ANALYSES OF MORTARS FROM ST. GEORGE'S CATHEDRAL, GREAT NOVGOROD

A VELIKIJ NOVGORODI SZT. GYÖRGY-KATEDRÁLIS HABARCSAINAK VIZSGÁLATA •

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Abstract

The Yuriev Monastery at Veliky Novgorod - one of the oldest monasteries in Russia – was founded in the 12th century by Prince Vsevolod Mstislavich. Now it is a UNESCO World Heritage Site. The dominating building of the Monastery is the Cathedral of St. George. It was constructed in 1119 and painted before 1130. During the archaeological research of 2021 carried out by the Department of Archaeology and Architecture of the Institute of Archaeology, Russian Academy of Sciences (Moscow), 15 samples of lime-mortar from the Cathedral and 2 more from an unknown building in the Monastery area were collected. Microscopy of cross sections and polarized transmitted light microscopy of thin sections were carried out to investigate the main components and differences in the mortars. Based on these analyses, the differences between mortars used in the various structural elements of the first (pre-Mongolian) building period and of the later periods were observed. The presences of crushed bricks (tsemyanka) – the main component of pre-Mongolian mortars – was found in the later mortars. Distinctions between different kinds of mortars (wall mortar, foundation mortar, floor mortar) and plaster were defined. Two types of sand used in the medieval mortars were identified. The preliminary dating of unknown construction found during the archaeological excavation by late 12th or 14th century was made.

Kivonat

A Velikij Novgorodban található Jurijev-monostort – Oroszország egyik legrégebbi monostorát – a 12. században alapította Vszevolod Msztyiszlavics herceg. A monostor ma az UNESCO világörökség része, meghatározó épületével a Szent György-katedrálissal együtt. A templomot 1119-ben építették és 1130 előtt készültek freskói. 2021-ben, az Orosz Tudományos Akadémia Régészeti Intézetének Régészeti Osztálya által végzett régészeti feltárás során 15 mészhabarcs mintát gyűjtöttek a katedrálisból, illetve két további töredéket egy másik épületből. A minták keresztmetszetének polarizációs mikroszkópi vizsgálatával meghatároztuk a habarcsok fő összetevőit, illetve elkülönítettük a különböző típusokat. A habarcstípusok a katedrális történetének különböző, a mongol hódítás előtti és utáni periódusaihoz köthetők. A tört téglával (csemjankával) való keverés a pre-mongol periódus jellegzetessége, azonban a későbbi habarcsokban is azonosítottuk. Meghatároztuk a fő habarcsváltozatok (fali, alapozási, padló-) jellemzőit, a középkori típusok között két homokösszetételt is elkülönítettünk. A régészeti feltárás során talált ismeretlen részek előzetes datálás alapján a 12. század végén vagy a 14. században épültek.

KEYWORDS: RUSSIAN ARCHITECTURE, HISTORICAL MORTARS, PETROGRAPHY, YURIEV MONASTERY, ST. GEORGE'S CATHEDRAL

KULCSSZAVAK: OROSZ ÉPÍTÉSZET, TÖRTÉNETI HABARCSOK, PETROGRÁFIA, JURJEV-KOLOSTOR, SZT. GYÖRGY-KATEDRÁLIS

• How to cite this paper: IANOVSKAIA, E.G., VOZNIAK, A.A., NOSOVA, A.A., SAZONOVA, L.V., LEBEDEVA, N.M. & EROFEEVA, K.G. (2025): Analyses of mortars from St. George's cathedral, Great Novgorod / A velikij novgorodi Szt. György-katedrális habarcsainak vizsgálata, *Archeometriai Műhely* **XXII/1** 39–54.
doi: 10.55023/issn.1786-271X.2025-004

Introduction and aim of the study

The archaeological excavations, carried out in 2013–2023 by the Department of Archaeology and Architecture of the Institute of Archaeology, Russian Academy of Sciences (Moscow), revealed a number of constructions in the area of the Yuriev monastery at Veliky Novgorod and architectural elements inside the Cathedral of St. George (Sedov & Etingof 2016, 16-18). Some of these constructions were never mentioned in the chronicles (Sedov 2021, 32-33). To try and establish the relative chronology of construction works and clarifying the archaeological excavation results, analyses of the building materials were conducted. One of the materials that can help archaeologists in dating a masonry structure is the mortar, as it had to be prepared and used at the moment of the construction while bricks and stone could be repeatedly used. The investigation of the main components and the differences in the recipes employed for the mortars offer precious data on the construction of the building, and therefore, in 2021, an investigation of the material used in the building of the Cathedral and the unknown constructions in the area of the Yuriev Monastery begun. Seventeen mortar samples were collected; their analysis yielded interesting results. This article presents the first data on this investigation.

Previously, medieval Russian mortars, including those originating from the St. George's Cathedral, were investigated granulometrically and petrographically by Mednikova E. Yu., Rappoport P. A, Selivanova N. B and Lipatov A. A. Novgorodian mortars were briefly described as mortars with more than 25% tsemyanka and 40–75% binder. Also, the addition of red shells stone was detected in the Novgorodian mortars at the end of 12th century. For the samples from St. George's Cathedral the data of granulometric analyses were given (Mednikova et al. 1983, 152-162). Unfortunately, there is no information where exactly that samples were taken from, therefore, those analyses cannot be considered relevant for a detailed comparison with our results.

Historical and architectural context

The St. George's Cathedral in the Yuriev Monastery (**Fig. 1**) is one of the largest churches at Veliky Novgorod. According to the chronicles, it was built in 1119 by Prince Vsevolod Mstislavich (grandson of Vladimir Monomakh) and Archbishop Kiriak. The name of the master-builder, Peter (NPL, 6627), is also known. The mention of the name of the builder is quite a rare circumstance in Russians chronicles, indeed, only four are known (Rappoport 1994, 127). Apparently, this cathedral was an important project for the Novgorodian authorities. The Yuriev Monastery belongs to the area registered as UNESCO World Heritage Site in 1992, under the name "Historic Monuments of Novgorod and Surroundings (UNESCO 1992)".

The current shapes and proportions of the St. George's Cathedral appear simple, however, the 12th century church is hidden under the layers of additions and reconstructions (Sedov 2022, 8-13). The building history of the Cathedral can be characterized by several periods. There is no information on building activities between the 12th and the mid-14th century, except for the fact that in 1345 the lead roof was renovated (NPL, 6853).

Fig. 1.: St. George Cathedral and the Yuriev Monastery. View from South-East.
1. ábra: A Szt. György-katedrális és a Jurjev-kolostor délkeleti nézetből.

At the beginning of the 18th century the walls of the Cathedral were reinforced by counterforts. In 1706 a new stone porch on the west side, and in 1745 the southern vestry were added. A global reconstruction of the monastery was carried out in 1825-1827 by Archimandrite Photius. At this time, a number of medieval constructions, including the western porch and the southern vestry were dismantled, and the 12th century frescoes were knocked down. The fresco debris was used as filling under the new cast iron floor and in some other places in the monastery area. New metal domes were fitted on the drums, niches and windows on the facade were removed and a new western porch, a southern vestry, and a northern side-chapel were built. Cross-sectioned columns were reinforced with brick masonry. The floor was raised, but some elements, such as the altars, remained at the same level. An underground tomb was placed in the south-western part of the narthex (Miltchik 2008, 293-294).

After the Great October Socialist Revolution, the Cathedral was closed (Miltchik 2008, 294). The first archaeological excavations and restoration were carried out in 1933–1936. During the restoration the annex buildings were dismantled, the windows and niches of the 12th century were reopened, the portals were restored, and the iron floor was removed. The main purpose of this renovation was the restitution of the 12th century appearance of the Cathedral, but the work was not finished completely (Karger 1946, 175-224).

Between the 12th and the 15th centuries, the Yuriev Monastery was one of the richest monasteries of Novgorod and the place of burial of princes and famous persons. Between 1166 and 1173, a now lost Gate Church of the St. Savior was built on the area of the monastery (NPL, 6674). The last stone construction mentioned by the chronicles was the church of the Birth of Our Lady, built in 1419 (NLP, 6927). These two churches were dismantled in different periods. In the 16th century a refectory, together with the church of the Metropolitan Alexey, and the belfry were erected. They were dismantled in the 18th century. At different periods in the 18th–19th centuries more structures were built: a stone wall, housings, the Saint Gate, the south-eastern tower, the Holy Cross Cathedral, the North Belltower (by Carlo Rossi, 1840), etc. (Miltchik 2008, 294).

All the changes, development and renovations certainly destroyed many of the earlier constructions both inside the Cathedral and in the area of the monastery. Nowadays these ancient structures are only recognizable as archaeological remains, and often the identification and understanding of their architecture and purpose is difficult. Written sources, archaeological data (i.e. fragments of architectural constructions discovered on archaeological excavations), drawings made by restorers, as well as old photographs give us only a partial information on the original shape of the Cathedral and the other buildings of the Monastery (Sedov 2022, 7-40).

The nowadays exterior of the Cathedral is a result of the restoration in the 1930s (**Fig. 1**). During the archaeological excavations of 2013–2021 inside the Cathedral, the 12th century floor made of limestone slabs, the Cintron with the Bishop's throne, three altars (in three apses), the underground tomb in the Narthex etc. were brought to light. In addition, more than 400 thousand fragments of fresco paintings, that had been knocked down and used as filler under the iron floor during the global reconstruction in 1825–1827, were found (Sedov et al. 2016). Now, almost all these constructions are open and visible, waiting for restoration (**Fig. 2**).

Materials and methods

During the 2021 excavation on the territory of the Monastery, 17 mortar specimens were collected from structural walls and foundations, flooring and plastering. Four samples come from different foundation constructions, discovered in the south-western underground tomb (S-1, S-2, S-3, S-4). Two mortar samples were collected from the northern altar, apparently built after the erection of the Cathedral: one from the actual altar (S-5) and one from a later phase on top of it (S-6). Two samples were taken in the northern gallery: one from the strip foundation under the base of the columns of the 19th (S-7) and the second from the filling under the floor of the 12th century (S-8). Two more samples come from the crimson plaster in the main apse (S-9), and one from the Eastern wall (S-10). One sample was taken from the wall of the Tower between the first and second floor (S-11). Two mortar samples were collected from the walls of the Chapel above the Tower (S-12, S-13) and two more from the South-West semi-pillar (in the narthex) that has an additional part of unknown date (S-16, S-17). Two samples of mortar from constructions with unknown function and date were taken from Sondage 11 (S-14, S-15) (**Fig. 3**).

A series of scientific analyses was carried out on 12 mortar samples. Regrettably, 5 samples were very friable, and the preparation of sections was not possible. The five samples are marked as S-3 (from the foundation of the narthex tomb), S-5 (from the North altar), S-9 and S-10 (from the main apse), S-11 (from the Tower). The friability was not obvious from the beginning, and the reason for this fragility is not clear, because they looked similar to other mortar samples.

The following methods were used: optical microscopy (OM) on cross sections and thin sections using an optical microscope Olympus BX-51. The percentage was calculated using petrographic "quarter" method.

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Fig. 2.: St. George Cathedral. Eastern part. Excavated constructions. View from Western gallery

2. ábra: A Szt- György-katedrális keleti része. A feltárt szerkezetek nézete a nyugati galériáról

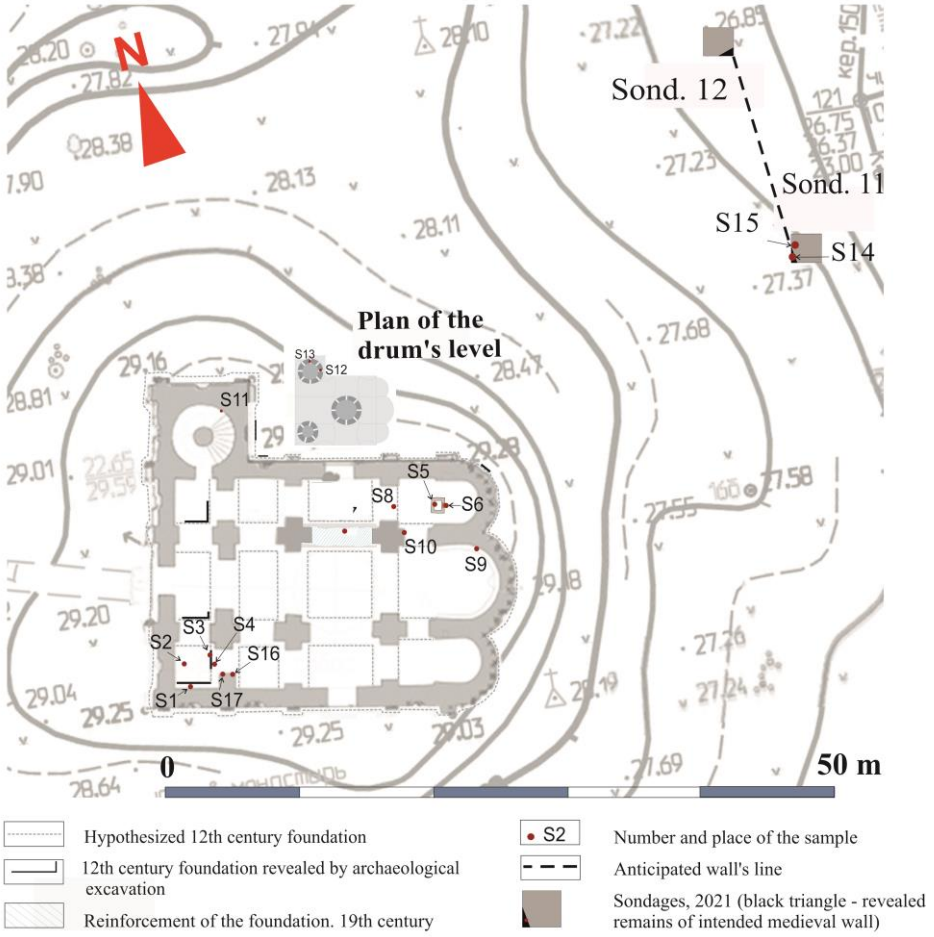

Fig. 3.: St. George Cathedral of the Yuriev Monastery. Plan with the samples

3. ábra: A Szt- György-katedrális és a Jurjev-kolostor alaprajza a mintavételi helyekkel

Results

The binder of all samples is composed of calcite and has micritic structure (**Figs. 4–6**). The binder of some pre-Mongolian mortar samples (S-8, S-13, S-17) contains cracks "healed" by crystallized lime (**Fig. 5b**, **Fig. 6c-d**). This phenomenon could be the result of pozzolanic reaction in the binder appeared as regenerative cementitious resilience that discovered in Roman pozzolanic cements (Jackson et al. 2017). Most cracks were detected in the floor mortar (S-8) which was under pressure of stone floor slabs (**Fig. 2**).

The binder-related particles, so-called lime lumps, were also detected in the samples (**Fig. 4a**, **Fig. 5f, Fig. 6a**). The majority of this aggregate type is presented in mortars with large quantity of sand (S-7 – 30%) but some of them are detected in the 12th century mortars with few sand grains. The origin of the lime lumps is still under discussion. There is an assumption that these particles could form during the production of dry-slaking lime (with minimum amount of water) when wet sand was used to convert CaO into $Ca(OH)_2$ (Elsen 2006, 1421). Our investigation could confirm the assumption of dry-slaking process, but the authors also suppose that some of the lumps with more angular shape could be the evidence of “old mortar”. Those are some volume of mortar that were slaked but not used before hardening, then crushed and added to the new batch of mortar.

Sand was detected in all samples. In pre-Mongolian 12th century mortars (**Fig. 4**) its quantity is about 5–7%, it consists of 0.5–1 mm, rounded quartz grains (**Fig. 4b-d, Fig. 5b,d, Fig. 6**). Post-Mongolian mortars contain sand composed of quartz, plagioclase, greenish pyroxene, microquartzite, clay-siltstone, etc. The grain size ranges from 0.02 mm to 2 mm. Some grains also have a rounded shape but the bulk is angular (**Fig. 4e, Fig. 5e,f**). The angular shape of the grains could be a result of mining sand in the quarry and crushing before usage. The quantity of sand in post-Mongolian mortars is 10–45%.

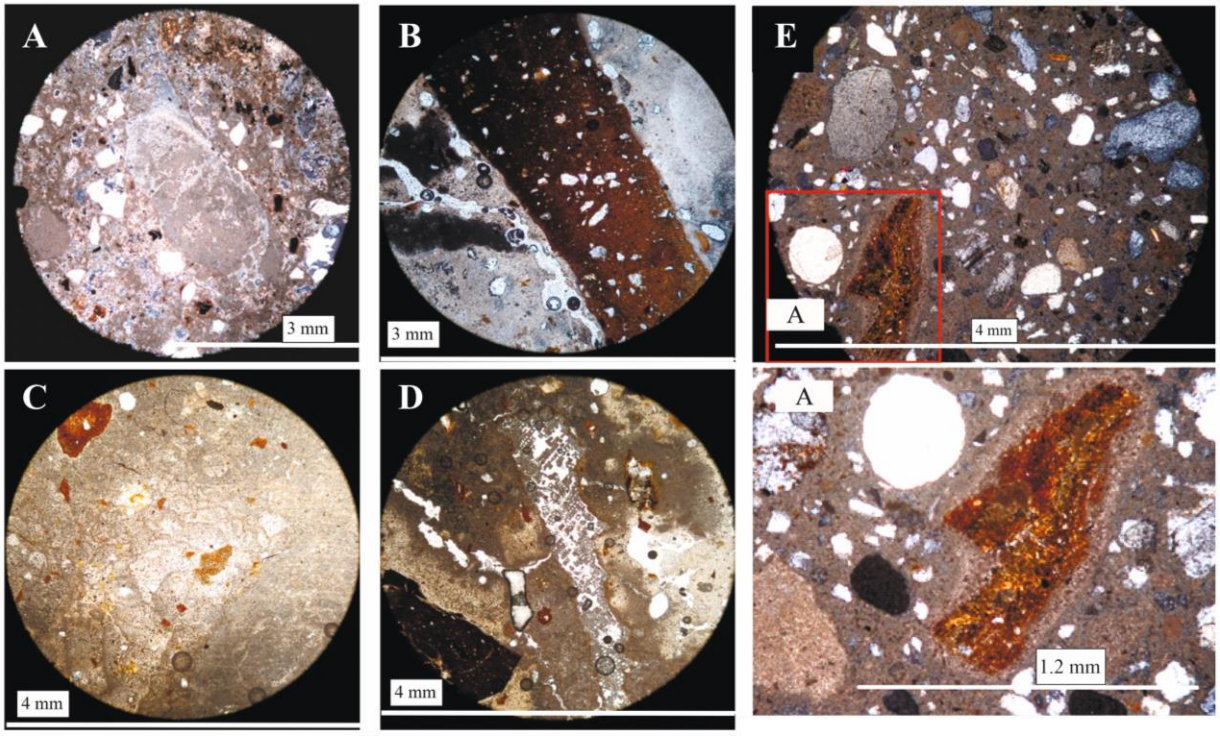

Fig. 4.: Microstructure of mortars: (A) sample S-1 – an oval lime lump (in the center) and angular fragments of quartz), (B) sample S-2 – large fragment of brick with quartz grains inside, (C) sample S-4 – “cloudy” texture of binder, (D) sample S-4 – fragment of organic material (tow or fiber?), (E) sample S6 – a reaction rim around the brick fragment.

4. ábra: A habarcsminták mikroszövete: (A) S-1 minta – ovális mészgöbecs (középen) és szögletes kvarcszemcsék, (B) S-2 minta – nagyméretű téglatörmelék kvarcszemcsékkel, (C) S-4 minta – “felhős” szövetű kötőanyag, (D) S-4 minta – szervesanyag utáni pórus (növényi rost?), (E) S6 minta – téglatörmelék körüli reakciószegély.

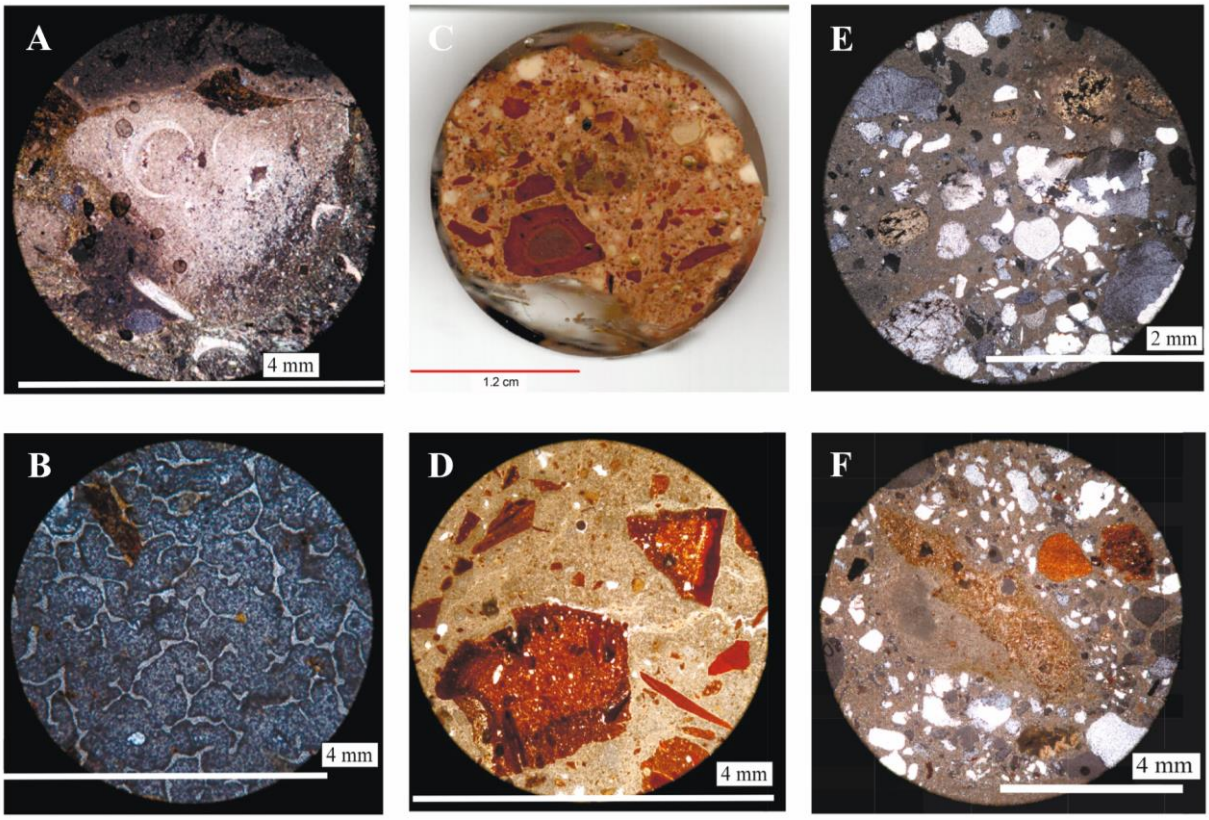

Fig. 5.: Microstructure of mortars: (A) sample S-7 – large fragment of fossiliferous limestone, (B) sample S-8 – cracks in the earlier mortar, "healed" by newly formed carbonate, (C) sample S-12 – macroscale view of the microstructure, (D) sample S-13 – dark border around the fragments of brick, (E) sample S-14 – accumulation of aggregate quartz grains, (F) sample S-15 – mixture of lime fragment (in the center), tsemyanka (left top) and quartz grains (white and grey).

5. ábra: A habarcsminták mikroszövete: (A) S-7 minta – nagyméretű, ősmaradványos mészkőtörmelék, (B) S-8 minta – a korábbi repedések "öngyógyulása" karbonát újrakristályosodásával, (C) S-12 minta – a szövet makroszkópos képe, (D) S-13 – a téglatörmelékek körüli sötét reakciószegély, (E) S-14 minta – az aggregátumot képző kvarcszemcsék koncentrálódása, (F) S-15 minta – mésztörmelék (középen), "csemjanka" (bal felül) és kvarcszemcsék (fehér, szürke) keveréke.

The quantity of tsemyanka varied from 2–3% (or even absence) to 50% depending on age of using and the type of mortar. In the 11th–first half of 13th century, Novgorodian mortars contained a quantity of crushed ceramic addition visible by the naked eye (tsemyanka or cocciopesto in modern Italian). Since the end of 13th century mortars were prepared with sand as the main additive to the binder (Rappoport 1994, 45-46). According to the results of our investigation, crushed ceramic still was in use in the later mortars in a small quantity (2–5%) and with tiny grains.

Petrographic research has shown that there are different types of mortars with varied quantities of aggregate (tsemyanka and sand). For example, floor mortar contains a smaller quantity of crushed ceramic in the form of quite tiny grains (**Fig. 5b**). Preparation plaster of 12th century for fresco paintings also has different composition. It contains mostly only straw and a small amount of fine sand (Giumlia-Mair et al. 2023, 271).

It is worth noting that some grains of the 12th century tsemyanka have darker rims (**Fig. 5c,d, Fig. 6c**). These rims could be a result of additional thermal impact (during or before the process of slaking). Another feature of tsemyanka is the presence of grains without any aggregates. There is an assumption that ad hoc special baked clay was used (Mednikova & Rappoport 1991, 102-103). Both phenomena must be investigated more in detail with additional methods and experiments.

Another important aggregate type which was detected during this petrographic investigation is the crushed limestone (**Fig. 5a**). Its pieces were found in mortars with sand as a main additive (see **Appendix** – **Table 1**).

For more detailed information about composition and their quantity see **Appendix** – **Table 1**.

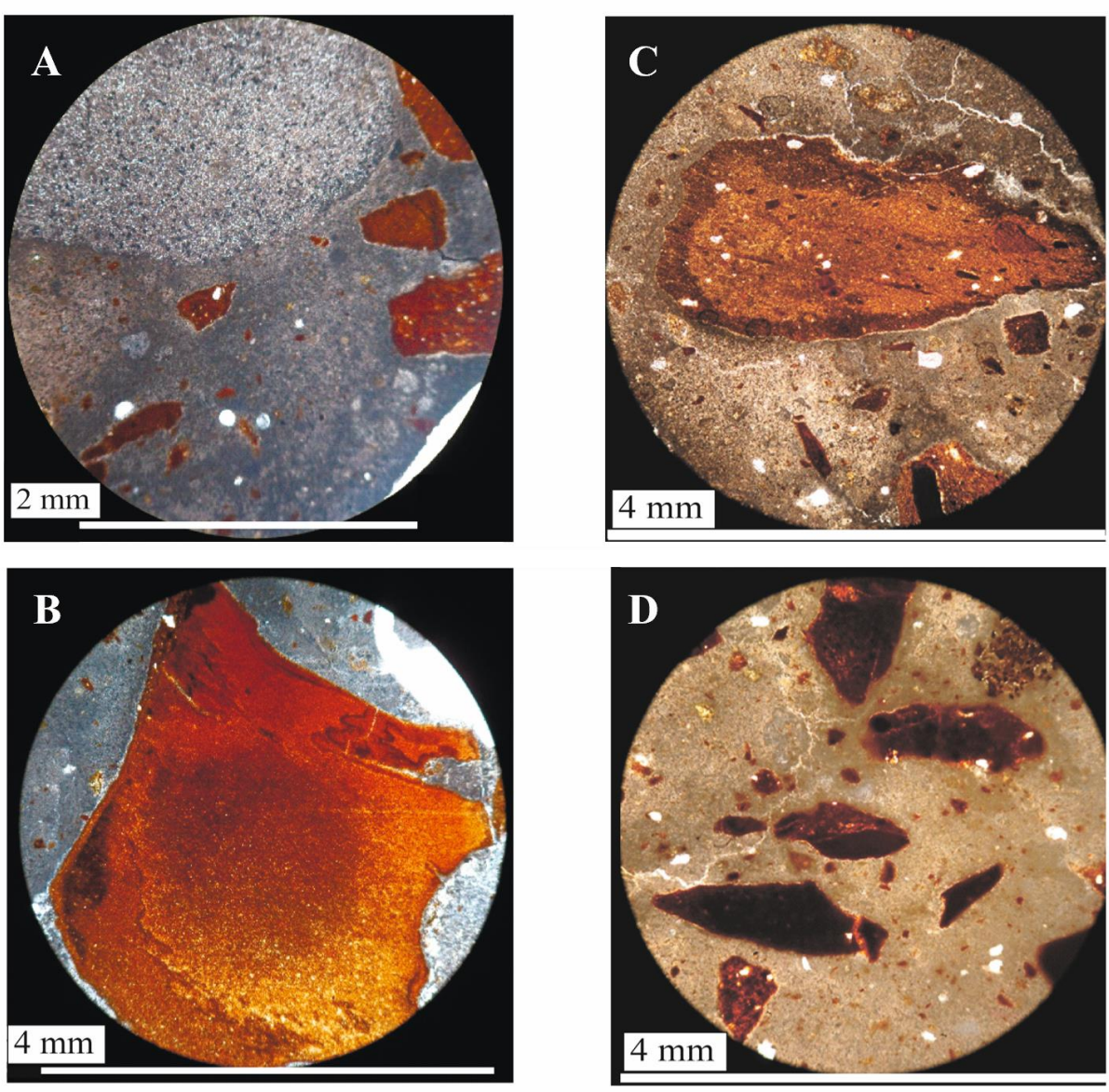

Fig. 6.: Microstructure of mortars: (A) sample S-16 – lime lump (top), (B) sample S-16 – homogeneous, ad hoc backed clay fragment, (C) sample S-17 – a fragment of a light orange brick with dark rim, (D) sample S-17 – elongated fragments of brick in the binder.

6. ábra: A habarcsminták mikroszövete: (A) S-16 minta – mészgöbecs (felül), (B) S-16 minta – homogén, ad hoc megégett agyagklaszt, (C) S-17 minta – világos narancssárga téglatörmelék sötét szegéllyel, (D) S-17 minta – nyúlt téglatörmelékek a kötőanyagban.

Discussion

In the Pre-Mongolian period (10th–13th centuries) on the territory of the Old Rus' mostly the mortars with large amounts of tsemyanka and small amount of sand were used (Rappoport 1994, 45-46). Using crushed ceramic came from Byzantine tradition with the master-builders of the first Russian stone building in Kiev (Ousterhout 1999, 112-114, 133-134). The technology changed at the end of the 13th century when sand became the major aggregate to the slaked lime (Antipov 2015, 59). After the Mongol invasion, all contact of Novgorod with southern territories of the Rus' and the Byzantium Empire were interrupted. New architectural style and technology came from the West, from Livonia (Sedov 2022-2, 120). There are more relevant differences between the southern and western mortars. It is supposed that a special preparation of ad hoc special baked clay lumps was used only at the beginning of the 12th century. After the 1230s, this material was replaced by crushed limestone. Sand was not used as a special additive but appeared in mortars only as a component of other additives (for example of crushed bricks) (Mednikova & Rappoport 1991, 102-103).

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It is supposed that tsemyanka was not used at all as special additive after the 13th century. However, according to our observations of Novgorodian buildings, small amounts of crushed bricks can still be seen in some of the mortars in churches of the 14th–15th centuries. We can hypothesize that this was a technological peculiarity in the preparation of mortars employed only in some cases or, perhaps, it was an imitation of the ancient tradition. The other case is the usage of large pieces of old mortars as the component of new binding materials, like in the case of sample S-6.

According to our petrographic research, two groups of mortars can be recognized. The first group comprises mortars of the pre-Mongolian period with a large amount of tsemyanka, a small amount of monomineralic sand, and some additional components like special baked clay or crushed limestone (samples S-2, S-4, S-8, S-12, S-13, S-16, S-17). The second group is that of mortars used after the 13th century containing multimineralic sand and crushed limestone (S-1, S-6, S-7, S-14, S-15).

However, we also found some small amount of tsemyanka in post-Mongolian mortars. For example, sample S-1 was taken as a plaster of the foundation that was supposed to belong to the reinforcement of the foundation of the underground tomb in the South-West of the narthex (**Fig. 7**). In spite of its supposed age, it contains a noticeable amount of brick fragments (around 15%) so that it could be considered both a mortar of a 12th century foundation or perhaps a later imitation of the ancient mortar. To revise the date of this sample more research of Novgorodian mortars of different periods must be taken.

Two samples of mortar from Sondage 11 (**Fig. 2**) were taken during the archaeological excavation of some still undetermined construction to the North-East from the Cathedral. Both samples contain a small amount of tsemyanka (S-14 2%, S-15 5–6%) and also show the same kind of binder – crystalline, cloudy, and brownish-gray colored. The small amount of tsemyanka (2%) in sample S-14 is not considered to be a special component of the mortar. Most probably it is the remnant of a burning process for lime production in a kiln made of bricks. Sample S-15 was taken from the archaeological layer containing the remains of a still undetermined construction. Considering the small amount of sand and 5–6% of crushed bricks present in it, we can suppose that these are the ruins of some destroyed foundation of a structure built in late pre-Mongolian time. A similar ratio of components in the foundation mortar was determined in the church of St. Panteleimon (1207) (Lipatov 2006, 348). Another more probable assumption is that the date of this ruins is the 14th–15th century when small amount of tsemyanka was used in the mortars of Novgorodian buildings.

Within the two large groups of mortars, we can differentiate mortar types used in different constructions: wall mortar (S-12, S-13, S-16, S-17), foundation mortar (S-2, S-4, S-15 12th–13th century; S-7, S-14 – 14th–19th century), floor mortar (S-8) and plaster (S-1 12th century; S-6 19th century). The largest particles of tsemyanka and a minimal amount of sand were found in the pre-Mongolian mortars in the foundation in the Cathedral of St. George. The mortar employed in the walls of the Cathedral also contains a large amount of large size particles of tsemyanka.

Fig. 7.: South-West Tomb. Foundation. South wall. View from the North

7. ábra: A délnyugati sír, a déli fal alapozása, északi nézet.

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Fig. 8.:
South-West Tomb. Strip foundation between semi-pillar and column, 12th century. View from the South-West

8. ábra:
A délnyugati sír, sávalap egy féloszlop és egy oszlop között, délnyugati nézet.

Fig. 9.:
South-West semi-pillar. Vertical seam in the center of the pillar. View from the North

9. ábra:
A délnyugati féloszlop, közepén függőleges varrattal, északi nézet.

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Samples S-2 and S-4 from the 12th century foundation (**Fig. 8**) are similar, with a large amount of brick fragments (0.3 to 5 cm in length) and a very small amount (around 5%) of sand, mainly consisting of monomineralic quartz. Organic material (possibly wood) is present in both samples. It is important to note that lime lumps which could be the fragments of earlier mortars (with angular shape) are also present in these samples.

Post-Mongolian foundation mortars, S-7 and S-14 are not similar to each other and most probably belong to different periods. S-7 i.e., the mortar of the reinforcement of the foundation, can be attributed to the time of the renovation in the 1820s (according to the archaeological data) (Sedov, 2015) (**Fig. 2**). The amount of sand in this type of mortar is only 10% with an addition of clay, limestone fragments and lime lumps. S-14 can be attributed to the earlier period according to the archaeological data (Sedov 2021, 33).

The samples from the wall, S-12 and S-13, were taken from the holes left by the now missing beams in the Tower Chapel. S-12 was very friable and had to be prepared in an epoxy mount. Both mortars contain fragments of ad hoc baked clay. This kind of additive was not found in the mortars of the foundation. However, it could be seen in sample S-17 of wall mortar from the south-western semi-pillar (**Fig. 9**) which contains two kinds of masonry. Both of them consist of the so-called plinfa (thin Byzantine brick) which was used in Novgorod only in pre-Mongolian period. The two types of masonry are divided by a vertical seam in the center of the pillar. The mortar on the East of the pillar contains a binder similar to that of the foundation mortars (S-2, S-4 with a more grayish color and the brick fragments show the same angular shape). The mortar on the West of the pillar is similar to the mortar from the Tower Chapel. We suggest, therefore, that some changes in the structure of the Cathedral were carried out already in the first construction period and that the western part of the pillar was rebuilt at the construction time of the Tower Chapel.

Sample S-8, from the preparation layer under the 12th century floor, has a peculiarity: it contains very small particles of tsemyanka and sand, 20% lime lumps (old mortar), and organic inclusions (wood). This kind of mortar had never been previously identified in the St. George Cathedral.

It is worth to notice the difference in the quality of the sand employed in the pre-Mongolian and the post-Mongolian mortars. The earlier one has a rounded shape and most probably it was river sand. The later one has a clastic shape and sharp angles indicating that the sand was crushed before using it in the mortar and might be sand excavated from a quarry.

Conclusions

This preliminary research allows us to reach several very important conclusions. Taking into consideration the differences between pre- and post-Mongolian mortars (i.e., the amount of tsemyanka fragments present in the mixture) we can hypothesize that the still not identified building – the remains of which were found during the 2021 excavation – was built in the late 12th or most probably in the 14th–15th century. In the last stage of work (during the erection of the Cathedral in the 12th century) the builders began to use ad hoc baked clay, specially prepared as aggregate for the mortar. In this period, some construction changes in the original building plan were also made.

A very important observation is that the angular shape of quartz grains in the post-Mongolian mortars indicates that the sand aggregate was ground before usage and might have been excavated in the quarry in contrast to the river sand of pre-Mongolian mortars.

It is hoped that future research on the mortars from the Yuriev monastery and the St. George Cathedral will give us more information on the history of the buildings.

Acknowledgments

The research was carried out within the state assignment of Ministry of Science and Higher Education of the Russian Federation (theme «Pre-Mongolian frescoes in Novgorod: archaeological context and scientific research: The frescoes of St. George's Cathedral, Yuriev monastery from the 2013/2020 excavations»), agreement No. 075-15-2021-576.

This paper is the elaboration of the topic presented in the abstract «Analyses of mortars from the St. George's cathedral, Great Novgorod» published in the 8th Balkan Symposium on Archaeometry – Book of Abstracts.

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Appendix – Melléklet

Table 1: Petrographic description of mortar samples from the Yuriev Monastery, Great Novgorod

1. táblázat: A velikij novgorodi Jurjev-kolostor habarcsmintáinak petrográfiai leírása

No.	Description and estimated dating	Binder	Tsemyanka (brick fragments)	Sand	Other aggregates
S-1	S-W Tomb. Reinforcement of the foundation. Plaster.	55%, cryptocrystalline muddy appearance, color changes from gray to brownish gray	15%, the shape is from angular-clastic to rounded, with smoothed (dissolved in lime) corners. The color is bright brown, brownish black. Size: to 1 mm.	20%, composed of quartz, grains of plagioclase, potassium feldspar, amphibole, microquartzite. The grain size from 0.01 mm to 1 mm. Larger grains have a rounded, (semi-rolled) shape, but smaller fragments have clastic forms, which indicates that the material was previously crushed.	Limestone, lime lumps
S-2	S-W Tomb. Mortar from the floor. 12th century	45%, fine-grained carbonate, color ranges from light beige to dark brown. In the brown zones, the cement is more crystallized, cracked, and porous. The cement structure is lumpy.	25%, the largest fragment, L.: 5 cm. Fragments sizes vary from 0.5 mm to 2 cm, many of them contain quartz grains, rounded or elongated, with a diameter of several mm-s with sharp, angular borders.	2–3% Quite a few fragments of quartz, apparently, they were crumbled as a result of crushing bricks.	Organic substance, fragments of an earlier mortar (the size to 1 cm, the amount is about 25%, without aggregate inside)
S-4	S-W Tomb. Continuous footing. Foundation mortar. 12th century	65%, fine-grained, carbonate, the color varies from light beige to creamy beige. Presents the areas of "cloud" appearance (incomprehensible structure). The porosity is low, but pores are large, up to 0.4 mm. Clusters of pores noted along large fragments of bricks.	25%, the largest fragment, L: 3 cm. The bulk of fragments is crystallized, contains mullite and quartz. Color is red. One crimson brick with quartz has a lot of cracks. The size is from 0.3 mm to 3 cm.	5%, small, up to 0.3 mm isometric grains of quartz and feldspar	Fragment of organic substance, fragments of red unknown rock (size up to 0.4 mm)

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No.	Description and estimated dating	Binder	Tsemyanka (brick fragments)	Sand	Other aggregates
S-6	North apse. East face of the altar, in the niche for relics. Plaster. 1820s	35%, cryptocrystalline muddy appearance, color changes from gray to brownish gray	2–3%, fragments of tsemyanka present in the fragments of earlier mortar. Some of them have a porous texture.	45% Compose of quartz, grains of plagioclase, potassium feldspar, microquartzite, quartz-clay siltstone, and mineral impurities (muscovite, biotite, zircon). The grain size ranges from 0.01 mm to 2 mm. Larger grains have a rounded shape, but mostly the fragments are clastic, which indicates that the aggregate material was previously crushed.	Limestone, lime lumps
S-7	Reinforcement of the continuous footing between N-E and N-W pillars. Mortar. 1820s	40%, cryptocrystalline muddy appearance, color changes from gray to brownish gray.	Absent	10%, composed of quartz, grains of plagioclase, greenish pyroxene, microquartzite and quartz-clay siltstone. The grain size ranges from 0.02 mm to 0.5 mm. The larger grains have a rounded, oval rounded shape, the smaller ones are mostly angular	Clay (as the inclusions in limestone fragments), limestone, lime lumps (30% of all aggregate)
S-8	Floor between the N-E wall blade and N-E pillar. Filling under the primary floor. Mortar. 12th century	60%, fine-grained carbonate, contains rounded quartz grains up to 0.1 mm and distributed small grains of ore mineral. The lime is slightly lumpy. Often, a zone up to 0.05–0.1 mm wide of very fine-grained carbonate is observed around the fragments of bricks, because faster crystallization began here.	25%, the fragments are small and very small, only one large (3x4 mm) fragment was found. Small fragments (0.01–0.5 mm) of red-brown color, angular shape, homogeneous crypto-fine-grained appearance. Sometimes small angular quartz grains are visible.	5–7%, quartz grains, angular shape, up to 0.1 mm in size.	Earlier mortar (with fragments of bricks and cracks), fragments of unknown substance (angular, up to 0.1 mm in size, are composed of yellowish and brownish crystals, which are cemented by a transparent isotropic mass), organic substances.

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No.	Description and estimated dating	Binder	Tsemyanka (brick fragments)	Sand	Other aggregates
S-12	Tower Chapel. From the hole left by the now missing beams. The north window slope between fresco of St. George and Our Lady. Mortar. 12th century.	60%, fine-grained, carbonate, cream-pink color with some darker zones. Heterogeneous, with the thin cracks filled by a darker, contaminated mortar. There are areas of coarser-grained lime around large pieces of unmixed lime. The porosity is average, the pore size reaches 2–3 mm.	30%, the largest fragment, L.: 8 mm, main size varies from 0.5 mm to 4 mm, many of them contain quartz grains, often rounded or elongated, with a diameter of several mm-s.	Very few	Tiny (less than 0.1 mm) fragments of bricks, organic substance and small pieces of lime and quartz
S-13	Tower Chapel. From the hole left by the now missing beams. The window slope to the left from the fresco of Sava the Consecrated. Mortar. 12th century	50%, fine-grained, carbonate, grayish-beige color. The structure heterogeneous with a large number of gray areas that could indicate ingress of earth or presence of organic substance during the process of mortar crystallization. Many cracks are "healed"	30%, the largest fragment, L.: 2 cm, the average size is about 1–3 mm. The fragments have angular edges (sometimes smoother). The main forms are subisometric, triangular, and strongly elongated. Inside the fragments there are crystals of mullite and small rounded quartz grains. It should be noted that in some large fragments, a darker border is observed around the lighter core, which may indicate an additional temperature or chemical effect on these fragments after their formation (perhaps these fragments are not bricks, but specially baked clay).	3–5%, there are individual fragments of quartz or plagioclase, as well as small fragments (up to 0.5 mm) of rocks, for example, amphibole diorite	Lime lumps, fragments of some pigment or early mortar, diorite amphibole

No.	Description and estimated dating	Binder	Tsemyanka (brick fragments)	Sand	Other aggregates
S-14	Sondage 11. Foundation of unknown medieval construction.	55%, cryptocrystalline muddy appearance, color changes from gray to brownish gray.	2%, it is formed either by small angular brown fragments of brick, up to 2 mm in size, or by fragments of irregular shape, up to 4–5 mm in size. Fragments of irregular shape have a color from brown to black, with inclusions of undiagnosed phases (carbonate?) and saturated with small pores. Reaction zones of dense opaque lime (sintering) are formed around such fragments.	40%, sand grains of quartz, potassium feldspar, plagioclase, and other rocks. The larger grains have a rounded, oval rounded shape, the smaller ones have an angular, comminuted shape. Grains of sand and their fragments are unevenly distributed over the area of the sample	Limestone, lime lumps
S-15	Sondage 11. Layer with the debris of unknown construction.	45%, cryptocrystalline muddy appearance, color changes from gray to brownish gray.	5–6%, the shape is from angular-clastic to rounded, with smoothed (dissolved in lime) corners. Color is bright brown, sometimes brownish-black color. The size of the fragments is from 0.1 mm to 3–4 mm. The composition is burned clay or a mixture of burned clay with the smallest quartz fragments.	20%, composed mainly of quartz, grains of plagioclase, potassium feldspar, microquartzite, biotite quartzite, and mineral impurities (muscovite, biotite, zircon, amphibole). The grain size up to 1 mm. Larger grains often have a rounded shape, small fragments are characterized by a clastic, comminuted appearance	Limestone, lime lumps

No.	Description and estimated dating	Binder	Tsemyanka (brick fragments)	Sand	Other aggregates
S-16	The north face of internal S-W semi-pillar. East of pillar. Primary masonry. Mortar. 12th century	40%, fine-grained carbonate with a large amount of black organic material and small grains of ore mineral. Heterogeneous, color is from grayish-white around the bricks to dark gray areas, probably enriched with organic substance. There are also zones with larger grains of carbonate.	45%, irregular shape, most often elongated, with rounded edges. The largest is 2x1 cm, average size 0.5x0.3 cm, 0.4x0.2 cm and up to very small (0.05 mm). The color is light red-brown. They are composed of an inhomogeneous fine-crystalline mass, in which quartz grains are scattered and grains of ore minerals are distinguishable. Some homogeneous fragments of are also presented.	Very few	Organic matter, some pigment, earlier mortar
S-17	The north face of internal S-W semi-pillar. W of pillar. Secondary masonry, but also pre-Mongolian. Mortar. 12th or 13th century	50%, fine-grained, carbonate, beige in color, rather homogeneous, along some fragments and cracks, a coarser-grained binder is observed. The porosity is average, the pores are round, up to 0.4 mm, practically not "healed".	40%, the largest fragment, L.: 1.5 cm, the average size is 2–5 mm, mostly have angular edges, in some fragments the boundaries are more undulating. The main forms are subisometric and strongly elongated. In some large fragments, a darker border is observed around the lighter core, which may indicate an additional temperature or chemical impact on these fragments after their formation (specially baked clay?)	2–3%, some fragments of quartz, probably they crumbled during of process of crushing a brick	There are no lime lumps, as well as fragments of early mortar are not found.