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Analyses of mortars from St. George's cathedral, Great Novgorod

E. Ianovskaia[1], A. Vozniak[2], A. Nosova[2], L. Sazonova[3], N. Lebedeva[3], K. Erofeeva[2]

1 Institute of Archaeology, Russian Academy of Sciences, Moscow, Russian Federation
2 Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry Russian Academy of Sciences, Moscow, Russian Federation
3 Lomonosov Moscow State University, Moscow, Russian Federation

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Introduction

The St. George Cathedral in the Yuriev Monastery is one of the largest churches at Veliki Novgorod (Great Novgorod). After the chronicles the church was built in 1119 by Prince Vsevolod Mstislavich (grandson of Vladimir Monomakh). The name of the master-builder – Peter is reported, a rare circumstance, apparently this cathedral was an important project. The Yuriev Monastery is a UNESCO World Heritage Site.

Forms and proportions look simple, but the 12th century church has a complex history of rebuilding, additions and restorations, as writing sources, drawings, photographs and archaeological data reveal.

The building history of the Yuriev monastery differs from that of the St. George Cathedral. The Yuriev monastery was first mentioned in chronicles in 1119. Between the 12th - 15th century it was one of the richest monasteries of Novgorod and the place of burial of princes and famous persons. Between 1166-1173 a now lost Gate Church was built on the area of the monastery. In 1297 a second gate church of the Transfiguration of the Savior was erected. The last stone construction mentioned by the chronicles was the church of the Birth of Our Lady, built in 1419. All churches were dismantled in different periods. In the 16th century a refectory together with the church of the Metropolitan Alexey and a belfry were erected. They were dismantled in the 18th century. At different periods in the 18th-19th century more structures were built: a stone wall, housings, the Saint Gate, the S-E tower, The Holy Cross Cathedral, N-Bell-tower (by Carlo Rossi, 1840) etc.

Several periods characterize the building history of the St. George Cathedral as well. We know nothing about building activities between the 12th and mid. 14th century. In 1345 the lead roof was renovated. At the beginning of the 18th century the Cathedral's walls were reinforced by counterforts . In 1706 a new W-stone porch and in 1745 the S-vestry were built. A global reconstruction of the monastery was done in 1825-1827 by Archimandrite Fotius. A number of medieval constructions, including the W-porch and S-vestry were dismantled and in the St. George Cathedral 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 on the monastery area.

New metal domes were fitted on the drums, niches and windows on the facade removed and new stone parts added: a W-porch, a S-vestry, a N-side-chapel. 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 S-W of the narthex.

After the Great October socialist revolution the Cathedral was closed. The first archaeological excavations and restoration were in 1933-1936. During the restoration the annex buildings were dismantled, the windows and niches of the 12th century reopened, the portals restored, and the iron floor removed. The main purpose of this renovation was the restitution of the 12th century aspect of the Cathedral [1].

All changes, development and renovations certainly destroyed some earlier or later constructions both inside the Cathedral and on the area of the monastery. Nowadays we can only recognize all these constructions as archaeological remains, and often the identification and understanding of their architecture and purpose is difficult.

Aim of the exploration

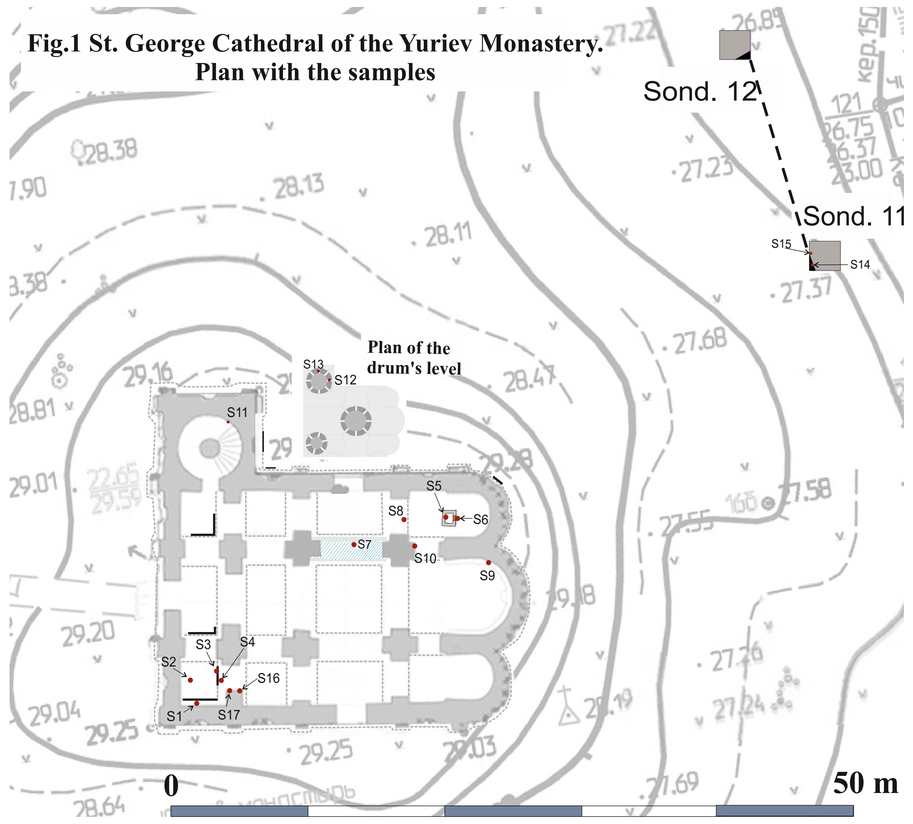
The archaeological excavations in 2013-2021, carried out by the Department of Archaeology and Architecture of the Institute of Archaeology, Russian Academy of Sciences (Moscow) revealed a number of constructions on the area of the Yiuriev manastery and inside the St. George Cathedral. To correlate these constructions with the chronicles data and to clarify the archaeological excavation results the analyses of the building materials were necessary. One of the best ways for dating a building is to study the mortar, as it had to be prepared and used at the moment of the construction, while bricks and stone could be used repeatedly. We began to collect the data on mortars in 2021 and possess now 17 samples. Even this small amount of samples gave us some interesting results. This poster presents the preliminary results of our investigation.

Methods

A series of scientific analyses was carried out on 12 mortar samples. 5 more samples were very friable and they did not allow the preparation of thin sections. We employed the following methods: optical microscopy (OM) on thin section for the identification of the mineralogy and texture of the aggregate. Scanning Electron Microscopy with Energy Dispersive Spectrometry (SEM+EDS) for the identification of some of the inclusions. The study results of thin sections with Scanning Electron Microscopy showed many areas with non-stoichiometric mixtures of carbonate and aluminosilicate slightly different from one another. The results were not sufficient and we decided to use optical microscopy. This method is the most convenient for the preliminary exploration for binder and aggregate.

Previously Medieval Russian mortars were investigated by granulometric and petrographic analysis by Mednikova E. Yu, Rappoport P. A, Selivanova N. B and Lipatov A.A. Unfortunately we do not know where the the samples from the St. George Cathedral were taken, therefore the earlier analyses cannot be considered complete [3]. The exploration was made by optical microscope Olympus BX53M. The composition of minerals and glasses was analyzed by Energy Dispersive Spectrometry at the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences, on an X-MaxN spectrometer (Oxford Instruments) with an ultrathin window and a crystal active zone area of 50 mm2, mounted on the basis of a JSM-6480LV Scanning Electron Microscope (Jeol, Japan).

Fig.1 St. George Cathedral of the Yuriev Monastery. Plan with the samples



№	Description and estimated dating	Binder	Tsemyanka (brick fragments)	Sand (quartz)	Other aggregates
S-1	S-W Tomb. Reinforcement of the foundation. Plaster. 1820s	55%. Cryptocrystalline muddy appearance, gray to brownish-gray	15% angular-clastic to rounded, with smoothed (dissolved in lime) corners. Light brown-brownish-black. Size ca. 1 mm.	20% quartz, grains of plagioclase, potassium feldspar, amphibole, microquartzite. Grain size from 0.01 to 1 mm. Larger grains with rounded, (semi-rolled) shape, smaller fragments with clastic forms, indicating that the material had been crushed.	Limestone, non-homogenized lime
S-2	S-W Tomb. Mortar from the floor. 12th century	Fine-grained carbonate, light beige to dark brown. In brown zones, the cement is more crystallized, cracked with porosity. Lumpy structure	70% largest fragment L.: 5 cm. Size from 0.5 mm to 2 cm, many contain quartz grains, rounded or elongated, with a diameter of several mm. with sharp, angular borders.	Quite a few fragments of quartz, apparently crumbled as a result of crushing bricks.	Organic substance, fragments of earlier mortar size up to 1 cm. About 25%, without aggregates
S-4	S-W Tomb. Continuous footing. Foundation mortar. 12th century	Fine-grained carbonate, light beige to creamy beige. Presents "cloudy" areas (incomprehensible structure). Low porosity, but large pores up to 0.4 mm. Clusters of pores noted along large fragments of bricks.	80% Largest fragment L:. 3 cm., bulk of fragments crystallized, contain mullite and quartz. Red color. One crimson brick with quartz with many cracks. Size 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 unknown red rock (up to 0.4 mm)
S-6	North apse. East face of the altar, in the niche for relics. Plaster (or mortar). 1820s	35% Cryptocrystalline muddy appearance, gray to brownish-gray	2-3% Fragments of tsemyanka present in the fragments of earlier mortar. Some with a porous texture.	45% Consists of quartz, grains of plagioclase, potassium feldspar, microquartzite, quartz-clay siltstone, and mineral impurities (muscovite, biotite, zircon). Grain size 0.01 mm to 2 mm. Larger grains with rounded shape, but most fragments are clastic, indicating that the aggregate had been crushed.	Limestone, non-homogenized lime
S-7	Reinforcement of the continuous footing between N-E and N-W pillars. Mortar. 1820s	40% Cryptocrystalline muddy appearance, colour changes from gray to brownish-gray.	Absent	10% Consisting of quartz, grains of plagioclase, greenish pyroxene, microquartzite and quartz-clay siltstone. Grain size 0.02 mm to 0.5mm. Larger grains with rounded or oval shape, smaller mostly angular	Clay (as the inclusions in limestone fragments), limestone, non-homogenized lime (30% of all aggregate)
S-8	Floor between the N-E wall and N-E pillar. Filling under the primary floor. Mortar. 12th century	Fine-grained carbonate, with rounded quartz grains up to 0.1 mm and small grains of ore mineral. Lime slightly lumpy. Some areas 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.	Small to very small fragments with only one large (3x4 mm) fragment. Small fragments (0.01-0.5 mm) of red-brown color, angular shape, homogeneous crypto-fine-grained appearance, sometimes small angular quartz grains inclusions.	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, cemented by a transparent isotropic mass), organic substances.
S-12	Tower Chapel. From the hole left by the now missing beams. The E window. 12th century mortar.	Fine-grained, carbonate, cream-pink with darker zones. Heterogeneous, with thin cracks filled by a darker, contaminated mortar. Areas of coarser-grained lime around large pieces of unmixed lime. Medium porosity, pore size 2-3 mm.	Largest fragment L.: 8 mm, size 0.5 to 4 mm, Many contain quartz grains, often rounded or elongated, with a diameter of several mm.	Very few	Tiny (less than 0.1 mm) fragments of brick, 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 Consecratedпо. Mortar. 12th century	Fine-grained, carbonate, grayish-beige. Heterogeneous structure with large number of gray areas that might indicate soil or presence of organic substances during the process of mortar crystallization. Many cracks are "healed". Low porosity, pore size up to 0.2 mm.	Largest fragment L.: 2 cm, average size ca. 1-3 mm. The fragments show angular edges (some smoother). Main forms subisometric, triangular, strongly elongated. Inside the fragments crystals of mullite and small rounded quartz grains. In some large fragments a darker border is observed around the lighter core, possibly indicating higher temperature or chemical effect on the fragments after their formation (perhaps the fragments are not bricks, but specially baked clay).	Individual fragments of quartz or plagioclase, and small fragments (up to 0.5 mm) of rocks, for example, amphibole diorite	Non-homogenized lime, fragments of quicklime, fragments of some pigment or early mortar, diorite amphibole
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 4-5mm 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, non-homogenized lime
S-15	Sondage 11. Layer with the debris of unknown construction.	45% Cryptocrystalline muddy appearance, gray to brownish-gray.	5-6% Angular-clastic to rounded shape, with smoothed (dissolved in lime) corners. Light brown, sometimes brownish-black. Size 0.1 to 3-4mm. Overburned clay or mixture of overburned clay with the smallest quartz fragments.	20% Mainly quartz, grains of plagioclase, potassium feldspar, microquartzite, biotite quartzite, and mineral impurities (muscovite, biotite, zircon, amphibole). Grain size up to 1 mm. Larger grains often with rounded shape, small fragments with clastic, comminuted appearance	Limestone, non-homogenized lime
S-16	The north face of internal S-Wsemi-pillar. East of pillar. Primary masonry. Mortar. 12th century	Fine-grained carbonate with large amount of black organic material and small grains of ore mineral. Heterogeneous, grayish-white around the bricks to dark gray areas, probably enriched with organic substances.Zones with larger grains of carbonates.	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). Light red-brown. Inhomogeneous fine-crystalline mass, with scattered quartz grains. Grains of ore minerals are distinguishable. Some homogeneous fragments are also present	Very few	Organic matter, some pigment, earlier mortar
S-17	North face of internal S-Wsemi-pillar. W of pillar. Secondary, but still pre-Mongolian masonry. Mortar. 12th or 13th century	Fine-grained carbonate, beige, rather homogeneous, along some fragments and cracks, a coarser-grained binder is observed. Medium porosity, round pores , up to 0.4 mm, practically not "healed".	Largest fragment L.: 1.5 cm, average size 2-5 mm, mostly with 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 a lighter core, possibly indicating higher temperature or chemical impact after their formation (specially baked clay?)	Some fragments of quartz, probably crumbled when the bricks were crushed	No fragments looking like non-homogenized lime or quicklime, and no fragments of early mortar

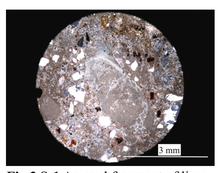


Fig.3 S-1 An oval fragment of lime (in the center) and angular fragments of quartz (white)

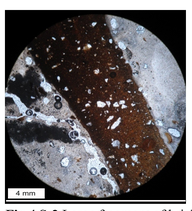


Fig.4 S-2 Large fragment of brick with quartz grains inside

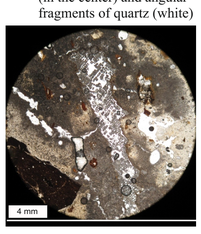


Fig.5 S-4 A fragment of organic material (tow or fiber?)

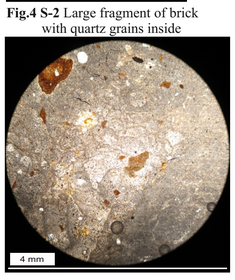
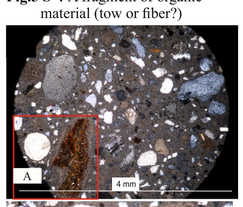


Fig.6 S-4 "Cloudy" texture of binder



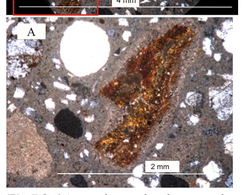


Fig.7 S-6 A reactionary border around the brick fragment

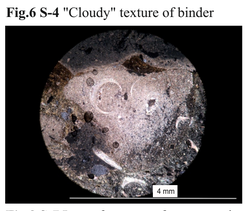


Fig.8 S-7 Large fragment of organogenic detritus limestone

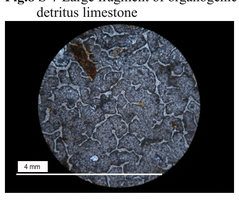


Fig.9 S-8 Cracks in the erlier mortar, "healed" by newly formed light carbonate

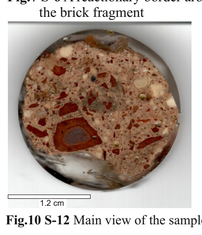


Fig.10 S-12 Main view of the sample

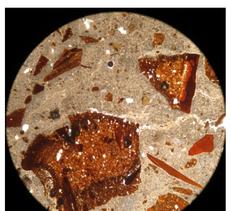


Fig.11 S-13 Dark border on some fragments of brick

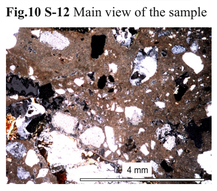


Fig.12 S-14 Accumulation of the aggregate grains

Fig.13 S-15 In the center: the fragment of lime; on the left top: two fragments of *tsemyanka* and white-gray is the fragments of quartz

Fig.14 S-15 Small fragments of quartz (white and gray); the smallest fragments of *tsemyanka* (brown-orange); on the right – a grain of plagioclase; on the left – irregularly shaped pores (black)

Fig.15 S-16 Earlier mortar at the top of the sample

Fig.16 S-16 Homogeneous special burned clay fragment

Fig.17 S-17 A fragment of a brick of light orange color with a dark border

Fig.18 S-17 Elongated fragments of bricks in the binder

Fig.2 St. George Cathedral and the Yuriev Monastery. View from South-East

Discussion

Mortar sample S-1 was taken from the supposedly later foundation, however it contains a sufficient amount of brick fragments (around 15%) to be considered the mortar of a 12th century foundation, and it cannot be dated to this century.

Sample S-2 comes from the floor of the tomb, while sample S-4 comes from a certain 12th century foundation. The mortars are similar, with a large amount of brick fragments (L.:0.3 to 5cm) and a very small amount of quartz (sand, around 5%) and organic material present in both. It is worth noting that fragments of earlier mortar are present in the foundation mortar, possibly taken from some other construction site (for example from St. Nicholas Cathedral on Dvorishche, 1117).

Samples S-6 from the altar and S-7 from the reinforcement of the foundation can be attributed to the time of renovation in the 1820s (according to the archaeological data) [5]. The main difference is the amount of quartz in the altar mortar (45%) and the presence of unburnt limestone and non-homogenized lime (30%) in the foundation mortar, perhaps added to create some kind of supporting structure.

Samples S-12 and S-13 come from the holes left by the now missing beams in the Tower Chapel. S-12 is very friable, was prepared in an epoxy mount. Both mortars contain fragments of clay burnt for this purpose (Fig.10, 11). This addition is not found in the foundation mortars, but the same aggregate can be seen in sample S-17 from the S-W semi-pillar (Fig. 17). The S-W semi-pillar shows two masonries, both of *plinfa* (thin Byzantine bricks) with brick fragments*(tsemianka)*, but they are divided by a vertical seam in the centre of the pillar. The binder on the East of the pillar is similar to that of the foundation mortars (S-2, S-4 with a more grayish color, s. fig. 15, 4, 5) and the brick fragments show the same angular shape. The mortar on the W of the pillar is similar to the mortar from the Tower Chapel (Fig. 11,12,17,18). This suggests that some changes in the structure of the Cathedral were carried out already in the first building period.

Two more samples of mortar were taken from sondage 11 outside the Cathedral. In 2021, during archaeological excavation some unknown construction to the N-E of the Cathedral, perhaps a Medieval wall, was found. Both mortars contain a small amount of *tsemianka* (S-14 2%, S-15 5-6%). They show the same kind of binder, crystalline, cloudy, and of brownish-gray color. Sample S-15 from the debris layer consists of building material, perhaps the remains of destroyed constructions. Sample S-14 from a construction foundation revealed by the archaeological excavation, shows a mortar with more sand and less brick fragments, while the mortar of the wall shows less sand and more bricks.

According to granulometric and petrographic research by Mednikova and al. [2] the total amount of *tsemianka* and the grain size were reduced in the 12th-13th century. In the same period very similar mortars were used in the Church of St. Panteleimon (1134, near Veliki Novgorod): the foundation mortar contains 0.4% *tsemianka* and 11.8% sand in the N-E foundation and few grains of *tsemianka* and 15.9% of sand in the W foundation.

Conclusions

This research allows several very important conclusions:

- Fragments of earlier mortars do not contain aggregates, therefore old slaked lime without any addition could have been used in the preparation of mortar.
- In the last stage of works in the Cathedral builders began to use burnt clay prepared on purpose as aggregate.
- A very important observation is that the clastic shape of quartz grains in the 19th century mortars indicate that the sand was ground before usage.

Future research on the mortars from the Yuriev monastery will give us more information on the building history of the Yuriev monastery.

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