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METHODS OF NATURAL SCIENCES IN THE STUDY OF CULTURAL HERITAGE OBJECTS

Memorial Cross from the Chapel of the Assumption of Kem Cathedral. Reconstruction of the Author's Color Decision on the Basis of the Data of Natural Sciences

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Abstract—A large, carved, polychrome memorial cross, located in the chapel at the Assumption Cathedral in Kem (an accurately dated artifact of the second half of the 17th century) was identified as part of an expedition of specialists from the Russian Museum in 2020. The first comprehensive study of the monument is carried out, the results of which make it possible to accurately determine the materials and technique of execution both of the base and the polychrome cutting. After an initial ultraviolet (UV) study, detailed photofixation, and X-ray fluorescence analysis of the pigments, determination of the composition of the layers of pictorial and metallized cuts is continued using analytical and histochemical methods. The results obtained do not reveal any data that contradict art-history dating. Thus, the result of the study is the identification, attribution and introduction into the information field of another precisely dated site of the White Sea region, and a comprehensive analysis of the finishing materials makes it possible to carry out the proposed restoration of the author's color scheme.

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INTRODUCTION

A wooden memorial cross from the reliquary chapel at the Assumption Cathedral came to the attention of a team of specialists (art historian, restorer, chemist, physics engineer and photographer) of the Russian Museum in the process of working on another similar artifact: fragments stored in the holdings, taken from a large memorial cross at the Muezersky monastery (1681) [1]. In search of stylistic and typological analogies, they turned to artifacts located in the city of Kem, from where the carved image "Fatherland" closest to it in artistic and technological terms comes from (now in the Museum of Fine Arts of Karelia, Petrozavodsk) [2]. As a result, brief references were found to the existence of a high cross in a wooden chapel at the Kem Cathedral [2, 3]. Since the discovered archival photographs did not clarify the situation, we decided to determine the presence of the artifact and its preservation today at this place.

Upon first inspection of the cross during an expedition in May 2021, it became clear that we were dealing with another accurately dated monument of the White Sea region of the third quarter of the 17th century: on both sides, along the lower end of the central horizontal branch of the cross, a carved inscription in ligature with the date of setting was preserved. Surprisingly, the artifact, rare in its artistic features, has so far remained unexplored. This work is the result of the first comprehensive study.

In the matter of preserving artistic heritage, it is especially difficult to study monuments that, for various reasons, cannot be removed from their historical and cultural environment. The entire scope of research activities, available for conducting in situ, was designed to solve a number of problems:

– to collect the maximum possible amount of information about the technique and materials of the artifact. Given that the cross is dated, this was of particular value to researchers;

– to determine the presence and composition of the latest retouching;

– to come up with a number of recommendations on the conditions of housing and conservation measures;

– to conduct sampling and prepare specimens for further research.

OBJECT OF STUDY

For the initial collection of information, the employees of the Russian Museum carried out a measurement and description of the preservation of the monument. The cross is a base with a height of 4.48 m

Fig. 1. General view of the cross in the chapel.

and a length of the central transverse beam of 2.18 m (Fig. 1). On the back side, the axial structure is additionally duplicated by a vertical wooden box. Of the major losses, we will mention the absence of the lower inclined crossbar and, presumably, two images, the grooves for which are located to the right and left of the figure of Christ on the middle crossbeam. A halo, a plate with the inscription "INGI" and part of the right foot are also lost (Tables 1–3).

Despite the fact that the cross has been affected by temperature and humidity changes in the environment, the state of preservation of the artifact as a whole should be considered satisfactory. The most difficult is the condition of the wood and the pictorial layer on the image of the City of Jerusalem, located at the bottom of the cross. Numerous losses and abrasions to the base over the entire surface of the cross attract attention, in which the destruction of wood is clearly visible. There are no traces of large repair of wood; on the oblique crossbeam of the Crucifixion below the figure of Christ there is a small insert of wood. On the back side, the axial structure is additionally duplicated with a vertical wooden box, and also reinforced with a horizontal beam.

In the process of describing the preservation, the main design features of the monument were determined. The cross is made of four tetrahedral beams. The two upper horizontal crossbeams are greatly raised, the unpreserved inclined lower one was located closer to the base (the distance between them is ~2.2 m), due to which the vertical axis seems to be disproportionately elongated. The semantic dominant, i.e., the figure of crucified Christ at the intersection, is higher than human height. The loss of fragments on the middle crossbeam made it possible to reveal the hidden system of manufacturing and fastening the central image. A small eight-pointed cross with crucified Christ (0.9 m without the image of Calvary) was carved separately and consisted of three parts: the main one with the figure of the Savior and Calvary and two side branches with Christ's outstretched arms. Probably, all these details were mounted onto a common base, repeating the contours of the Crucifixion. If the side parts were fixed on it with metal brackets with nails, then it is not yet possible to determine the method of fastening of the central part without dismantling the carved image of the Savior.

The iconographic rendering of the image of the Savior is traditional: the figure has a slight bend, the head is inclined to the right shoulder, and the eyes are closed. The cross is erected on Calvary with two peaks of hillocks and the head of Adam in a cave, on which the letters "G" and "A" are carved on both sides. Below, on the plane of the large cross, the letters "ML" and "RB" are arranged in two rows. Under the letters there is a carved Tree of Life with smoothly curving branches and leaves on them. A distinctive feature of the image is the head with closed eyes located at the foot of the tree. Under the lower crossbeam at the base of the cross is a carved image of the City of Jerusalem.

Table 1. Determining the wood

Sampling location	Vertical pillar of the base	Horizontal base crossbeams	Middle horizontal crossbeam	Vertical box on the back of the base	Carved crucifix	Medallions	Restoration insert
Pine (fam. Pinaceae, *Pinus* sp.)	+	+	+	+			+
Birch (fam. Betulaceae, *Betula* sp.)					+	+	

Table 2. Elemental composition of the samples according to XRFA data

Measuring point	Si	Al	P	S	K	Ca	Mn	Fe	Cu	Pb	Br	Hg	Ag	Au
Place of fastening of the lower crossbar	70.3	11.6		2.2	1.4	5.2		7.2		1.1	0.8			
Back side of the base	70.7	10.8		2	1.5	6		6.5		1.4	0.7			
Upper end of the base	71	11.		2.1	1.1	5.7		7		1.2	0.8			
Architectural cross. Red background	43	14.2	1.2	1.8	1	2.1		16.3		18.8				
Architectural cross. Black background	19.6	6.6	0.8	2.5	1.8	12.6	0.6	2.6		52.7				
Architectural cross. Dark carved background	20.2			1.1	1.3	17.8		2.5	26.4	29.3		2.6		
Architectural cross. Rectangle black colorful background	13.2			1.5	0.9	11.5		1.1	50.6	21				
Architectural cross. Rectangle white colorful background	18.8			2.4	0.5	23.1	0.5	2.7	7.3	44.4				
Architectural cross. Frontal plane. Letters and decoration	43.1	13.1		0.7	0.6	4.4		11.3		21.8			3.8	1.2
Ends. Black background	56.5	13.6	0.6	2.8	4.6	9.3	0.6	4.1		7.2	0.7			
Ends. Letters in white	27	9.7		3.5	10.4	13.1	0.4	3.9	0.4	14.6	0.6		15.8	
Crucifixion. Image of a cross	51.2	17.7	0.8	0.6	1.6	1.9	0	22.6		1.9	0	1.6		
Crucifixion. Image of the body of Christ	45.7	11.7	0.9	2.8	6.2	4.9	0.4	5		22.4				
Crucifixion. Depiction of Christ's loincloth	20	6.6	0.8	1.5	2	2.4		2		64.7				
Crucifixion. Image of the decorative cut of Christ's loincloth	9.3	4.2		1.6	3.2	1.8		0.6		74.4			3.3	1.6
Calvary. Background image	44.1	11.2	0.7	1.2	9.7	6.3		10.6		26.4		1		
Image of the Tree. Black background	56.4	12.3	0.8	1.5	1.8	4.5	1.1	10.7	2.5	8		0.4		
Image of the Tree. Leaves image	26.2	1.1		1	0.8	7.2	0	1.5	55.4	6.8				
City image. Background	62.1	11.6		1.2	1.8	13.2	0.4	7.2	0.5	1.1	0.9			
City image. Yellow	41.4	9.8	0.6	1.4	0.8	4.4	0.3	29.3	2.4	8.6				
City image. Red	11.6	2.8	1.1	1.2	0.9	3.3		8.2	0.3	70		0.6		
Medallions. Image of letters	41.1	11.2		2	1.1	5.4		4.9		28			4.	1.8

At the ends of the two existing crossbeams are circles (d = 0.3 m) with monograms: "TsR'" and "SVY" on the top, "IC" and "XC" on the central. As in the case of the Muezersky Crucifixion, these monograms were made in separate medallions, inserted into grooves specially adapted for them (depth up to 0.02 m) and additionally attached to the base with large forged nails.

On both sides, along the lower end of the central horizontal branch of the cross, an inscription has been preserved: **"ЛЕТА ЗРѰИ (7168) Г МАIЯ В В (2) ДНЬ ПОСТАВЛЕН СИЙ ЧЕСТНЫЙ И Ж // ИВОТВОРЯЩИЙ КРЕСТ ГОСПОДНЬ ПРАВОСЛАВНЫ(М) ХРИСТИАНОМ"**. (In summer of the year 7168, May on the second day this honoured and life-giving cross of the Lord is set by Orthodox Christian).

The composition of the Kem cross, already saturated with symbolic and sacred meanings, is completed by carved inscriptions consisting of fragments of several prayers and troparia. These texts are located on the side ends of the cross, starting from the central horizontal beam to the very base. On each side, 55 lines are carved in a half uncial (with elements of ligatured script), using embossing. The height of the letters is ~10 cm, the letters protrude 1 cm above the background. The background is selected and processed carefully and smoothly.

EXPERIMENTAL

Photo fixation (Fig. 2) of the general view of the artifact and its fragments was carried out in direct and oblique light using Nikon D3 and Nikon D7500 cameras and the lens set: AF-P NIKKOR 70–300 mm f/4.5–5.6E ED VR, AF-S 50 mm f/1.8 NIKKOR, AF-S NIKKOR 24–70 mm f/2.8, AF-S NIKKOR 60 mm f/2.8G ED Micro, Sigma AF 17–50 mm f/2.8 EX DC OS HSM Nikon F. Illumination was provided by a set of LED illuminating lamps in a set of four master alpha 16 LED 4000K LED illuminators (provided by MASTER lighting systems).

Identification of the base material was carried out by the microscopic method, including the signs of the

Table 3. Binder for layers of pictorial and decorative cutting

Sampling location	Priming	First paint layer (presumably the author's)	Cover layer	Later colorful layers	Presence of varnish
Architectural cross. Red background	–	Protein	–	Oil	–
Architectural cross. Black background	–	Protein	–	Oil	–
Architectural cross. Dark carved background	–	Protein	–	–	–
Architectural cross. Rectangle black colorful background	–	Protein	–	–	–
Architectural cross. Rectangle white colorful background	–	Protein	–	–	–
Architectural cross. Frontal plane. Letters and decoration	Protein	Protein	Oil	Oil	–
Lateral plane. Black background	–	Protein	–	–	–
Lateral plane. Letters in white	Protein	Protein	–	–	–
Crucifixion. Image of a cross	Protein	Protein	–	Oil	–
Crucifixion. Image of the body of Christ	Protein	Protein	–	Oil	Based on alcohol-soluble resins
Crucifixion. Depiction of Christ's loincloth	Protein	Protein	–	Oil	–
Crucifixion. Image of the decorative cut of Christ's loincloth	–	Protein	–	–	–
Calvary. Background image	Protein	Protein	–	Oil	–
Calvary. Image of letters	Protein	Protein	–	Oil	–
Image of the Tree. Black background	Protein	Protein	–	–	–
Image of the Tree. Leaves image	Protein	Protein	–	Oil	–
City image. Blue	Protein	Protein	–	Oil	–
City image. Yellow	Protein	Protein	–	–	–
City image. Red	Protein	Protein	–	Oil	–
Medallions. Image of letters	Protein	Protein	Oil	–	Based on alcohol-soluble resins

anatomical structure of the wood samples, by comparing them with standards. In the course of the study, ultrathin sections were made along three planes, which were then examined in the transmitted light of a BIOLAM-I microscope with a magnification of up to 250× (Fig. 3).

After the stage of measurement of the artifact and sampling of the wood, the entire accessible surface of the crucifix was studied. The nature of the UV luminescence (illumination was carried out by two LED UV illuminators with UV filters "master alpha 16 UW365 LED") made it possible to assume the presence of several types of binder on different parts of the composition and to record later retouching and repairs. A study in the near-infrared (IR) region (a Nikon D70 camera modified to shoot in the 700–1050-nm IR range, illuminated by two "master alpha 16 IR850 LED" IR illuminators) provided information about the absence of the underlying preliminary drawings and compositional changes.

The specifics of the in situ study of the artifact is manifested, among other things, in an extremely limited set of available research methods. Difficult working conditions, on the one hand, and the presence of an extremely small amount of mobile equipment, on the other hand, make the work planning stage and the sampling- and sample-preparation algorithm important. The problem of obtaining comprehensive information about the stratigraphy of the decorative coating with a minimum number of samples was solved as follows.

By means of portable X-ray fluorescence analysis (XRFA) more than 300 measurements were performed (portable XRFA Delta Innov-X ("Olympus") (silicon drift SDD detector; X-ray tube anode material was rhodium), the spot diameter on which the measurement was made amounted to 1 mm), including:

– samples of all color mixtures; special attention was paid to the convergence of the results of the elemental composition of the cutting of paired or similar elements;

– an analogue of the mapping of extended sections, executed in one color;

Fig. 2. Photographing the cross.

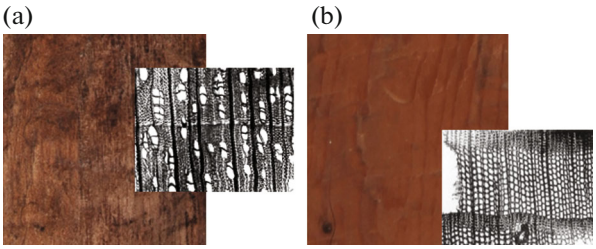

Fig. 3. Macrophoto and cross sections (×230) of pine (a) and birch (b).

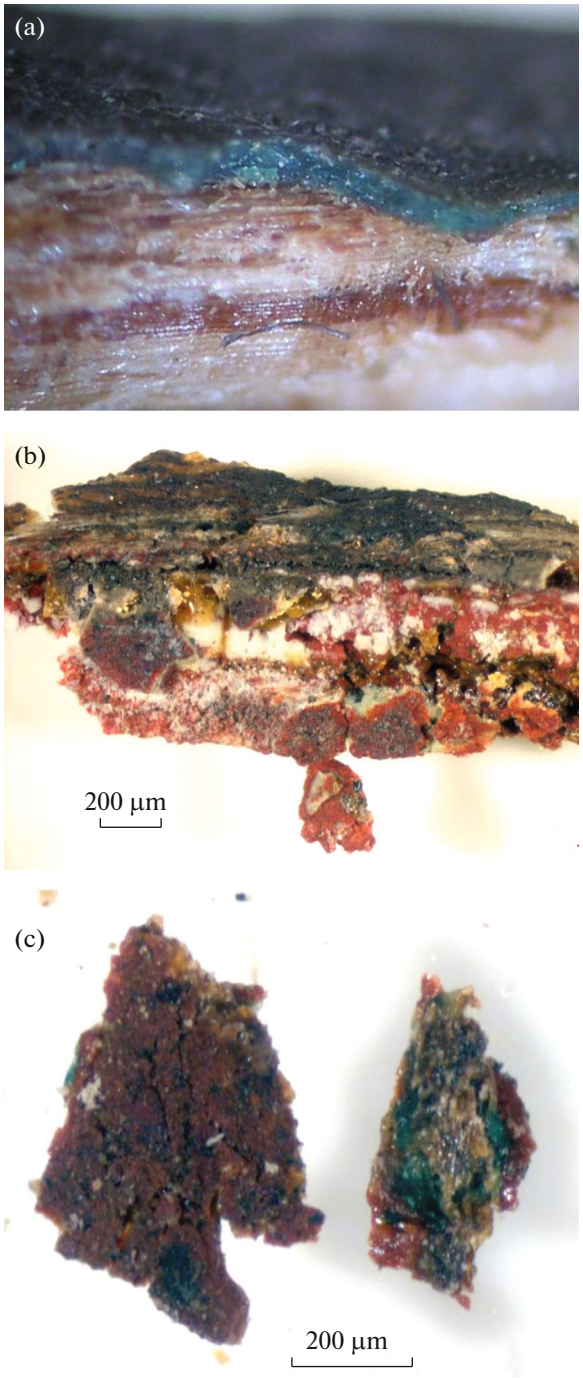

Fig. 4. Fragments of pictorial cutting from the image of the Tree of Life (a), the medallion of the first row (b), and from the image of the second row (c). Photo in reflected light.

– finishing elements, the macrophotographs of which made it possible to suspect the presence of underlying layers.

The first results of XRFA made it possible to detect metallized cutting on a number of elements of the composition, which, due to the state of preservation, was not visually determined.

The results of XRFA made it possible to accurately determine the sampling sites for further research.

Samples of all color mixtures were taken with a microscalpel, as well as fragments of the finishing of those areas, the results of XRFA of which left questions. If the XRFA data obtained in different areas of the same type of cutting of each element coincide, for subsequent conclusion about the author's technique, it was considered sufficient to conduct a detailed analysis of one sample. The discrepancy between these data both for one element and when comparing elements of the same type of composition required addi-

tional research. Thus, ~50 samples were taken. The sample was fixed in direct reflected light at a magnification up to ×50 (Fig. 4) (Zeiss Stemi 2000C microscope with an Axiocam 506 color digital camera and Zeiss KL 1500 LED illuminators). Then, immersion preparations were made: thin sections in which all layers of each microsample were represented, and samples of each paint layer were individually placed between a slide and cover slips in a layer of Copaiba balsam for further study in transmitted light and polarizing microscopy at a magnification of ×70–100. Determination of the pigments and organic binders of all layers by microchemical qualitative analysis and histochemistry was carried out on the remains of the selected material.

When determining protein binders, a biuret reaction, universal for all proteins, was carried out. To verify the results, sections of the microsection or fragments of the layer were stained using amido black dye [8].

To identify lipid binders, i.e., drying vegetable oils, a saponification reaction was carried out, in which, during hydrolysis, lipids decompose into glycerol and fatty acids. The fragment was placed in an aqueous solution of NaOH, and the saponification process was observed under a microscope in reflected light against a dark background [8]. Resins were determined using the Storch–Moravsky reaction [8].

The data obtained made it possible to determine the author's method of cutting, to draw up a stratigraphic scheme of the coloristic cutting of the artifact with later retouching, and to propose a variant of the reconstruction of the appearance.

RESULTS AND DISCUSSION

Construction and Base Materials

In the process of measuring and describing the preservation, 12 samples of wood were selected, one from each fragment of the composition, including restoration inserts and the duplicating structure. As a result, it was found that the base and technical and architectural elements are made of pine (family Pinaceae, *Pinus* sp.), while the crucifix itself with the figure of Christ and individual medallions inserted into grooves specially fitted for them are made of birch (family Betulaceae, *Betula* sp.) [4, 5].

The density, strength and suitability for processing by cutting tools of wood of both species are very close, while pine is more resistant to decay due to the resin content. These tree species are equally widespread in the territory of Karelia.

Materials for Pictorial and Decorative Finishing Layers

Priming (a thin white layer based on white lead and a protein binder) was found exclusively as a preparatory layer for metallized cutting.

Colorful layer. The author's binder is protein. The binder of the later retouching of some areas (for example, such as the background of the medallions) is oil.

The author's color decision is somewhat different from the current state. Analysis of the selected samples made it possible to conduct a full-fledged stratigraphic study, the results of which were as follows:

– the general background of the architectural cross was made of red lead (minium);

– the painting of the figure of Christ is multi-layered (from three to five layers) with a smooth change from dark reddish-ocher to light beige. The composition of the layers includes: white lead, ocher, red lead (minium), cinnabar, and a small amount of chalk;

– the loincloth is made using white lead. The geometric cutting of the now black color along the lower edge of the fabric is made using gold and silver;

– since the state of preservation of the polychrome finish of the carved image of Jerusalem is unsatisfactory, it is possible to draw unambiguous conclusions about its coloristics only from the remains of the polychrome cutting in the recesses of the relief. The painting, as in other areas, was done with paints based on a protein binder using red lead (minium) and white pigments, ocher;

– the medallions of the upper crossbar are somewhat different from the medallions of the middle one not only in terms of their compositional solution, but also in the composition of color mixtures. The letters "IC" and "XC" in the middle register are carved on a diamond-shaped base and decorated with floral decorations, while the medallions of the upper register are more strictly resolved and represent letters against a white circle. All medallions have a red border, separated from the background and the central part by embossed rims. The painting on the edge of the medallions reveals three layers, including retouching: a red layer based on a protein binder using iron red and a small amount of coal; a white layer based on an oil binder using white lead and rare inclusions of azurite; the top layer based on an oil binder is red lead (minium).

At the top register medallions in the middle of the white color, you can see two layers of paint: the lower layer on a protein binder using indigo and white lead, the upper dirty white color is white lead on an oil binder. The top coat is a heavily soiled oil varnish. In the medallions of the lower register, the white centerpiece is made using white lead with the addition of a small amount of copper and cinnabar, while the pigment composition of the diamonds does not include cinnabar.

The painting of the large red cross has several colorful layers (the first is a protein binder, then oil), including white lead, red lead, and hematite (Fig. 5). The ends of the central crossbar are made of black soot over a layer of white lead. Thin backgrounds along the perimeter of the entire cross have three types of cut-

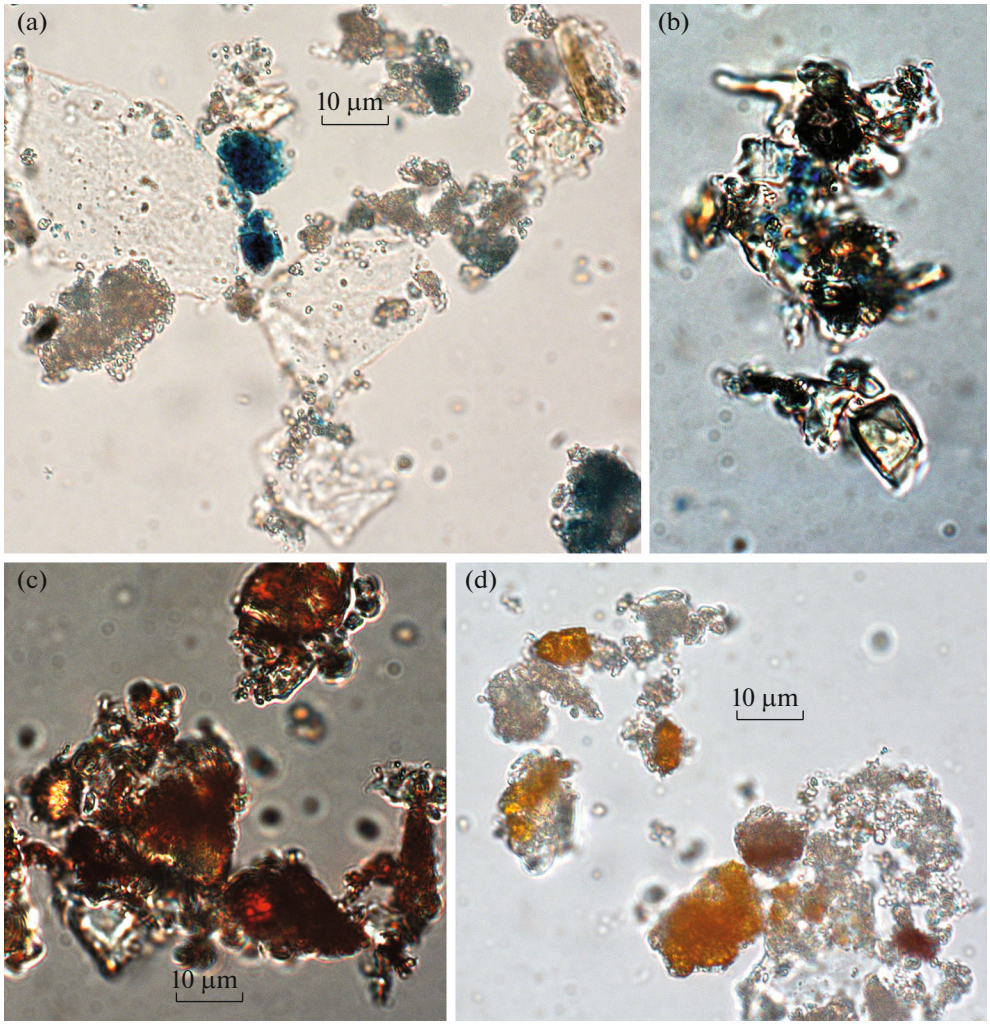

Fig. 5. Some pigments used in the cutting: indigo (a), white lead (b), cinnabar (c), iron-containing pigment (d). Photo in transmitted light.

ting: monochrome dark gray at the ends of the middle intersection (copper pigments); alternation of rectangles of dark (copper pigments) and white (white lead) colors on the central Crucifix; a background of white with a cutting in the form of carved recesses of round shape (white lead). The background of the carved inscriptions on the sides of the cross is black on lead primer. Small areas of red color do not coincide with the cutting of the frontal part and are made with hematite [6, 7].

Metallized cutting is varied. The rims and letters of the medallions and the letters of the frontal plane of the architectural cross are finished with gold and silver (so-called "double"), the decoration on the medallions and the letters on the side planes are silver, and the decorative cutting of the background and some elements of the image of the tree are made of copper.

Thus, even the first stage of a comprehensive study, carried out using a number of mobile and fairly accessible methods, has made it possible to determine and describe the materials and design features of the base of the artifact, its pictorial and metallized cutting. All revealed and determined materials used in the creation of the cross do not contradict either the geographical location or the art-history dating. The different types of binders found during the study of the samples make it possible to fairly reasonably determine the author's decision even in the absence of a widespread cover layer separating the original cutting from later retouching. The metallized coating detected by the XRFA method also greatly changes the idea of the original color scheme of the artifact (Fig. 6).

CONCLUSIONS

In summary, we can say that the main results of the expedition are the identification and authentication of a dated artifact from the middle of the 17th century.

The data of natural-science research do not contradict the dating of art history and introduce into scien-

Fig. 6. Reconstruction of the appearance of the artifact.

tific circulation a large amount of factual data on the medieval polychrome carved plastic art of the White Sea region. Reasoned selection of materials allows us to confirm the assumptions of art historians in a short time, including obtaining more detailed information about the existence of the artifact, and clarifying the sequence and features of renovations. A mobile group of specialists of various profiles, having a necessary and sufficient set of research equipment that meets the tasks of a particular expedition, is able to comprehensively study immovable or hard-to-reach cultural heritage artifacts, collecting and analyzing information directly on the spot.

Understanding the author's methods and color solutions allows not only to draw up a number of recommendations in the field of conservation work, but also to develop a methodology for further restoration activities.

It should be noted that such experience can be useful in working with large-scale art artifacts, regardless of their remoteness from modern research centers and legal ownership.

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