white slightly pinkish fine crystalline marble with slight mottling. The granoblastic micro-fabric and veins characterize this lithotype.

According to the measurements, the two inlays of Saint John's tunic are significantly different. White marble 2 (the tunic sleeve) contains aluminium, thus the material contains clay minerals or clay inclusions. It is less likely that the aluminium remains from subsequent Baroque mortar. White marble 3 (the tunic on John's chest) has higher sulphur content (see *Table 2*).

It is important to note that a significant amount of subsequent mortar was found on mainly each measured spot. This can be explained by the circumstance, that the tympanum was built in the foundation of the Calvary for a half century till 1822.[30] The inlay of Saint John the Baptist's tunic on his chest (white marble 3) contains nearly ten times more sulphur than the rest of the tested marbles. This could be the trace of a subsequent restoration, but it is more probably the gypsum from the eighteenth-century mortar.

PS-2

The basement of the fragment with Daniel the Prophet's head is microcrystalline red limestone from the Tardos quarry (Gerecse Mountains).[31] The inlay of the prophet's face is yellowish white prevailingly medium grained, but not homogeneous marble. Its surface is nearly flat, which suggests that either surface weathering was not significant or later its surface was flattened (restored). The material of the tefillin is green serpentinite that has a typical fibrous micro-structure. The serpentinite is lighter green in colour than most common dark green serpentinites. The serpentinite of the tefillin has a white inclusion, which is considered as a natural phenomenon, rather than a later incrusta-

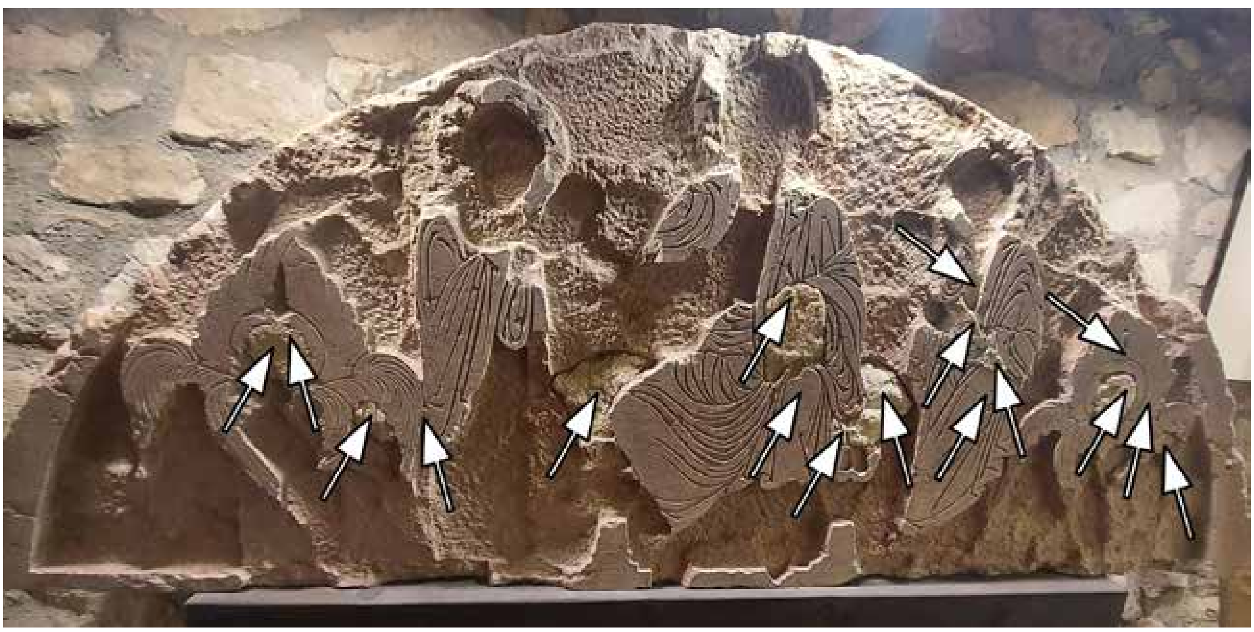

Fig. 3. X-ray fluorescence (XRF) measurement points on the Deësis tympanum (PS-1)

Table 2. Fragment PS-1, material analysis and measurement results

Material	Description of features	Measured spots	Element composition
Red limestone	Microcrystalline highly cemented red limestone. The surface of the stone is slightly dissolved. At parts small pits were formed on the surface, which is clearly visible on Saint John's figure. At some places grey surface coatings are visible, that show small scales. The red limestone surface shows toolmarks of chisel. These toolmarks are considered fairly recent, due to their fresh unaltered surface. Hence these are not Medieval traces, rather marking modern time interventions.	Flat polished surfaces on the seraphim's wings, on Saint John the Baptist's coat, on Christ's knee, and engraved surface on Saint John the Baptist's chest.	Si 2.14 w% S 0.0508 w% K 0.1947 w% Fe 0.4214 w% Sr 0.0132 w% Cl 0.2812 w% Mn 0.0457 w% P 0.48 w% Ca 52.54 w% LE 43.78 w%
White 1	Greyish-white marble. Medium-grained granoblastic, xenoblastic texture with slightly polygonal crystal borders. At one of the measuring points, its surface is strongly weathered and shows dissolution features. At some places, its texture has coarse crystals, and it is strongly xenoblastic, where the crystal boundaries are zigzaggy. The size of the crystals can vary from very coarse to fine.	Inlays under the seraphim's wings. Skin surfaces on the seraphim's face, Christ's and Saint John the Baptist's hand. Seat cushion of Christ's throne	Si 3.87 w% S 0.3441 w% K 0.2016 w% Fe 0.4114 w% Sr 0.0372 w% Cl 0.3217 w% Ca 50.76 w% LE 44.02 w%
White 2	Greyish, slightly yellowish-pink, mottled stone, fine crystalline marble. Its texture has some calcite veins and a typical granoblastic type. The material is not identical with white marble 1.	Inlays of Saint John the Baptist's tunic sleeve	Si 4.38 w% S 0.1562 w% K 0.4787 w% Fe 0.6063 w% Sr 0.1184 w% Cl 0.3803 w% Al 2.74 w% Ca 48.55 w% LE 42.58 w%
White 3	White marble with finer-grained, more homogeneous texture than white marble 1. Fine-grained material with little yellowish discoloration and with granoblastic texture.	Inlays of Saint John the Baptist's tunic on his chest	Si 2.64 w% S 2.4115 w% K 0.5672 w% Fe 0.3720 w% Sr 0.1314 w% Cl 0.41 w% Ca 36.79 w% LE 56.68 w%
Black	Based on its texture, it is a cemented low porosity crystalline limestone: a carbonate, rather than basalt. Between Maria and the seraph, a few light calcite flakes also appear.	Background elements between the seraphim's wings, and between Mary and Saint John	Si 2.60 w% S 0.0742 w% K 0.2607 w% Fe 0.3560 w% Sr 0.1920 w% Cl 0.6678 w% P 0.46 w% Ca 51.59 w% LE 43.79 w%

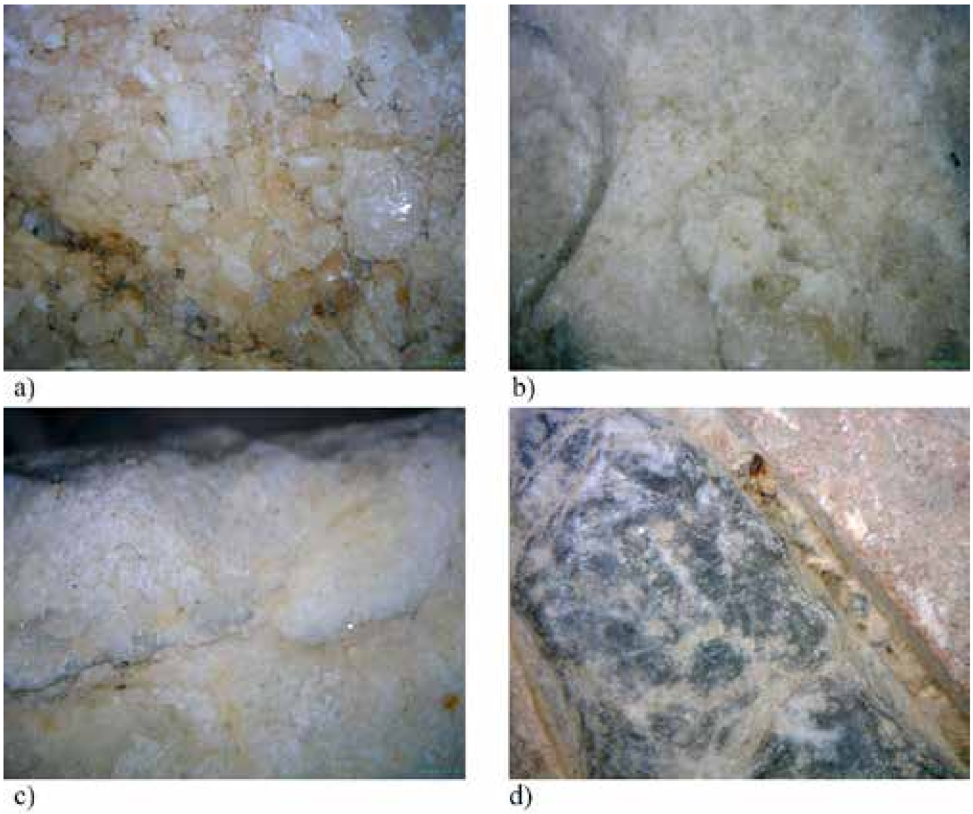

Fig. 4. Microscopic images of PS-1: a) white marble 1, b) white marble 2 from St John the Baptist's tunic sleeve, c) white marble 3 from St John the Baptist's tunic on his chest, d) black inlay between a seraph's wings

Fig. 5. Microscopic images of PS-2: a) white marble of the face, b) green serpentine of the tefillin, c) white inclusion in the serpentine of the tefillin

Fig. 6. Microscopic images of T-1: a) white marble, b) background inlay with neighbouring stones, c) crack in the black background

Table 3. Fragment PS-2, material analysis and measurement results

Material	Description of features	Measured points	Element composition
Red limestone	Flat polished part of the red marble basement. Micro-crystalline dense cemented type limestone. It is similar to the Jurassic Tardos red limestone. It has some tiny bioclast fragments.	Flat polished surface on the upper part of the basement	Si 1.20 w% S 0.1066 w% K 0.1410 w% Fe 0.2718 w% Sr 0.0176 w% Mn 0.0252 w% Ca 51.71 w% LE 46.47 w%
White	White xenoblastic marble with medium crystal size. The crystal size is not uniform. Its surface shows some traces of weathering.	Daniel the Prophet's face	Si 0.65 w% S 0.1161 w% K 0.0645 w% Fe 0.0977 w% Sr 0.0158 w% Ca 54.15 w% LE 44.89 w%
Green	The green inlay of the tefillin is serpentinite dominated by green fibrous serpentine. The serpentinite crystals have a well developed crystallisation pattern, namely crystal groups re arranged in a radial from within a white inclusion. A less geometric arrangement of green serpentinite crystals also occurs. Besides serpentine needles, there are also black blocky crystals, which are considered pyroxene.	Daniel the Prophet's tefillin: green part and white inclusion	Si 13.74 w% S 0.1468 w% K 0.0735 w% Fe 1.7656 w% Sr 0.0159 w% Cl 0.1561 w% Mn 0.0425 w% P 0.42 w% Cr 0.0229 w% Ni 0.0438 w% Cu 0.0074 w% Zn 0.0081 w% Ca 27.64 w% LE 55.90 w%

tion. The binder of the marble and the serpentinite is a coloured (pigmented) reddish restoration render that is believed to be a product of a recent restoration of the twentieth century. The red colour is related to haematite pigment.

T-1

The stone material of the throne arm-rest is red crystalline massive limestone, which most probably originated from Tardos (Gerecse Mountains, Hungary). Certain incrustations are composed of black microcrystalline massive limestone. The material of the black limestone inlays is not clearly identical. In some of the inclusions, black limestone with a homogeneous texture is present, while in others, black limestone with a few fossils (very small shell fragments) and calcite spheres are visible. Some of the black limestone incrustations have calcite veins, and some contain yellowish mottles. Tiny grooves, scratches and signs of mechanical damage are clearly visible on the surface of the black limestone incrustations. The white inlays are composed of fine crystalline marble, with the surface slightly rebounded in several places (see *Table 4*).

The arm-rest fragment has the most signs of subsequent restorations and fractures among the four examined monuments. Fortunately, there are some archive photographs that can explain subsequent materials and cracks. The oldest one is from 1901, showing a more complete composition with a second man stretching a bow[32] *(Fig. 7 a)*. By 1914, some of these lower inlays were already lost, but there were still more than today: a bunch of grapes, a leaf and one more black background inlay below the bow were still

Table 4. Fragment T-1, material analysis and measurement results

Material	Description of features	Measured points	Element composition
Red	Flat polished limestone with similar features to the basements of PS-1, PS-2, and T-2.	There was no measurement.	–
White	White, fine crystalline marble. It has a granoblastic texture. Its surface is slightly dissolved. It has a crack, which was subsequently repaired. Sporadically it also has light-coloured (white or ochre) calcite vein of natural origin.	Grape tendril	Si 1.01 w% S 0.7064 w% K 0.1115 w% Fe 0.1031 w% Sr 0.0546 w% Cl 0.3941 w% Ca 53.30 w% LE 44.30 w%
Black	Black, relatively homogeneous, microcrystalline, strongly cemented limestone. Its texture is relatively homogeneous. There are scratch marks on its surface with grooves indicating mechanical effects.	Background element next to the trunk of the tree	Si 0.81 w% S 0.1124 w% K 0.0854 w% Fe 0.1172 w% Sr 0.0354 w% Mn 0.0865 w% Ca 53.19 w% LE 45.55 w%

at their place[33] *(Fig. 7 b)*. By 1937, these latter inlays were gone too. In a photo from 1937, it is clear, that a thick substitution was slushed on the contour of the remaining part below *(Fig. 7 c)*. The next photo was taken in 1971, when the substituted contour is missing, and the composition is the same as today *(Fig. 7 d)*. The arm-rest was completed with its lower part and was exposed in standing position. The current artificial stone reconstruction of the throne was created later *(Fig. 7 e)*.

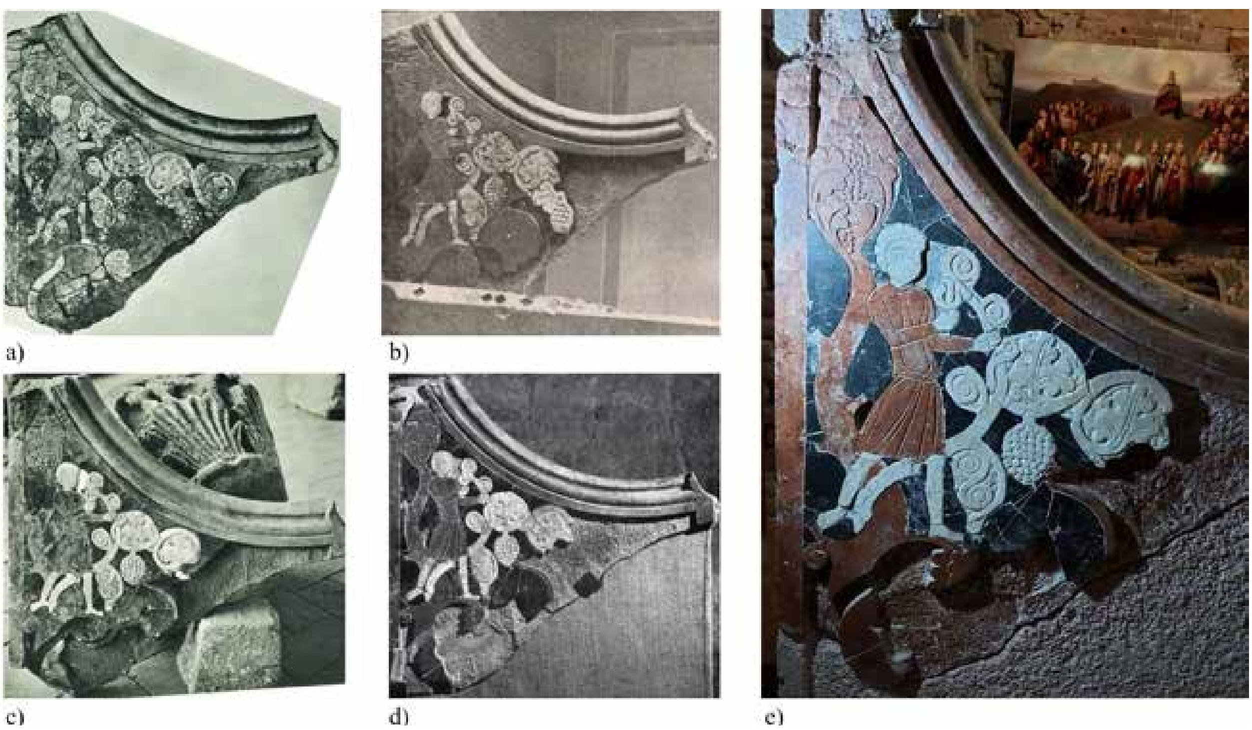

Fig. 7. Sequence of archive photos of the arm-rest fragment with man pruning grape (T-1): a) 1901, b) 1914, c) 1937, d) 1971, e) state in 2020

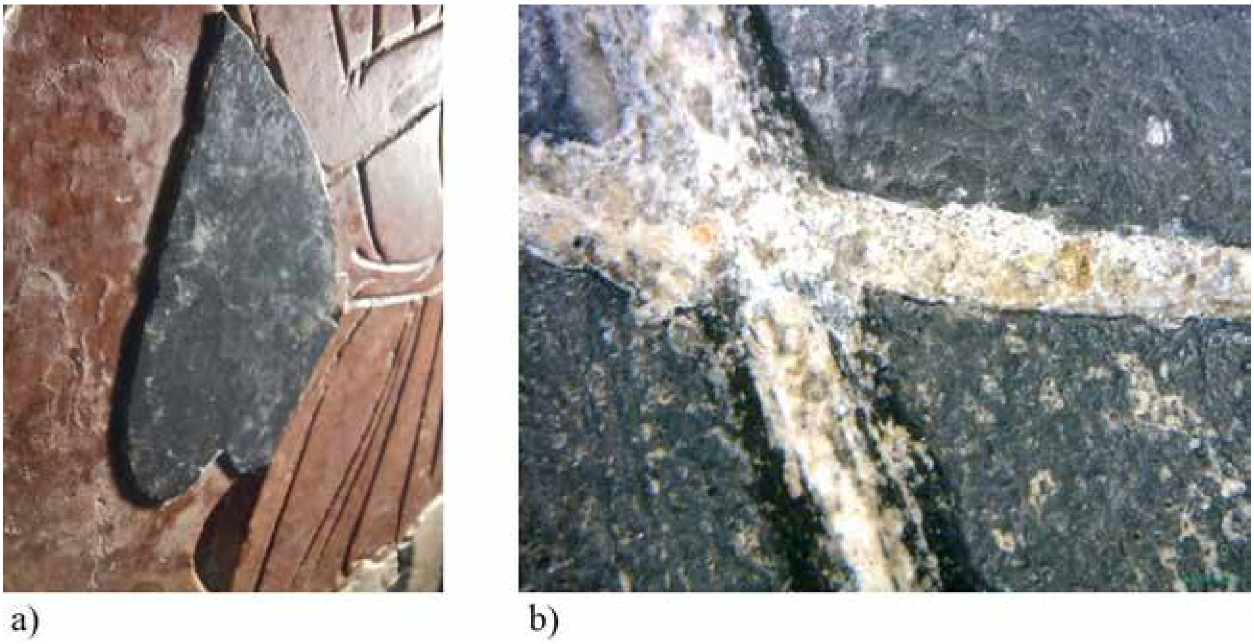

Fig. 8. a) higher – probably subsequently stuck inlay in fragment T-1, b) microscopic image of black inlays with ruptures, the vertical line is the chord of the bow, while the horizontal one is a natural rupture

By the closer examination of the arm-rest fragment T-1, the inlays seem to be stuck in the basement subsequently. Several clues support this assumption. Some black inlays are higher than the whole composition's surface *(Fig. 8 a)*. The inlays are often broken within the same field *(Fig. 8 b)*. The sequence of archive photos showing less and less part of the image prove, that the inlays must have been loose, especially in the lower zone of the fragment. An interesting detail in the 1901 photo suggests, that some inlays could fall out from the basement, and they could be reassembled. There is a background piece in a wrong place, namely a triangular black inlay under the second man's hand stretching the bow, that would belong to the empty hole with the same shape above the vines and under the curved edge *(Fig. 9)*.

The arm-rest was built in the castle wall, that could harm the inlays and their cohesion with the basement.

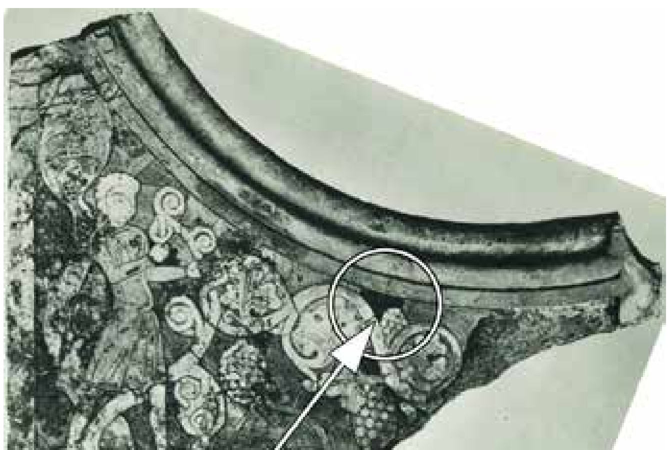

Fig. 9. An inlay at a wrong place in 1901 (photo: Magyar Építészeti Múzeum – Műemlékvédelmi Dokumentációs Központ / Hungarian Museum of Architecture and Monument Protection Documentation Centre, Budapest, Fotótár, 027.501N)

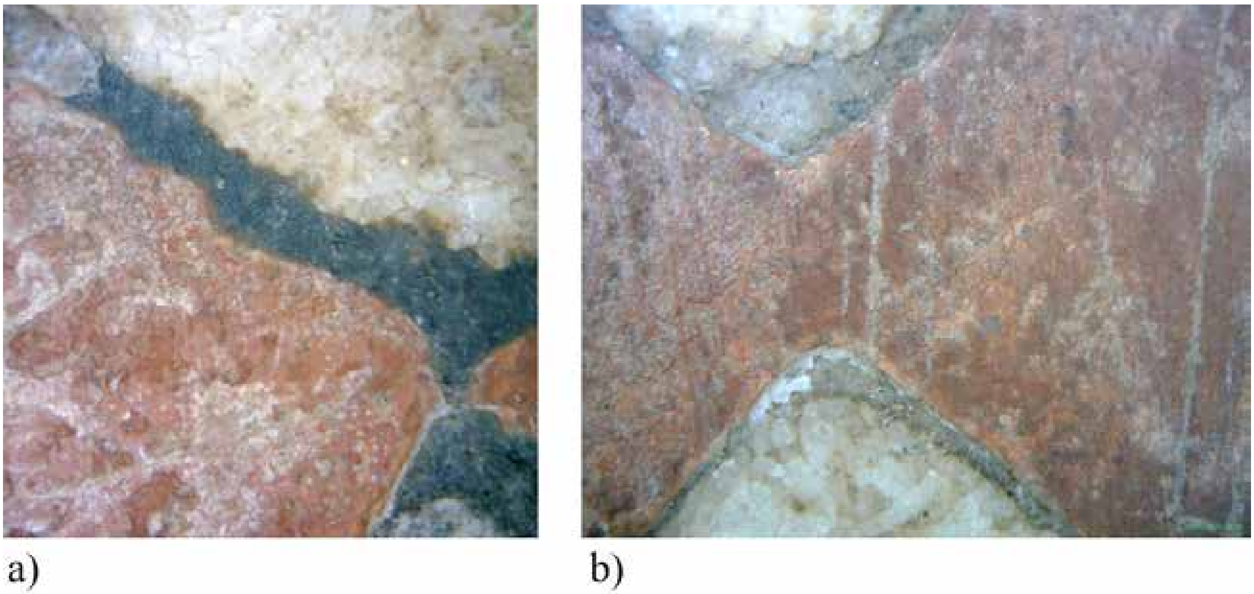

Fig. 10. Microscopic images of T-2: a-b) white rhombus inlays in the red limestone basement

However, the cracks of the inlays do not necessarily mean the complete re-assembly of the whole puzzle. In opus sectile and incrusted monuments, fields often consist of broken stone mosaic pieces.[34] Taking all into consideration, it is most likely that the majority of the inlays are in their original place with the original adhesive underneath, but some of them were loose and stuck back later.

T-2

The throne arm-rest fragment with standing figure is also made of Tardos-type red cemented limestone. On the red limestone surface, a small area of the incised parts (e.g. at the foot of the human figure) is covered with black organic matter-rich material. Probably black organic resin-like adhesive material. Besides the

Table 5. Fragment T-2, material analysis and measurement results

Material	Description of features	Measured points	Element composition
Red limestone	Tardos-type microcrystalline dense red limestone, with small fossils in it. There are scratches on its surface and a small indentation, in which small patches of lime remnants are visible.	Flat polished surface of red limestone basement	Al 2.77 w% Si 5.11 w% S 2.4064 w% Cl 0.4169 w% K 0.7917 w% Ca 47.16 w% Mn 0.0518 w% Fe 0.7222 w% Sr 0.0151 w% LE 40.53 w%
White	Yellowish-white, finely crystalline marble. Its texture is granoblastic, in some places it already has homoblastic texture. Its surface is slightly dissolved and shows some surface decay.	White marble rhombus shape inlays on the front edge of the arm-rest	Si 1.90 w% S 2.0225 w% K 0.1726 w% Ca 53.48 w% Fe 0.1355 w% Sr 0.1004 w% LE 42.17 w%

figure's incised cell, this material is also present as an adhesive below and in between at some of the rhomboidal incrustations. This is considered to be the original material, but it is also possible to discover that a grey, slightly cementitious patching material has been used to patch the areas where this adhesive material was missing. Where the original marble rhombus has fallen out and has not been replaced, this black organic adhesive material, which is considered to be original, can still be found in several places at the bottom of visible indentations.

The diamond-shaped marble pattern is yellowish white, fine crystalline marble. It has a uniform in crystal size, the surface is rebounded in places and slightly weathered.

A reddish-tinted artificial stone addition forms a significant part of the throne chair.

V. CONCLUSIONS

By the non-destructive testing of the selected four incrustated artefacts and structures, it can be stated with high probability that Tardos-type red cemented Jurassic limestone was used for all basements. The limestone was quarried in the nearby Gerecse Mountains (Hungary). The use of Tardos limestone was approved some years ago in the case of another fragment from the *Porta speciosa* by carbon and oxygen stable isotopic analysis, which is suitable for identifying the provenance of the stone material.[35] With sampling and trace element analysis it is possible to obtain valuable information on the provenance. This technique is most reliable for marbles, using stable isotopes, because a rich database for marble types already exists, but as it was described by Germann, Holtzmann and Winkler,[36] the method has limitations as well. As in the current study, only non-destructive research was applied without sampling, the exact provenance of materials cannot be determined. However, a wider area of probable origins could be outlined by a series of our comparative analysis.

The elemental composition of the red limestone basements varies in the four examined fragments, because of the depositional differences and also linked to the surface soiling or dirt. On certain stone surfaces salt efflorescences were proved based on the elementary composition, namely Cl and P were detected. These elements can be linked to natural salts and also to the activity of organisms such as birds or micro-organisms. Several types of white marbles could be distinguished based on their micro-fabric and textural differences. Lithologically different marbles were used even within one fragment, namely at the Deësis tympanum (PS-1), where three types were found. Despite the textural differences it is also probable, that these stones were extracted from the same quarry, but representing different banks. One feasibility is that these inlays are secondarily used Roman marbles. Their possible origin can be from the territory of today's Italy, Greece, Turkey or Austria. The black inlays from the tympanum (PS-1) and the arm-rest with grapes (T-1) show slight textural differences. None of them are volcanic basalt, but limestone. Such stones can be found in the Carpathian Mountains, Mecsek Mountains or in the Slovenian or Austrian Alps. It can be mentioned that the so called 'Belgian marble' (black limestone) also shows some similarity to these black limestones, but the former has more fossils. The green stone of Daniel the Prophet's (PS-2) tefillin is serpentinite, that can most probably come from Italy or the Alps in today's Austria. The Hungarian provenance of this stone can be excluded.

None of the analysed stones were especially expensive or special in the Middle Ages. All of them were rather easily affordable and available.

The closer analysis of the two arm-rests (T-1 and T-2) suggested that they hardly could be the sides of the same throne opposed to the conception of the current artificial stone reconstruction. The adhesive materials of the two sides show significant differences, but on T-1 we can consider subsequent adhesive materials. The organic black adhesive of T-2 cannot be detected on any of the visible surfaces of T-1. The composition of the two arm-rests is also completely different, as in T-1 the whole side is decorated with a dynamic scene from several little inlays, while in T-2 the remaining figure is much bigger with a flat and quite empty background. The role of the red limestone basement is also different on the two sides: in T-1, elements of the picture (the tree, the man's clothe, the bow and the frame) were carved from the basement and the background was added with black inlays, but in T-2 the red basement is the background of the standing figure without any frame. Noting that such anomalies (i.e. various sized figures) are common within one piece of art in the Middle Ages, the differences between the two arm-rests are so fundamental, that they could rather be the part of two chairs with similar shape.[37]

BIBLIOGRAPHY

DERCSÉNYI 1937 – Dezső DERCSÉNYI: Középkori kőemlékeink védelme [Protection of our medieval stone monuments], *Magyar Művészet* 13. 1937, 324–328.

DERCSÉNYI 1947 – Dezső DERCSÉNYI: Az esztergomi Porta Speciosa [The Porta Speciosa in Esztergom], *Regnum Egyháztörténeti Évkönyv* 4, Budapest: Szent István Társulat, 1947, 69–94.

GERMANN et al. 2007 – Klaus GERMANN, G. HOLZMANN, F. WINKLER: Determination of marble provenance: Limits of isotopic analysis, *Archaeometry* 22. 2007, 99–106. 10.1111/J.1475-4754.1980.TB00271.X.

ISTVÁNFFY 1622 – Nicolaus ISTVÁNFFY: *Historia Regni Hungariae libri XXXIV*. Coloniae Agrippinae, 1622.

LŐVEI 2005 – Pál LŐVEI: Kőanyagvizsgálat, művészettörténet, műemlékvédelem [Monument petrology, art history, and monument protection], *Archeometriai műhely* 2005/3, 1–6.

LŐVEI et al. 2007 – Pál LŐVEI, Farkas PINTÉR, Bernadett BAJNÓCZI, and Mária TÓTH: Vörös és fehér díszítőkövek, kristályos és metamorf mészkövek, márványok (Műemléki kutatások természettudományos diagnosztikai háttérrel 1.) [Red and white decorative stones, crystalline and metamorphic limestones, marbles (Monument researches with the help of scientific diagnostic methods 1)], *Művészettörténeti* Értesítő 56. 2007, 75–82. https://doi.org/10.1556/muvert.56.2007.1.5

LŐVEI 2017 – Pál LŐVEI: Bíbor Esztergom – A Szent Adalbert-Székesegyház, a Bakócz-kápolna és a királyi/érseki palota vörös márványa [Purple Esztergom – Red marble of the Saint Adalbert Cathedral, the Bakócz Chapel and the royal/archiepiscopal palace], in *Metropolis Hungariae, Strigonium Antiquum* 8, ed. András HEGEDŰS, Esztergom, 2017. 96–106.

MAROSI 1971 – Ernő MAROSI: Einige stilistische Probleme der Inkrustationen von Gran (Esztergom), *Acta Historiae Artium* 17. 1971, 171–229.

MAROSI 1994 – Ernő MAROSI: Esztergom középkori Szent Adalbert-székesegyháza – Tíz év múltán [Medieval Saint Adalbert Cathedral in Esztergom – After ten years], *Limes. Komárom-Esztergom megyei tudományos szemle* 1994/3, 13–28.

MATHES 1827 – Joannes Nep. MATHES: *Veteris arcis Strigoniensis … descriptio*, Strigonii, 1827.

MIKÓ–TAKÁCS 1994 – Árpád MIKÓ and Imre TAKÁCS (eds): *Pannonia Regia. Művészet a Dunántúlon* 1000–1541 [Pannonia Regia. Art in Transdanubia 1000–1541], exhibition catalogue (Hungarian National Gallery), Budapest, 1994.

PINTÉR et al. 2001 – Farkas PINTÉR, György SZAKMÁNY, Pál LŐVEI, Mária TÓTH, and Attila DEMÉNY: „Vörös márvány" faragványok nyersanyaglelőhelyeinek kutatása [The research of the places of occurence of red marble carvings], *Műemlékvédelmi Szemle* XI/1–2. 2001, 53–70.

PINTÉR–BAJNÓCZI 2014 – Farkas PINTÉR, Bernadett BAJNÓCZI: „Vörös márvány" műtárgyak kőanyagának eredethatározása petrográfiai és stabilizotóp-geokémiai vizsgálatokkal [Definition of the origin of the stone material of 'red marble' artefacts by petrographic and stable isotopic geochemical analyses], in Tibor ROSTÁS: *„Magyarország földjére küldtek". Villard de Honnecourt és az érett gótika megjelenése Közép-Európában – A klosterneuburgi Capella Speciosa és Pannonhalma francia kapcsolatai, Budapest,* 2014. 183–203.

TAKÁCS 1993 – Imre TAKÁCS: Porta patet vitae. Az esztergomi székesegyház nyugati díszkapujáról [Porta patet vitae. About the western portal of the cathedral in Esztergom], in *Kezdés és* újrakezdés, *Strigonium Antiquum* 2, ed. Margit BEKE, Budapest, 1993. 53–60.

TAKÁCS 2012 – Imre TAKÁCS: A Marble Thron from Esztergom with a View to the "Renaissance of the Twelfth Century, in *Le plaisir de l'art du Moyen* Âge. *Commande, production et réception de l'œuvre d'art. Mélanges en hommage à Xavier Barral i Altet*, Paris: Picard, 2012. 108–114.

TAKÁCS 2017 – Imre TAKÁCS: Az esztergomi Porta speciosa programjának kérdéseiről [About the questions of the program of the Porta speciosa in Esztergom], in *Metropolis Hungariae, Strigonium Antiquum* 8, ed. András HEGEDŰS, Esztergom, 2017. 107–134.

TAKÁCS 2018 – Imre TAKÁCS: *A francia gótika recepciója Magyarországon II. András korában* [Reception of the French Gothic in Hungary at the age of Andrew II], Budapest: Balassi Kiadó, 2018.

TAKÁCS 2020 – Imre TAKÁCS: *Az esztergomi Porta speciosa* [The Porta speciosa in Esztergom], Budapest: Martin Opitz Kiadó, 2020.

NOTES

[1] The historian Miklós Istvánffy mentions that the arches of the sanctuary, collapsed due to Turkish cannon fire, were covered with incrusted red marble slabs: „… templi majoris præalta Orientalis fornix concamerati ac rubri marmoris tabellis incrustati operis …" ISTVÁNFFY 1622, LIB. XV, 264.

[2] See TAKÁCS 2004, 51, fig. 9.

[3] See TAKÁCS 2020, 65–70.

[4] See primarily DERCSÉNYI 1947; MAROSI 1971; TAKÁCS 1993, 2017, 2018, 2020.

[5] BOGYAY 1950; 1971.

[6] TAKÁCS 2012.

[7] LŐVEI 2005, 2017; LŐVEI et al. 2007; PINTÉR et al. 2001

[8] PINTÉR–BAJNÓCZI 2014.

[9] LŐVEI 2005. 4.

[10] LŐVEI 2005. 5.

[11] Supported by the Hungarian Academy of Sciences (MTA 01 259): "A thesaurus of the architecture and ornamental carvings of medieval Hungary", research group leader: Imre Takács.

[12] *„Természetes kőzetek megnevezése"* (MSZ EN 12670:2001) standard.

[13] *„Kőzettani vizsgálat"* (MSZ EN 12407:2000) standard.

[14] MAROSI 1971, 1994; TAKÁCS 2017, 2018, 2020.

[15] For further details, see TAKÁCS 2020, 35.

[16] See Takács 2020. 35.

[17] After Takács 2020. 35.

[18] Marosi 1971; Mikó–Takács 1994, cat. No. I-82b; Takács 2020.

[19] Takács 2020, 113.

[20] Pintér–Bajnóczi 2014.

[21] It is not surprising, as the Tardos stone mine provided material for most of the Hungarian artefacts and constructions throughout all historical ages.

[22] Esztergom Castle Museum reference number: 84.29.1. Mikó–Takács 1994, cat. No. IV-3a. See also Takács 2020, 85.

[23] See Takács 2020, 85.

[24] Takács 2018, fig. 53.

[25] See the description and interpretation in Takács 2020, 86.

[26] According to Takács 2020, 85.

[27] Takács 2012, 111–112; Takács 2018, 34–36.

[28] Esztergom Castle Museum reference number: 84.29.2. It is depicted: Mathes 1827, T. XIc; Mikó–Takács 1994 cat. No. IV-3b Mikó–Takács 1994. 236. Also see Takács 2012, 109–110; Takács 2020, 85.

[29] Based on the results of Pintér–Bajnóczi 2014 on the *Porta speciosa* fragment of Saint John the Apostle, it can be stated with no doubt that the stone comes from the Tardos stone quarries.

[30] See Takács 2020, 35.

[31] Based on the results of Pintér–Bajnóczi 2014.

[32] Takács 2018, fig. 53

[33] Dercsényi 1937, 325.

[34] See e.g. the Basilica of Junius Bassus in Rome.

[35] Pintér–Bajnóczi 2014.

[36] Germann et al. 2007.

[37] Acknowledgement: The authors are grateful to the Castle Museum of Esztergom for its hospitality during the research. We also thank Bálint Analytics Ltd. (M. Bálint) for lending us the portable XRF device.