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ARCHAEOLOGICAL IRON CONSERVATION: THEORETICAL BACKGROUND OF FINDS DETERIORATION, ORGANIZATION AND SUPPORT OF PRESERVATION ACTIVITIES[1]

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The paper considers the theoretical background of archaeological iron deterioration on the different stages of the artifacts “life cycle” (period of use, period of burial in the ground, excavation stage), the organization and supports of *“in-situ”* measures in field conservation on the example of the expedition on the Bahai (AD 698—926) archaeological site in Kraskino (the south of the Russian Far East), as well as the main stages of the post-excavation procedures for the treatment of iron archaeological objects (laboratory stabilization, conservation, and long-term storage). The experience described in the paper increases the variability of workable solutions to the problems and methodology of field conservation while accompanying the entire cycle of the archaeological iron objects conservation.
Keywords: conservation science, field *“in-situ”* conservation, archaeological iron, Kraskino walled town, Bohai (AD 698—926).

INTRODUCTION

Archaeological finds are one of the primary factual information carriers in archaeological research. Almost all finds need special preservation treatment. Generally, the conservation process includes three stages: *(1) “in-situ”*

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field conservation, *(2)* treatment in the laboratory, and *(3)* long-term storage (Буравлев и др. 2021). The most stressful stage for the objects is after removal from the soil accompanied by rapid changes in environmental parameters. At this stage, it is critical to provide *"first aid"* to the finds, pack them properly, and start the stabilization process as soon as facilities permit. The success of implementing a set of measures for the preservation of a unique find will depend on the collaboration of archaeological and conservation teams.

The *"in-situ"* field actions are poorly reported in the literature, usually in the format of a set of recommendations that provides only the basic knowledge necessary to develop solutions to conservation problems. There are some reasons for this. First, the approach to research in this field involves the identification, systematization, and analysis of a significant amount of different practical solutions whose academic significance is underestimated, so the goal is not to describe them in detail in the scientific literature. Thus, successful solutions from a practical point of view are recorded in the restoration passport and in the reports on the fieldwork, which are not always publicly available. Secondly, when organizing an archaeological expedition, the tasks of historical research and providing living conditions for the field unit are the dominant ones. At the same time, conservation issues are often undeservedly regarded as secondary.

Regardless of the strategy chosen for archaeological materials conservation, one thing is sure — the worst-case scenario is to postpone the beginning of the conservation process indefinitely. The earlier the conservation work begins, the more guarantees that the object's material will not have hidden causes of destruction at the time of the completion of the treatment. The task, therefore, comes down to the successful organization of processes, equipment, and tools, typical of a traditional set of laboratory activities in the conditions of a particular archaeological expedition. It involves taking into account the possibilities, limitations, and individual features of the expedition conditions.

The archeological sites of Primorsky Krai in the summer are characterized by a constant 100% relative humidity and temperature fluctuations from 15°C at night to 30—45°C during the day. The worst condition among the others is the objects found in the territory of the Bohai settlements (Kraskino, Gorbatka). Firstly, this is caused by the quality of soil, and secondly, by features (imperfections) of metal of this era. From this point of view, the experience of the preservation work gained in the territory of the ancient settlements of Bohai is of particular interest for working out the methods of field *"in-situ"* conservation.

In the field season of 2021 we developed the *"in-situ"* conservation concept which was further tested in the conditions of the archaeological expedition to the Kraskinskoye ancient settlement. Kraskino site is located on the shore of Expedition Bay near the Tsukanovka (Yanchiche) River (Fig. 1). Kraskino was the center of the district Yanzhou (Salt District), which was part of the area governed by the eastern capital Lunyuanfu (Balyancheng site near

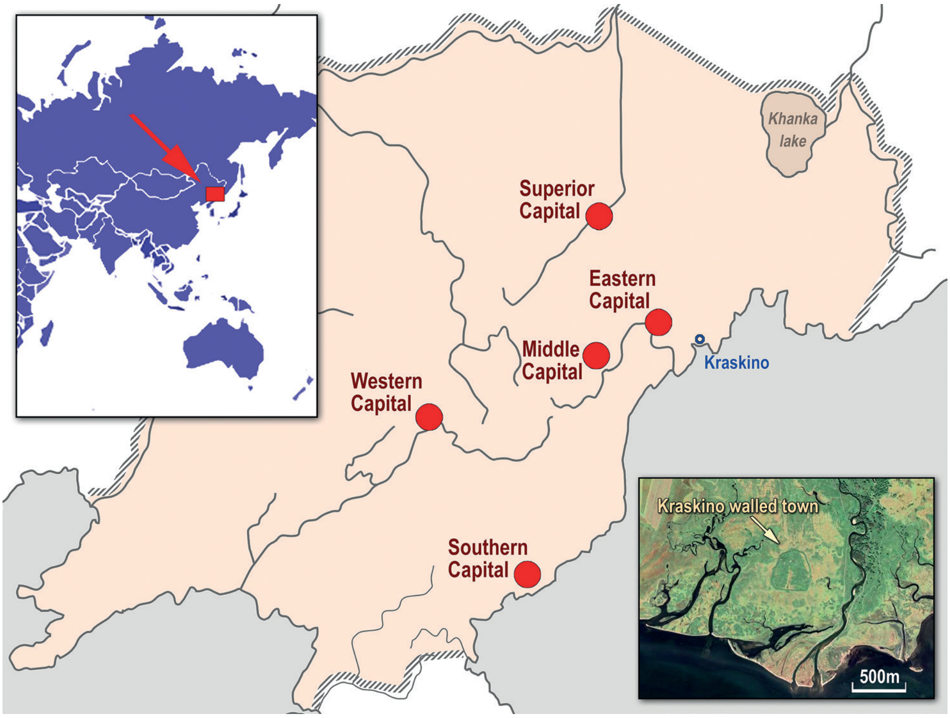

Fig. 1. The Bohai State's territory (AD 698—926)

Hunchun), located about 50 kilometers from the Kraskino. Medieval city with an area of more than 13 hectares and a length of fortress walls 1380 meters performed an administrative function and was an important trade and craft center and seaport, to which the land and sea roads. Through this port diplomatic and trade relations were maintained with Japan, China, and the United Silla, and its name is recorded in Chinese chronicles (Ивлиев, Болдин 2006; Шавкунов 1994).

Iron archaeological objects are found on this ancient site in layers II—V of its period and, as a rule, are very poorly preserved. The poor preservation of the objects lies in the salt-saturated soil near seawater. The accumulated 30-year experience of working with objects collected on the territory of this site has shown that they very quickly deteriorate without conservation. After six months, the finds deteriorate with a 30—40% loss.

In 2021, the excavations were located at a site approximately 40 minutes away from the field campsite by walking. It was not possible to deliver the contingent and equipment to the excavation site using special transport. A portable set of the necessary tools and a considerable amount of packing material was prepared for the conservator. During the four weeks of the expedition, more than sixty archaeological iron finds were unearthed. 90% of the finds are solid and stable, with minor damage to the surface. There is also a small amount of soil residue and corrosion layers on the surface of the objects. Therefore, these finds were packaged using the dry packing method. 10% of the items required immediate placement in a humid environment. In the absence of this measure, the damage would have been significant.

All the necessary materials and tools for conservation were packed into a portable case so that treatment could be carried out both in the expedition camp and directly near the excavation site.

An additional stage of the project was an educational block. The conservator was tasked to hold a lecture for the students who participated in the expedition, some of whom were undergraduate and graduate students in History and Pacific Archaeology master's programs. There was a literacy, recommended materials for self-study, and recommendations on the primary processing of the archaeological iron in the field for the expedition participants. Such events should raise the awareness of young specialists in this field and popularize the preservation of iron artifacts among representatives of archaeological science.

The paper investigates the current state of archaeological iron objects conservation and evaluates the possibility of adapting its processes to field *"in-situ"* conservation conditions. The consecutive solution of four tasks achieves the goal set in the present work: *(1)* analysis and generalization of the contemporary theory of archaeological iron deterioration; *(2)* development and provision of the field laboratory staffing and work concept; *(3)* analysis of traditional and alternative methods used in the processing of archaeological iron in a laboratory with an assessment of the possibility of their complete or partial transfer to field.

THEORETICAL BACKGROUND OF ARCHAEOLOGICAL IRON DETERIORATION

Present-day science uses archaeological analogs to predict corrosion phenomena over long periods (Dillmann et al. 2014). In particular, soil and atmospheric corrosion studies are related to nuclear waste's long-term storage (Monnier et al. 2008). From this point of view, interest in archaeological objects deterioration is relevant not only from developing effective measures for long-term preservation but also fair and permissible to extract information about the decay mechanisms of archaeological materials from science sources.

Deterioration of iron finds can be divided explicitly into lifetime period of the find (the period of use of the object until it is abandoned), formed in the process of burial, and post-excavation (the moment of removal from the ground, restoration-conservation intervention, long-term storage).

All the possible activities carried out with iron can be considered in the sequence of individual stages of the existence of an archaeological object. Fig. 2 shows the model of *"life cycle"* of objects made of iron. According to the model proposed, the object is made, then it is used. At some stage, the moment of non-use comes, and it turns out to be buried in the ground, where the object stays for an indefinite period. The object is removed from its

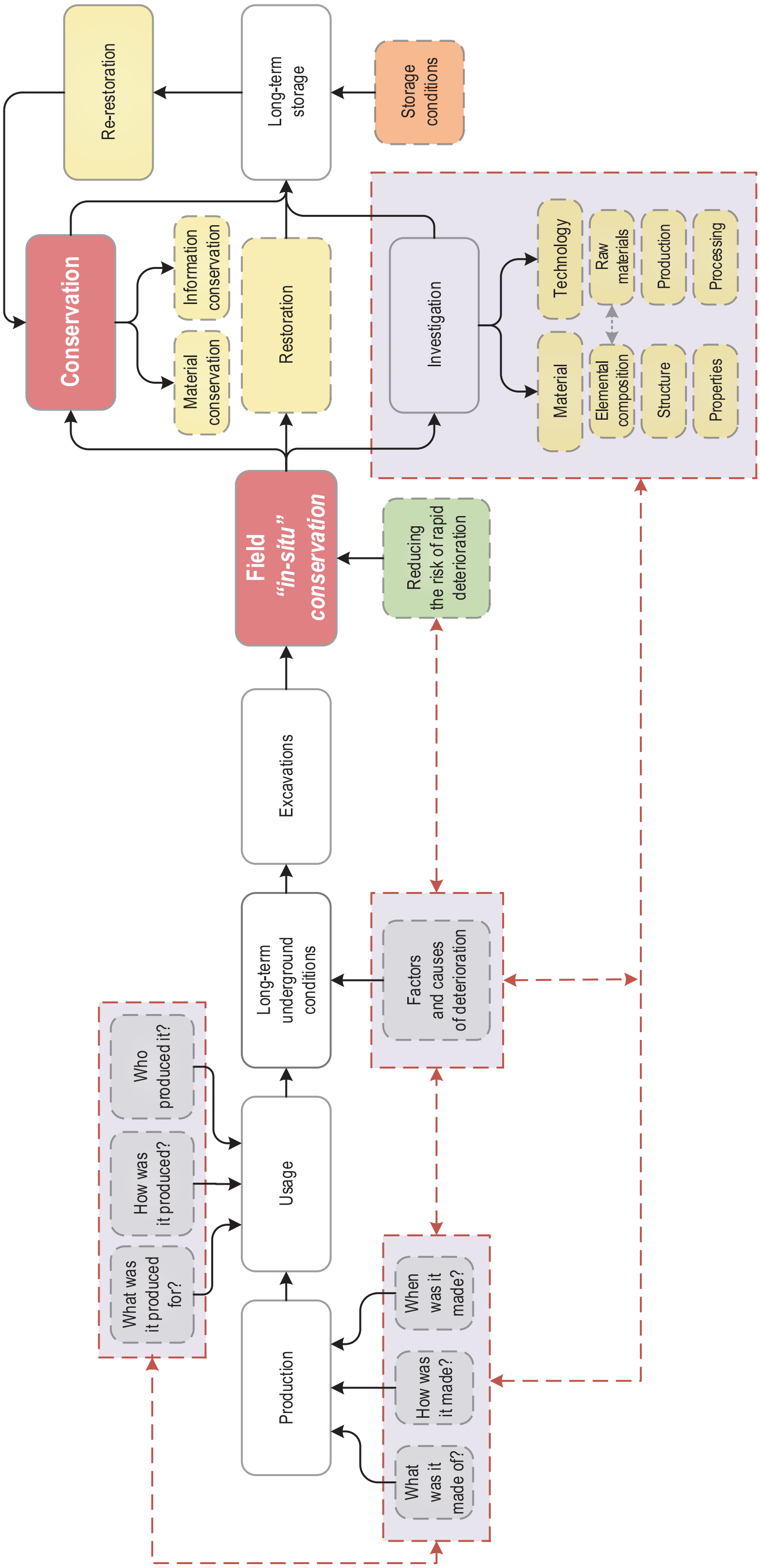

Fig. 2. The model of *"life cycle"* of an iron archaeological object

environment during excavations, and the primary *"in-situ"* preservation measures in the field are carried out. Then the object is comprehensively examined, processed in the laboratory, restored if necessary, and then passed on to long-term storage. After a certain period, the object undergoes a new treatment. A similar cycle can be presented for all materials (including those of non-archaeological origin). The *"life cycle"* described is also suitable for bronzes and ceramics.

Period of use of the object

The main questions that archaeological science addresses to an object when considering the likelihood of its being made in one way or another are to examine the composition, structure, and properties of the material. The task generally comes down to answering the questions "What is it made of?", "How is it made?" and "When is it made?". The conservation and restoration process always involves determining the material. This stage in the complex of conservation measures is disclosed to determine whether the material belongs to one type or another. The conservation process can involve the broadest range of physicochemical research methods, which is aimed purely at extracting information that allows improving the conservation processes but which are of no side value for the needs of historical research (Stuart 2007). Not all the information to solve conservation issues can be used to solve the problems of historical research.

Period of burial in the ground

The deterioration of an iron alloy in soil conditions is due to the heterogeneity of its chemical composition and its structural components. Underground, iron is affected by corrosion. As a result, iron mineralizes to the chemical compounds similar to those in which it was in the ores.

In soil conditions, corrosion processes in iron-carbon alloys proceed by the heterogeneous mechanism at the interface during the interaction of solid matter with the liquid. In soils, iron-carbon alloys have constant contact with the soil solution, which determines the electrochemical nature of corrosion. Soil solution is an aqueous electrolyte, in the presence of which anodic oxidation of iron is possible: $Fe^0 - 2e^- \rightarrow Fe^{2+}$, $Fe^{2+} - e^- \rightarrow Fe^{3+}$. In most corrosive environments, the anodic oxidation reaction proceeds at a high rate. The probability of the cathodic reaction $2H^+ + 2e^- \rightarrow H_2$ will depend on the environment (it is possible at $pH < 4$). The most straightforward scheme of the metal corrosion mechanism of an iron archeological object can be represented as the following main stages: *(1)* transport of reactants to the interface; *(2)* chemical interaction of reactants with metal; *(3)* removal of reaction products from the reaction zone. The structural components of alloys of the $Fe—Fe_3C$ system differ in the value of the electrode potentials, so the short-circuited corrosion microelements formed by contact of these alloys with electrolyte solutions work very intensively. The intensity of the electrochemical corrosion process depends on the level of impurities dissolved in the electrolyte. There is a migration of anions in the corrosive system. The system intends to decrease the surface energy because the charge of potential-determining iron ions, directly connected to the surface, is compensated by the charge of anions coming from the surrounding electrolyte. The dominant anions in the soil solution are Cl^- anions. Chlorides are present in almost all soils; their concentration depends on the geographical factor. Cl^- anions dominate in diffusion processes due to their mobility. As a consequence, iron chloride is formed: $Fe^0 - 2e^- \rightarrow Fe^{2+}$; $Fe^{2+} + 2Cl^- \rightarrow FeCl_2$. Cl^- anions increase the conductivity of the electrolyte and have the ability to activate the metal, displacing passivators from the surface, thus facilitating the transition of metal ions into solution (Selwyn et al. 1999; Turgoose 1993).

As a result of anion adsorption on the surface of the anode particles, an interphase double electric layer is formed. The passage of electric current through the electrode-solution interface causes polarization of the electrode after specific non-equilibrium processes occur, the double electric layer structure changes. Concentration anodic polarization results in an increased concentration of ions in the anode zone. The pores in the corrosion product near the anode site are filled with iron chloride.

As an iron object is corroded, the anodic and cathodic reactions become localized. The anodic and cathodic polarization decreases the potential difference and, therefore, reduces the corrosion current. The magnitude of the corrosion current drops after the circuit is closed and becomes constant after a specific time. A shift in the initial potential values with a decrease in their difference leads to depolarization of the electrodes. The corrosion rate decreases, and the acidity in the anodic area increases due to the reaction of iron hydrolysis Fe^{2+} to form $Fe(OH)^+$ and H^+ in solution (Selwyn et al. 1999): $Fe^{2+} + H_2O \rightleftarrows Fe(OH)^+ + H^+$.

Forming phase or adsorption layers on the surface that inhibit the anodic process can slow the corrosion process. Protective phase films on the anode can be formed due to the deposition of weakly soluble secondary corrosion products on the metal surface, hindering the electrolyte's access to the metal surface. The passive film formed on the iron is not strong enough and is easily destroyed when the metal is removed from the passivator area. Iron passes into the solution with the corrosion product in Fe^{2+} cations, which are then oxidized to Fe^{3+} cations. Under corrosion conditions in soils, the surface of iron is passivated by irregular, loose, brittle, and poorly bonded with the metal surface corrosion product, cemented with organic inclusions, sand, and other impurities. The oxide film on the surface of the metal consists of a mixture of different compounds of iron that has a variable composition. It does not meet the requirements for protective oxide films. The formed layer cannot protect the iron from corrosion in the presence of an aqueous electrolyte.

Anodic depolarization and thickening of the passivating film of weakly soluble iron corrosion products slow down the intensity of reagent diffusion to the anodic area over time. Eventually, the material of an iron archaeological object as a system consisting of residual metallic iron and its corrosion products can reach a relatively stable state. In this state, iron archaeological objects can remain in the ground for many centuries, undergoing slow deterioration.

From all of the above, it follows that the preservation of an object in soil conditions is affected by many different factors. Since soil is a polyfunctional heterogeneous open changing four-phase system (solid, liquid, gaseous phases, and living organisms), it is impossible to consider its influence on the object's condition in separate periods of centuries-long contact with the surface of archaeological iron. Soil conditions in the process of soil corrosion directly impact the object and the qualitative composition of the various compounds of the corrosion product.

Excavation stage

In the underground, oxygen access to the object is limited. There are no drastic temperature fluctuations, the humidity is relatively constant, and there is no access to light. The material's pseudo-equilibrium state of nature conservation in such conditions results from forming a layer of corrosion products on its surface, which acts as a protective barrier. Removing archaeological objects from the environment of natural microclimatic conditions inevitably accelerates destructive processes in the material. The excavated object is affected by a more oxygenated environment, has excessive humidity, and has a higher temperature with a wide range of temperature fluctuations. The extracted object is affected by light, which destroys dyes and pigments. The object is subject to the changing effects of bacteria, fungal spores, and other chemicals and biochemicals. Under such conditions, the process of biodegradation of preserved organic materials is usually activated, corrosion of many metals is accelerated, and there is a risk of desiccation. Higher temperatures and open access to oxygen accelerate chemical reactions and intensify biodegradation. For objects recovered from wet or waterlogged environments, moisture loss, especially abruptly, leads to destruction.

Humidity, temperature, and gas composition of the air directly impact the qualitative composition of moisture films formed on the metal surface. Consequently, various iron compounds, their oxides, hydroxides, and oxyhydroxides, are active precipitates.

Active corrosion of iron archaeological objects. Extraction of the object from the ground is accompanied by a rapid change in the complex physical parameters of the environment. Hydration of hygroscopic compounds of chloride iron salts $FeCl_x$ accumulated in the anode areas at the boundary of metallic iron and in the corrosion product leads to forming a yellowish-red solution with pH 1—3 in the layers of the corrosion product. The solution formed is sufficiently mobile to fill the entire volume of mineralized iron. In some cases, droplets of the solution appear on the material's surface (Fig. 3). This phenomenon is the first visible sign of active iron corrosion. As usual, it is observed

a *b* *c*

Fig. 3. The most common iron archaeological objects deterioration: *(a)* signs of active corrosion with ferric chloride solution on the surface of freshly excavated an iron archaeological object, *(b)* the accumulation of ferric chloride salts and other chloride containing compounds, and *(c)* their effect on the object deterioration after moisture loss and crystallization accompanied by volume changes

after 20—30 minutes after excavating the object from the soil. Thus, heterogeneous electrochemical processes taking place in thin layers of moisture condensing on the metal surface are of great importance at the stage of iron object extraction from the ground.

The high surface tension can hold the drops of ferric chloride solution on the object's surface in a characteristic spherical shape. Since the concentration of dissolved O_2 at the interface between the air and the outer shell of the ferric chloride solution is of the most significant importance, solid oxyhydroxide *FeOOH* can form in this area. The *FeOOH* shell is fragile and brittle; its destruction can form defects on the surface of metallic iron and its mineralization products in the form of craters of various shapes and sizes. The increase in the volume of *FeOOH* causes stresses, cracks, and damage, which, in turn, create favorable conditions for oxygen and moisture access. The hydrolysis of iron cations explains the formation of the *FeOOH* shell at the liquid-air interface, where the concentration of dissolved O_2 is maximum.

The more intensively the ferric chloride solution is formed on the object's surface, the more pronounced the object's destruction afterward. If the iron object is excavated from the ground, exposed to humid air, and subsequently subjected to drying, the dehydration of the compound $FeCl_x \cdot nH_2O$ is accompanied by accumulative crystallization. It leads to the concentration of salts in the pores of the material and some areas. At the interface between the metallic iron and the corrosion product, the concentration of crystals will be much higher than it was when removing the object from the ground. The powdery mass of yellow and red color is represented by a set of $FeCl_x \cdot nH_2O$ compounds and oxyhydroxides. By increasing its volume, the crystallizing salts create pressure in the micro-volumes of the material. The salt solution's pressure supersaturated overcomes the material's mechanical strength, thus causing its destruction — stresses accumulate in the object in micro-volumes, which leads to the appearance of macroscopic defects. As a result, the outer corrosion layers separate from the metallic remains.

This very type of deterioration — accumulation of collective crystallization concentrations at the boundary of metallic iron and corrosion product — is most typical for the absolute majority of cases of destruction of iron archaeological objects. According to the mechanism described above, even the specimens that demonstrated relative stability at the time of removal from the ground are already decayed after four months of storage in room conditions.

Shape metamorphosis of the artifact. Almost all iron archaeological objects have a metamorphosed form after a long stay in the ground. Corrosion damage can vary in geometric character and volumetric changes. Grinded and polished objects may have a more uniform, continuous oxide film on the metal surface. Forged objects retain the geometrically regular shape of their metal residue. An iron archaeological object may have a metallic iron residue or may be entirely a product of corrosion. The corrosion product may contain sedimentary minerals (mineralogical and organic inclusions). As a result of the increase in volume due to iron mineralization, the layer of the formed corrosion product may repeat a typologically similar shape to the object or form with it a conglomerate that is difficult to describe.

Air Oxygen Access. Access to oxygen intensifies the corrosion process. Atmospheric corrosion of the iron in the presence of $FeCl_2 \cdot 4H_2O$ and β-$FeOOH$ compounds stops at 12% relative humidity (RH) (Wang 2007). At 25% RH, there is a sharp increase in the intensity of the process. The synergistic effect of corrosion in the presence of a continuum of compounds $FeCl_2 \cdot 4H_2O$, β-$FeOOH$ and iron implies a much greater deterioration than the sum of damages caused by each of these compounds separately. It is known that at a RH value less than 19%, tetrahydrates $FeCl_2 \cdot 4H_2O$ turn into dihydrates $FeCl_2 \cdot 2H_2O$, in the presence of which the corrosion of iron is impossible. However, it should be noted that as a result of reduction of iron in the area of contact of chloride iron solution with the residual metallic material with the formation of $FeCl_2$ compound, crystals of $FeCl_2$ are formed, which have a cubic shape and, depending on the concentration of the reagents, can reach a crystal size with a cross-section of more than 1 mm.

The phase composition of the archeological iron corrosion product. In well-ventilated soils, the metallic remains are surrounded by a thick layer of corrosion products consisting of iron oxyhydroxides, which may contain a mixture of maghemite γ-Fe_2O_3 and magnetite Fe_3O_4. In the case of corrosion processes in oxygen-free soils containing carbonates, corrosion layers may also contain siderite $FeCO_3$ (Lubelli et al. 2006). A study of the content of various phases on various objects from various sites shows that chloride-bearing phases can form both in chlorine-rich media and in media where the chlorine concentration is relatively low (about 10 mg/l) (Lubelli et al. 2006). Compounds such as vivianite $Fe_3(PO_4)_2 \cdot 8H_2O$, strangite $FePO_4 \cdot 2H_2O$, siderite $FeCO_3$ are often mentioned in the literature as components of the corrosion product (Matthiesen et al. 2003; McGowan, Prangnell 2006). In addition, the corrosion product may retain traces of various other materials, such as wood or textiles. Various kinds of organic material are of undeniable value for archaeological research, including radiocarbon dating, so they should be preserved.

Formation of oxyhydroxides. The process of metastable oxyhydroxide formation is accompanied by a change in the pH value in the corrosion medium: $4Fe^{2+} + O_2 + 6H_2O \rightarrow 4FeOOH + 8H^+$. The decrease of pH value in the corrosive media directly impacts the rate of local corrosion processes and solubility of corrosion products, which, in turn, becomes the cause of physical destruction of the historical material — the appearance of cracks and weakening of the object (Turgoose 1993). The material is cracked, and oxygen access to the residual metallic iron significantly increases (Selwyn et al. 1999). Iron oxyhydroxides are present in abundance in soil and sedimentary rocks in the form of nanosized particles, where they form agglomerates with oxides and hydroxides (Kaneko 1989; Otte et al. 2012). The crystal lattice of oxyhydroxides is made up of metal cations, hydroxyl ions, and oxygen ions (Чалый 1972). The composition and properties of oxyhydroxides depend on deposition and aging conditions. Synthetic oxyhydroxides generally have a consistent color and shape. Several polymorphic modifications of iron oxyhydroxides are found in the mineralized layer of iron archaeological objects: *α*-, *β*-, and *γ-FeOOH*. Of these, *α-FeOOH* (goethite) is the most common and thermodynamically most stable polymorphic modification of *FeOOH* (Otte et al. 2012; Thickett, Odlyha 2010). The adsorption properties of the *β-FeOOH* crystal surface create favorable conditions for the occurrence of local corrosion. The formation of *β-FeOOH* removes Cl^- from the solution, but further interaction of *β-FeOOH* with water vapor leads to chemical adsorption of water on the surface (Schwertmann, Cornell 1991). Water dissolves chlorides to form an electrolyte (Blytholder, Richardson 1962; Kaneko 1989). In addition, the hydrophilic surface of *β-FeOOH* makes it challenging to cover the surface with polymer films (Kaneko 1989).

ORGANIZATION OF THE FIELD METAL CONSERVATION LABORATORY AT THE KRASKINO ANCIENT SITE

Preparing to organize a field laboratory under expedition conditions

Planning and budget. In archaeological excavations, conservation is necessary, which should be reflected in all financial and project planning stages. Deciding on a course of action at an early stage of excavation planning makes it possible to determine and allocate a conservation budget.

Before planning for the organization and maintenance of the field laboratory, a meeting with the expedition team is highly recommended. Issues to be brought up for discussion should include:

- results of the archaeological survey: climatic conditions of the expedition site (temperature, ratio of cloudy and sunny days, rainy season), geographical features of the area (landscape, availability of water bodies), the predominant type of vegetation (deciduous, coniferous), soil acidity, accessibility of the field camp to central highways and roads (passability, probability of temporary loss of communication);

- expected results of expedition work (quantity, size, and condition of artifacts).

Based on the received data, an assessment of risks in the expedition is carried out, the strategy is developed, the laboratory is staffed, and the budget is determined.

A choice of an "in-situ" approach to field work. In general, it is possible to distinguish three approaches with different scales of implementation of conservation work in the field:

Approach No. 1. Removal of the object with the burial environment (removal with the soil block, storage in a wet environment or groundwater).

Approach No. 2. Packing of objects with the formation of microclimate (dry, wet).

Approach No. 3. Starting the process of material processing directly in the field.

The removal of the object together with the soil allows to move the find in a soil block and carry out all the necessary operations in a laboratory setting. The difficulty is ensuring the mechanical integrity of the soil block and the need to keep it in a relatively unchanged moist state. At the same time, collected and preserved *"in-situ"* materials may occupy considerable space when storing and transporting objects than create inconvenience at all stages in case of space shortage. It depends on the conditions of the camp, its equipment, and the number of the contingent involved. As a rule, there are no problems with the containers used in the operational circulation (containers for washing ceramics at the stage of primary chamber processing) and containers for temporary storage. At the same time, since it is impossible to predict the number of finds precisely, there is a risk of shortage of containers, packaging, and expendable auxiliary material intended for long-term storage (containers for transportation). The latter should be considered one of the main risks, elaborated on at the planning stage. A practical solution would be to use a container of expedition resources and materials to store finds. There is no lack of storage space in expedition conditions, but safe storage is always relevant. Finds are taken by large trucks, and the possible risks lie in this plane.

Assuming that the object was excavated from a wet environment (waterlogged soils, seawater), options for its temporary storage without changing the temperature and humidity conditions can be considered. For this purpose, approaches involving complete immersion of the finds in a solution or maintenance of moisture by contact with impregnated materials are used.

Packaging with microclimate formation is carried out in hermetic containers using moisture and oxygen absorbers or by displacing oxygen from the container by nitrogen or argon atmosphere (González et al. 2003). Silica gel is used as a moisture adsorber (150 g silica gel per 1 liter of volume). Portable hygrometers are used to monitor adsorption efficiency. Silica gel is low cost and can be used repeatedly after drying. With this approach, the outwardly visible destruction of the material during the first stages of storage is of low intensity.

The beginning of the material treatment process directly in the field significantly reduces the effect of the deterioration of the object immediately in the conditions of the archaeological expedition by the instant launch of the stabilization process — the withdrawal of aggressive agents from the material. The storage process of the find is carried out in a slightly alkaline (0.01 mol) NaOH solution (Selwyn, Argyropoulos 2003). The experience has shown that the positive effect of chloride removal by washing will be even if distilled water is used because this procedure will wash most of the chlorides from the object. Thus, treatment of the material can begin immediately in the first hours after it is removed from the ground. Moreover, the dechlorination solutions used at this stage are treatment solutions and temporary storage solutions.

In practice for the 2021 work, the second and third approaches were implemented. The first approach, the extraction of objects with a soil block, was implemented only partially. Those items that were excavated from highly humid soils (seawater) were stored at the excavation site for a day inside sealed containers filled with humid soil taken directly from the excavation site. Then the object in this condition was moved to the camp, where the number three approach was applied.

In particular, among the artifacts found were relatively large hubs covered with a thick layer of corrosion product firmly cemented to the clay soil. Storing such finds in the air was inadmissible, so a reasonable course was to wash the finds in water and then immerse them in a temporary storage solution. The objects were placed in a polypropylene sealed container. They were immobilized using polyethylene foam, which perfectly retains moisture and protects the object from mechanical damage (including, when wet, from abrasion). An essential condition when using polyethylene foam is to ensure that it is static in the container as the material may float in water. Another protective material can be bubble wrap.

Determining the scope of the conservator's presence in the expedition. One of the most critical issues at the planning stage of the expedition is to determine the extent of the presence of a professional conservator at the excavation site. Possible options are:

- the conservator is on-site full-time for the entire period of fieldwork;
- the conservator regularly visits the site to address all conservation-related issues (e.g., as part of a mobile field laboratory team);
- consulting support in remote mode using cellphone video communication apps.

The most common option is for one team member working at the excavation site to oversee the preserver's advice on conserving the finds. It is also possible for a conservator to join the expedition in case of significant difficulties. It is desirable to have a conservator present when packing the items before shipment (in the last weeks of the expedition).

Training and tutorials. Before the expedition, the participants of the field team must obtain basic knowledge and acquire basic skills. In particular, understanding of the processes of restoration-conservation complex of activities for the preservation of the finds. In work (Watkinson, Neal 2001), the authors describe the primary ways of packing archaeological objects and methods of microclimate formation in the conditions of the expedition. The textbooks (Scott, Grant 2007; Sease 1994; Цыбульская и др. 2012) are also recommended to familiarize the reader with the basic techniques of carrying out conservation work in field conditions.

Safety of life and health. Transportation of chemical reagents, tools, and equipment from the laboratory creates a considerable space for dangerous situations for the life and health of the field laboratory staff and field team. Unprepared people, for example, from the contingent of students of the humanitarian profile, who pass practice in expeditionary conditions, can get into the space of work. To the number of visitors, it is possible to include participants of excursion groups among which, frequently, it is possible to meet children of school and preschool age. For this reason, one must identify all kinds of possible dangers to life and health (chemicals, tools, etc.), measures to prevent the occurrence, and the possibility of eliminating the consequences. A critical remark should also be made that the notion of a *"field laboratory"* does not literally mean a room. The *"field laboratory"* is a collective term, which refers to all the resources available in the expedition.

Personnel of the field laboratory is provided with personal protective equipment in the following minimum set:

- protective clothes (gown, apron);
- eye protection (eyeglasses, shields, full-face masks);
- respiratory equipment (respirator, full-face mask with filters to protect against fumes of acids, alkalis, and organic solvents);
- hand protection (gloves, armbands);
- the field laboratory shall be provided with medical supplies for first aid.

Strictly enforced requirements include:

- availability of a source of clean water within walking distance;
- working with hazardous substances shall only be carried out in the presence of a partner;
- chemical substances must not be taken out of the field laboratory and/or left unattended;
- it is forbidden to use as storage containers, containers, and utensils with chemical substances that can be mistaken for food product packaging. It is strictly prohibited to store chemicals in beverage containers;
- access to field laboratory instruments must be excluded for persons who are not specialists in conservation and restoration; or who have not been trained to perform such work; for other members of the field team, access to the laboratory arsenal must take place in the presence of responsible persons;
- it is forbidden to use the tools of the field laboratory for tasks that are not intended for their original purpose (cooking);
- to work away from places of possible accumulation of a large number of people.

Assessing the scope and developing a field laboratory strategy. The potential feasibility of operations in the conditions of a field expedition is evaluated. Depending on tasks, number and preparation of participants, and also on a budget of the expedition, all possible operations can be divided into four categories:

- categorically necessary (primary *"in-situ"* processing, ensuring mechanical integrity, packaging, transportation);
- desirable, possible, acceptable;
- possible, but challenging to implement;
- impossible in the given conditions of the expedition.

The possibilities and scope of work in the field are influenced by:

- availability of a chemical waste accumulation system, including the ability to neutralize, clean up, and dispose of it on site;
- availability of water supply system;
- availability of electricity;
- availability of a system of conditioning and exhaust of harmful vapors.

Workplace organization. The conservator's work takes much more time than the practicing archaeologist's and could not be limited to daylight hours. A critical factor in the convenience of the work is the availability of a large work area (worktables) and the ability to quickly and efficiently transport the necessary tools and equipment between the camp and the excavation site. A lightweight mobile hard-shell case is most suitable for transporting tools. In 2021, such a set of tools was assembled and tested in practice at the Kraskino site.

The primary competing material in terms of the use of working space (the resource of working planes) and storage containers should be considered pottery, which belongs to the most common archaeological finds in all the sites of Primorsky Krai, and consistently exceeds the number of metal finds.

Providing the field laboratory with materials, reagents, tools and instruments. The list of purchases and budget approval is formed approximately six months before the start of the expedition. The staffing of the laboratory is provided based on the individual tasks of the expedition, which are developed at a general meeting after the submission of the report of the archaeological survey. In general, the necessary elements of laboratory staffing should include:

- packaging (volume and number of containers);
- packaging materials (seals, polyethylene, heavy cardboard);
- chemical reagents (acids, alkalis, salts, organic solvents);
- chemicals glassware (glass and plastic beakers of various capacities);
- adhesives (glues, consolidants, epoxies);
- moisture and oxygen concentration control (silica gel, oxygen adsorbents).

When selecting containers and packaging to their material requirements of chemical inertness, colorlessness (transparency is advisable), containers and packaging for storage and transportation must have sufficient mechanical strength and must not change the shape and volume in the loaded state.

Transportation. *Dry packaged objects transportation.* Corrugated plastic boxes can be used for batches of small dry finds and can serve as a rigid support for groups of polyethylene boxes. In the case of unfilled areas, it is suggested to use bubble wrap packing for additional containers stativity.

Objects immersed in solutions transportation. In case to avoid the risk of leakage, findings packaged with the formation of a humid microclimate are transported in well-secured, airtight containers. It is crucial to make sure that items immersed in solutions are secured and cannot move freely. Containers with water should have tightly fitting lids with gaskets, be filled to the brim, have no free volume (air layer) under the lids. It is also recommended to have light boxes, stock of distilled water, and packing materials in case the original ones are damaged.

Safety in transportation. Ensure that materials are not exposed to climatic conditions during transport. The use of a covered vehicle is strongly recommended. When the findings are delivered to the laboratory, all necessary conditions should already be in place to begin laboratory processing immediately.

Portable analytical equipment. A handheld pH meter can be used to monitor pH values. Its operation in the field is not particularly troublesome. However, the availability of calibration solutions, rinsing solutions, and storage solutions for the electrode should be considered. Since the pH control of solutions in the operations for archaeological iron does not require high accuracy, it can be limited to the availability of pH indicator paper.

A portable X-ray fluorescence spectrometer can be used to identify the material of finds. However, it should be noted that this device is costly and requires careful handling and storage.

The field laboratory

Members of the field laboratory are involved in removing objects from the environment, carrying out procedures to reduce the intensity or neutralize the processes of material deterioration, and providing quality packaging sufficient for their safe storage and transportation to the laboratory. A flowchart of *"in-situ"* iron archaeological finds preservation complex procedures conducted in the field is shown in Fig. 4.

Once found through excavation, the object is removed from the ground using standard archaeological methods. If the object is not strong enough, it may be necessary to consolidate the object using adhesives. Once removed from the soil, the find is assessed for its condition, and the object's material is identified. If active corrosion is found, it is necessary to carry out the elimination of causes. Then the object is appropriately packed, ensuring its mechanical integrity (including preservation during transportation) and forming the necessary microclimate for it (temperature, humidity, oxygen concentration, limitation of light access). After that, the object, as a rule, is stored in the conditions of the expedition for some time. External signs control its condition through a transparent colorless container with a thermo hygrometer inside.

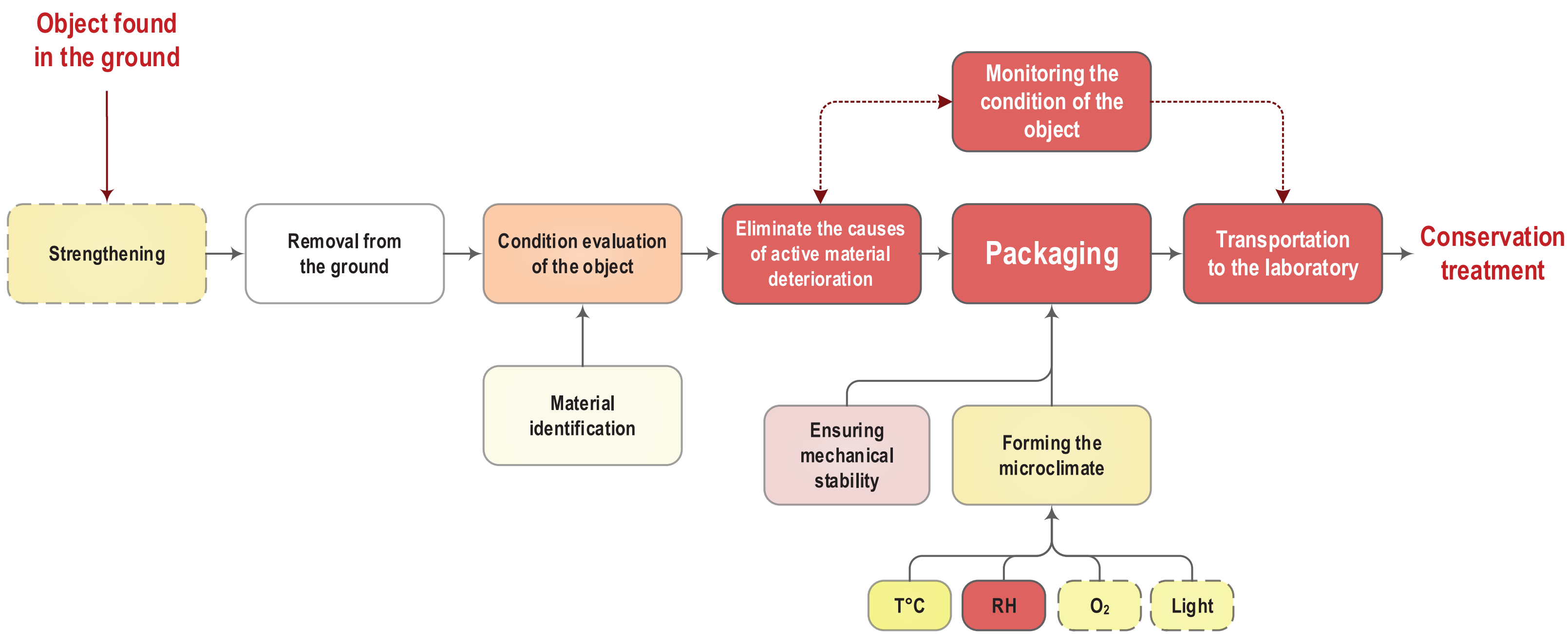

Fig. 4. A flowchart of *"in-situ"* iron archaeological finds preservation complex procedures conducted in the field

At the stage of *"in-situ"* preservation measures, the following points are critical to determining the quality of the procedures:

1) active corrosion signs (iron "weeping");
2) decision-making on the choice of *"in-situ"* strategy and special (individual) measures;
3) packaging methods;
4) forming and maintaining the RH;
5) ways of controlling the condition of the object.

One of the most frequently asked questions by practicing archaeologists at conferences, round table meetings, and *"in-situ"* measures master-classes is the question of the procedure of immediate actions in the field. It is a complex question that does not have a solution in a general form. A convenient and functional approach which are successful for developing solutions in the field is to formulate what is known as the process decision program chart (PDPC flowchart), an example of which is shown in Fig. 5. for the case of initial preservation measures for an iron archaeological object.

Experience with PDPC flowcharts shows a good result of their application in practice directly in the field, making this format of instructions promising. This format has proven particularly useful for training young archaeologists whose primary education does not include knowledge of materials science. However, it should be emphasized that each separately considered find is a unique object with its own set of unique properties and damage features. Therefore, using PDPC flowcharts requires extreme care and does not imply blind following.

Initial "in-situ" activities in the field. In the case where the strategy excludes the treatment of artifacts with the use of reagents, the scope of work is reduced to solving the following three tasks:

- eliminating (slowing down) the rapid processes of deterioration of the artifact material;
- packaging to ensure mechanical integrity while forming a unique microclimate;
- transportation of objects to the laboratory for further treatment.

Eliminating (slowing down) the rapid deterioration of the artifact's material. *Cleaning metals in the field.* There is a generally accepted rule that it is advisable to avoid intervention on metals in the field. Uncontrolled cleaning can remove informative organic and inorganic residues associated with the metal, either on it or in its corrosion products. Depending on the composition of the metal or alloy and the nature of its corrosion, corrosion products may contain information about the grain structure of the metal and the position of its original surface. One can use this information to identify technical information about an object and help determine its authenticity (Scott 1992).

For the entire restoration-conservation complex, it is crucial to follow the order of restoration-conservation activities. One of the key issues is determining whether it is possible to begin treating an artifact immediately after being removed from the burial environment. Once started by washing,

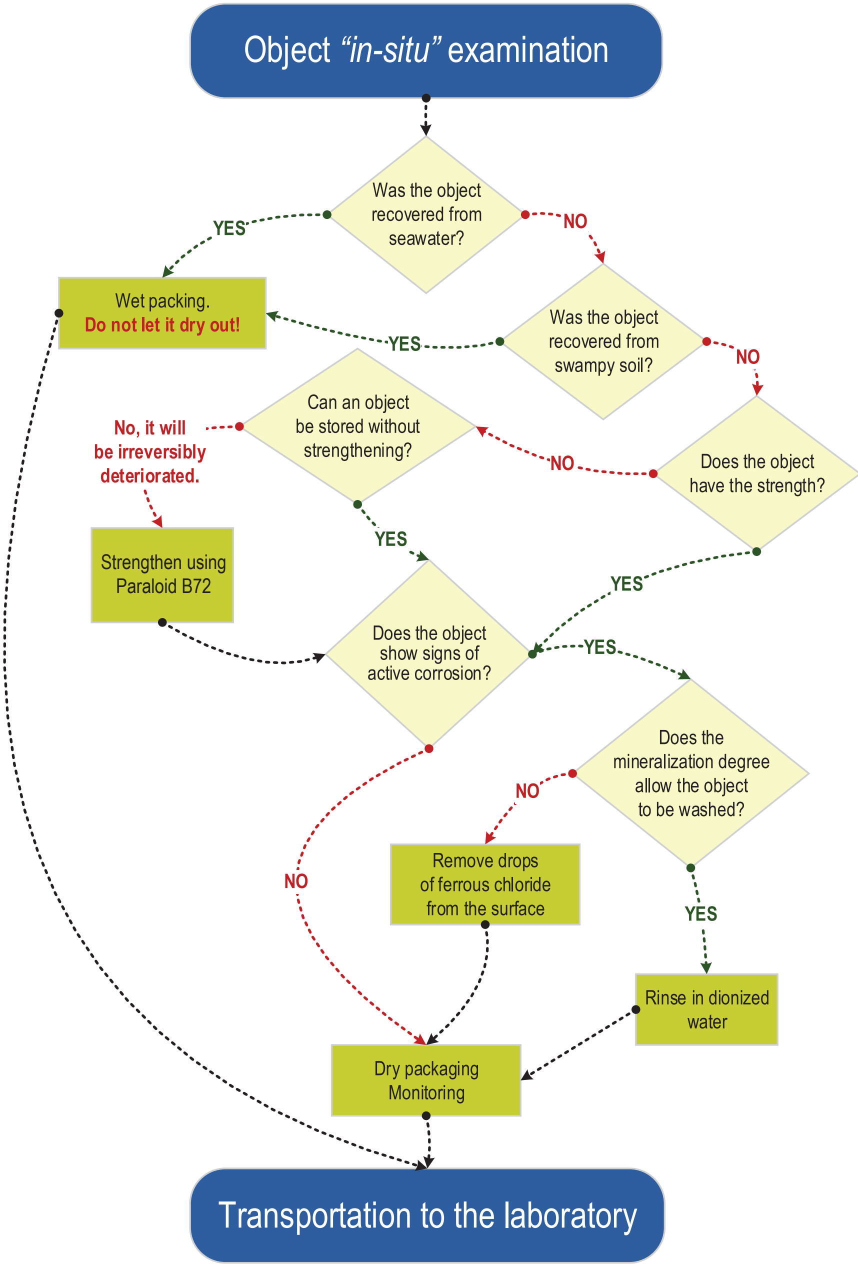

Fig. 5. An example of the decision-making process (PDCP flowchart) regarding initial preservation measures for an iron archaeological object

the treatment process should be completed in its entirety and logically continued by rinsing out the reagents, followed by drying and applying a protective coating. Several cycles of wetting and drying of the object are undesirable, as they will negatively affect the integrity of the mineralized layer.

A significant disadvantage of starting the material stabilization procedure directly in the field is that only limited material identification methods can be used.

The use of a portable X-ray fluorescence spectrometer makes it easy to identify the material and determine its type. However, analysis of the object's condition for the presence of a metallic residue requires X-ray examination, which cannot be performed during the expedition without special conditions. Due to the complex morphology of both the archaeological object itself and the complex stratigraphy of mineralized surfaces, it is necessary to clarify the typology of the object and its structural features, the presence of metal residue and its borders, the nature and characteristics of corrosion and mineralization using research methods. One of the most severe field disadvantages preservation is the impossibility of using X-ray radiography. X-ray defectoscopy is a study that allows to assess the state of preservation of an object, identify details that are not visible when we examine it *"in-situ"* and determine the original surface of the object. The original surface of an object is the surface that the object possessed when it was abandoned. The boundary of the original surface in a broad sense represents the boundary between the material of the object and the environment at the time of the initial stage of burial of the object. The original surface in the absolute majority of cases is hidden in the mineralized layer of the object cemented with soil particles. A particular concern is the possibility of losing decorative elements of metal objects, such as precious metal inlaying, at an early stage of treatment (Watkinson 2010).

Nevertheless, when complying with the requirements for organizing a conservation laboratory in the field, immediately beginning treatment of objects where necessary or possible is the most desirable. With other approaches, the effectiveness of further laboratory treatment will be determined by how soon it begins after the artifact has been removed from the ground.

An archaeological artifact may be a combined type item as an iron knife with a bone or wooden handle. In some such cases, when decayed, one material may preserve the other or be evidence of it. Organic materials are most susceptible to bio-damage and most often decay completely, rarely leaving only traces of their shape, texture, etc., as information about themselves in the layers of the corrosion product.

General recommendations insist that dry cleaning is always preferable. Washing in water is only possible for objects in good condition and show no outward signs of deterioration, and therefore concerns mainly only objects with a low degree of mineralization. The possibility of pre-washing an object from a high concentration of chlorine compounds that have already penetrated the material's surface cannot be completely ruled out. Since the latter observation is a sign of active corrosion processes, slowing down their rate is possible by immersing the object in aqueous solutions. One should consider that an object with a fragile (crumbling, cracking, flaking surface) may require preliminary strengthening with consolidants. In this case, it is necessary to consider the chemical interaction of the coating-consolidant (will dissolve or not) with the washing medium.

Structural strengthening. In all cases, to temporarily strengthen the surface layer is recommended to use only reversible adhesives (Paraloid B-72).

For impregnation, use solutions-consolidants in low concentrations (2—3%), pre-drying the surface with organic solvents (ethanol, acetone). The solvent is repeatedly applied to the entire surface to be reinforced with a brush. After treatment, also with a brush, apply the hardening composition.

Providing mechanical integrity. In excavations, it is of particular primary importance for preserving objects to ensure their mechanical integrity. Objects require careful handling and appropriate packaging to exclude the possibility of external destructive effects on them during all further storage stages. Here is should also include the influence of the human factor, firstly, negligence and haste in removing the object from the ground, secondly, interference in the integrity of the object, driven by the curiosity of the researcher (for example, cleaning the artifact), thirdly, measures not taken into account to ensure the preservation of objects in their already packed form.

The sequence of conservator actions. The following is a sequence of practical conservator actions in the field.

1. The conservator arrives at the excavation site on his/her own with the necessary tools, reagents, devices, and instruments.

2. For carrying the tools, the toolbox is used. Working with a toolbox assumes that all tools can be placed inside it, and the case itself can be easily carried between the camp and the excavation site (if they are distant from each other).

3. Tare and packing materials are the responsibility of the field team. It is assumed that the container and packing materials are already at the excavation site. However, the conservator must plan, calculate, procure, and staff the field unit with packaging containers and materials themself. All activities carried out before delivering containers, and packing materials are the responsibility of the conservator. The type, list, and quantity are negotiated at the planning stage of the expedition. Also, distilled water is delivered to the expedition in advance. It is beneficial at the stage of joint planning of the expedition to develop a separate list of items delivered by the field team at the moment of arrival. It is recommended to store the containers filled with metal finds in a dark, cool place, separately from other finds.

4. After arrival to the expedition, the conservator organizes a workplace in the camp and at the place of direct excavation. The site is prepared in advance according to the arrangements made during the planning phase of the fieldwork.

Good practice implies that the workplace is organized with the following requirements and recommendations in mind:

- a high-hanging roof that protects from direct sunlight;
- the roof space is windblown. Otherwise, the heat accumulated by sunlight paired with high air temperature and high humidity will create discomfort when working;
- there is a working table. Of particular importance is the depth parameter of the table because a narrow table makes it dangerous to store finds on it. A tabletop with a depth of at least 1.2 meter is recommended,

but the more profound the tabletop, the better. To avoid the cases when finds fall from the table, it is forbidden to store them on the tabletop surface less than 30 centimeters from the edge;

- the worktable is rigidly fixed (e.g., dug into the ground), the work surface is flat;
- the table can be arranged for both standing and sitting work;
- it must be possible for two (preferably threesome) to work at the table simultaneously. This refers to cases when the help of a partner may be required where another pair of hands may be needed (for example, during gluing). For this purpose, it should be possible to approach the working table from at least two sides;
- good daylighting. A workspace arrangement should be avoided where the conservator may need to carry an object in his hands out from under the canopy to view it in the sunlight;
- availability of a source of clean water or a supply of water.

Unfortunate decisions in selecting a workspace for *"in-situ"* conservation should include:

- any workspace that excludes the presence of shade;
- any enclosed space that is not air-conditioned or ventilated, such as a closed tent or an un-air-conditioned caravan. Such spaces can be highly stuffy, which in extreme cases of discomfort can even cause a person to pass out from the heat.

Potential problems in the workplace include:

- insects (it is not easy to work with finds concentrated);
- allergies to flowering plants (ragweed flowering is typical for Primorsky Krai in the second half of summer) or reagents (in particular, cyanoacrylate glues or acetone);
- sunburns and sunstroke.

5. The conservator treats finds by eliminating the causes of rapid deterioration of their materials. Objects are packed with a mandatory provision of mechanical integrity of the objects (each object must have a rigid backing, to which it adheres through a foam padding, which provides it with shock absorption) in storage and during further transportation, as well as with the provision of temperature and humidity microclimate regime in sealed boxes for temporary storage.

6. The conservator leaves the expedition and does not take the finds with him. The finds are taken to the place of laboratory work on their preservation by archaeologists.

Problems in expeditionary environments. The problem of too long a temporary downtime between removing an object from the ground and the beginning of its processing (stabilization) should be noted as the main problem. The solution to this problem is to reduce the period of storing the object in a non-conserved state to the minimum possible with the obligatory provision of the most suitable temporary storage conditions.

It is practically impossible to use radiography in the conditions of the expedition. It is so complicated that it is easier to arrange for emergency delivery of the object to the laboratory. This inconvenience creates difficulty in deciding whether it is possible to begin processing objects directly in the field. In the absence of an understanding of the object's structure, the conservator should not begin to stabilize the material.

A separate group of problems is created when working with severely damaged objects with high mineralization. The most challenging task is to work qualitatively with objects which are "composite" (made of several materials). The problem is not solved in the general case; it is necessary to develop a technique for each object.

The realization of the approach to processing varied archaeological collections is required (archaeological iron simultaneously assumes the parallel work with bronze objects and ceramics). As a solution, it can be proposed to increase the working area (this applies first of all to the working surfaces) of the laboratory premises. The latter should be taken into account when designing the laboratory and preparing for the fieldwork.

The perspective and potential of the mobile field laboratory. The experience of working at the Kraskino site during the 2021 field season showed that the idea of developing a solution in the form of a mobile field laboratory deserves attention, as it can potentially solve many problems associated with restoration and conservation activities in small museums (providing the necessary materials and information, training, skills transfer) and archaeological expeditions. In order to organize a mobile laboratory, a modified commercially available vehicle can be used after the preliminary dismantling of interior details and subsequent reorganization of the interior space to use it more efficiently. Necessary conditions for the van — access to electricity (availability of autonomous battery) for heating the interior when the engine is off and heating water, plumbing system and sink, table panels, sliding cabinets, racks, storage cells.

Below are a number of indisputable advantages of such a laboratory over the organization of the laboratory in the tent version:

- the possibility of organizing the reliable storage of expensive equipment;
- storage of archaeological artifacts in proper conditions with controlled parameters of temperature and humidity;
- function as a vehicle of expedition team;
- inside can be installed a complex for the production of clean water (reverse osmosis unit);
- solar panels can realize power supply;
- functional furniture for work;
- high-quality and safe storage system for chemical reagents, tools and equipment;
- air-conditioned room for comfortable painstaking *"in-situ"* work;
- restricted access to ensure safety.

Despite the positive experience of this approach, particularly noted in work (McCawley, Stone 1983), it is impossible not to note a certain kind of skepticism regarding the feasibility of organizing a field laboratory in a mobile (vehicle) version. It is not fair to deny that the availability of such special vehicles is also an additional financial burden on the organization. Indeed, the option of using a van as a laboratory is preferable since it allows to carry more laboratory facilities in the field. However, the vehicle requires constant maintenance. In addition, experience gained in 2021 showed that the main difficulties or inconveniences in the fieldwork are associated primarily with the lack of working space (surface) rather than with the compact organization of resources in a limited space. It is possible to bring such transport to the camp, but in most cases, it is extremely difficult or even impossible to get it to the place of the excavation. From this point of view, it is much more helpful for the practice to increase the working area both directly in the camp and at the excavation site. At the same time organizing the canopy in a convenient way. Considering the example of work in Kraskino: the whole area — fields and the canopy to organize the shade is made with the support of trees. Near to an excavation (a potential place for the design of a workplace), all is overgrown with high grass. In such situations, only the option of camp treatment is possible.

As an alternative or supplement to the mobile field laboratory, the use of a specially designed mobile toolbox, which includes a set of tools to ensure conservation work in the field, has been proposed. It becomes especially relevant when it is not possible to reach the archaeological site using vehicles. The box is completed according to the developed list, which is constantly updated to optimize and provide comfortable conditions for the work.

LABORATORY STABILIZATION, CONSERVATION AND LONG-TERM STORAGE OF IRON ARCHAEOLOGICAL OBJECTS

Archaeological metal preservation procedures can be divided into material intervention techniques, which involve adding or removing something from an object to preserve it, and preventive techniques, which aim to prevent corrosion by controlling the environment (Watkinson 2010). Both approaches require an understanding of metals' physical and chemical structure, their interaction with environmental variables, and the properties of corrosion products. At the same time, the whole set of measures does not have its own universally defined standards. Usually, it works on objectives designed to meet a specific problem, situationally developed for an individual subject in a private way. However, in the most general way, the basic scheme of the route of conservation procedures and measures under laboratory conditions can be represented in the form of the scheme shown in Fig. 6.

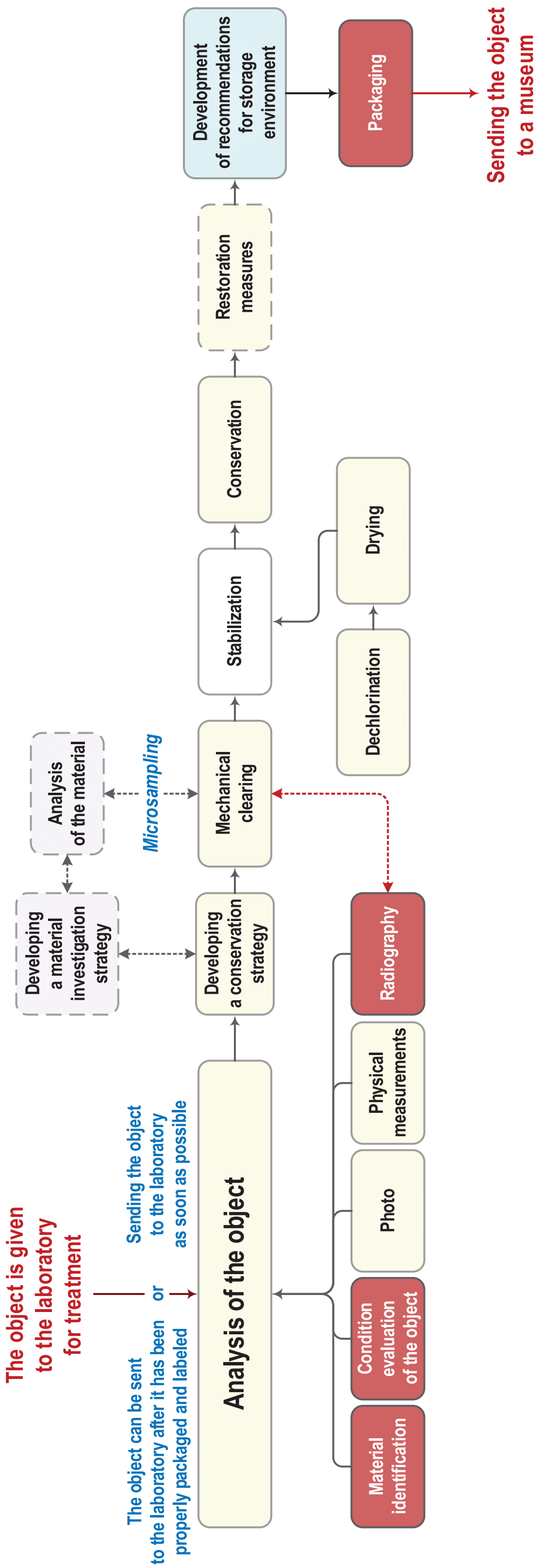

Fig. 6. Iron archaeological objects preservation basic laboratory procedures

Analysis of iron archaeological finds

Before beginning conservation work on an object in a laboratory, it must be thoroughly examined, including identifying the object's material, condition evaluation, photographs, physical measurements, and radiography. This information forms the basis for developing individual conservation and research strategies for each find. After these required initial analyses of the find's condition, the preliminary conclusions can be made about the possibility and prospects of applying destructive and non-destructive analysis methods. At this stage, the archaeologist studying the find and the conservator dealing with its preservation may also reach certain agreements on the reasonable possibility of taking a sample during the conservation process for analysis by physical and chemical methods.

Clearing of iron archaeological object

The main objective of any conservation intervention procedure is to improve the stability of the material being treated. The clearing is an essential part of the stabilization process because contaminants have destructive potential and hinder further treatment. In the case of material stabilization of iron archaeological objects, it is difficult for the washing solution to penetrate through dense cemented soil residues deep into the corrosion product to reach the boundary between the mineralized layer and metallic iron residues in the area of concentration of chloride continuum compounds. However, the corrosion product layer must often be preserved because many iron objects are so heavily mineralized that they are represented only by corrosion products. From the restorer's perspective, contamination can be considered material that is not part of the object or a product of its deterioration, i.e., appears as a result of mixing with the original material (for example, it can be soot, grease, stains, conservation coatings, fillers, etc.).

Various methods can clear the preservation object: mechanical, abrasive, vibration (ultrasonic), chemical, thermal, chemical-thermal, laser, etc. However, clearing consists of mechanical treatment using tools such as a sandblasting machine, ultrasonic scaler, micro-grinder, etc. Many issues influence the decision about the depth of clearing. Among them are questions of restoration ethics and questions of a historical nature. The science of the matter does not give an unambiguous answer and does not take away from the conservator the responsibility for his decisions. It only offers options, tools and points out the likely consequences of intervention or non-intervention.

For this reason, it is essential to think carefully about the next steps before conducting a clearance. First of all, the composition of the contamination must be characterized and figured out what and how it has contributed to the deterioration. Then assess the state of preservation of the find by analyzing the material's current physical and chemical properties. Consider all possible safe options for the procedure. Develop a clearance strategy or decline to do so depending on the end goal set. Adhere to ethical considerations in the process.

Archaeological iron stabilization

The process of stabilization is central in the preservation of archeological iron. Stabilization involves the removal of moisture and corrosion catalysts, followed by the application of a protective coating, isolating the object from contact with the environment (Юдаков и др. 2010). At present, stabilization with aqueous alkaline solutions is widespread in the world practice (North, Pearson 1978). The effectiveness of this treatment is due to the increased solubility of various substances at high pH values (Selwyn, Argyropoulos 2003). The alkaline environment promotes soil residues and organic compounds saponification and partial softening and dissolution of corrosion products. They are additionally reinforced before immersing objects in the washing solution (sewn into the plastic mesh, covered with a fishing line). Water baths are used to intensify the mass exchange processes.

The concentration of chlorine anions determined in the spent washing solution serves as an indicator of the efficiency of such treatment. The treatment is notable for its duration, it does not always allow to achieve a quality result in absolute terms, but it allows treating items in relatively large batches. Increasing the temperature and pressure in the system (use of subcritical state of water, which changes its properties) improves the quality of washing and can favorably influence the removal of unstable corrosion products of the archeological iron during dechlorination (de Viviés et al. 2007; Drews et al. 2013; González-Pereyra et al. 2011; González et al. 2004).

Removal of residual reagents of washing media is achieved by intensive washing under ultrasonic cavitation conditions in deionized water. Removal of residual moisture is achieved by drying the objects in a vacuum drying oven.

The treatment of iron archaeological objects in marine environments should be considered a separate case of challenging conservation tasks. Some of the most common objects of this type include shipwrecks (Bell et al. 2009; MacLeod 2013; Pearson 1972) and submarines (González et al. 2004; Mardikian 2005; Scafuri 2017). The kinetics of fracture, *"in-situ"* methods, and laboratory conservation of underwater objects have been studied and are relatively widely represented in the literature (Busse 1997; Croome 2004; González et al. 2004; Kergourlay et al. 2018; MacLeod 2013; Matthiesen et al. 2004; Patoharju 1975; Riera et al. 2016; Scafuri 2017; Simon et al. 2018; Unglik 1995). Especially noteworthy are the developed methods for stabilizing large underwater objects that do not allow them to be submerged in a dechlorinating medium (Batis et al. 2015).

Conservation coatings

Acrylic resins, particularly Paraloid B72, have traditionally been used for the conservation of archaeological iron. Coatings are applied to objects by vacuum impregnation. The objects can be additionally vacuum packed with oxygen absorbers placed in the storage container to improve preservation. The use of corrosion inhibitors on archaeological iron objects is also known (Bobichon et al. 2000; Musa et al. 2013; Sangouard et al. 2015).

Restoration processes and materials

In the complex of restoration-conservation activities for archaeological iron, processes of gluing, consolidation, restoring lost fragments, etc. are used, in the implementation of which epoxy resins, acrylate adhesives, fillers, mineral pigments, mineral pigment, and acrylic-based paints, reinforcing components of elements of losses to be restored.

Long-term storage and monitoring

The basic procedures that an iron archaeological object undergoes in the process of its long-term storage are shown in Fig. 7. These procedures include ensuring the mechanical integrity (safety) of the object, developing the interaction of the object with the main risk factors (physical damage, handling, temperature fluctuations, gas composition and dust, direct sunlight), forming a microclimate for the object (temperature, relative humidity, oxygen, lights source impact) and further monitoring the condition of the object (detecting signs of recessive corrosion and breach of the cover material surface).

One of the main risks of damaging an object is handling. Before an archeological object gets to a museum collection, it goes through many work stages, during which specialists of different fields deal with it. The temperature and humidity conditions recommended for storing preserved items in museum conditions: 20—25°C with a relative humidity of 45%. Storage avoids sudden temperature drops (thermal shocks from heating sources, open windows for ventilation, etc.). Storing archaeological iron excludes direct sunlight. If possible, it is necessary to use artificial light sources that do not contain rays of the ultraviolet spectrum, which are a source of heat and have a significantly adverse effect on polymer coatings.

Re-restoration of iron archaeological objects

High-quality restoration involves the harmless removal of previously applied conservation materials from the object. Among other criteria for selecting restoration materials, the principle of their selection is applied based on the possibility of *their* complete reversibility without destructive consequences. If this condition is met, the restoration process depends entirely on the restorer’s experience and capabilities.

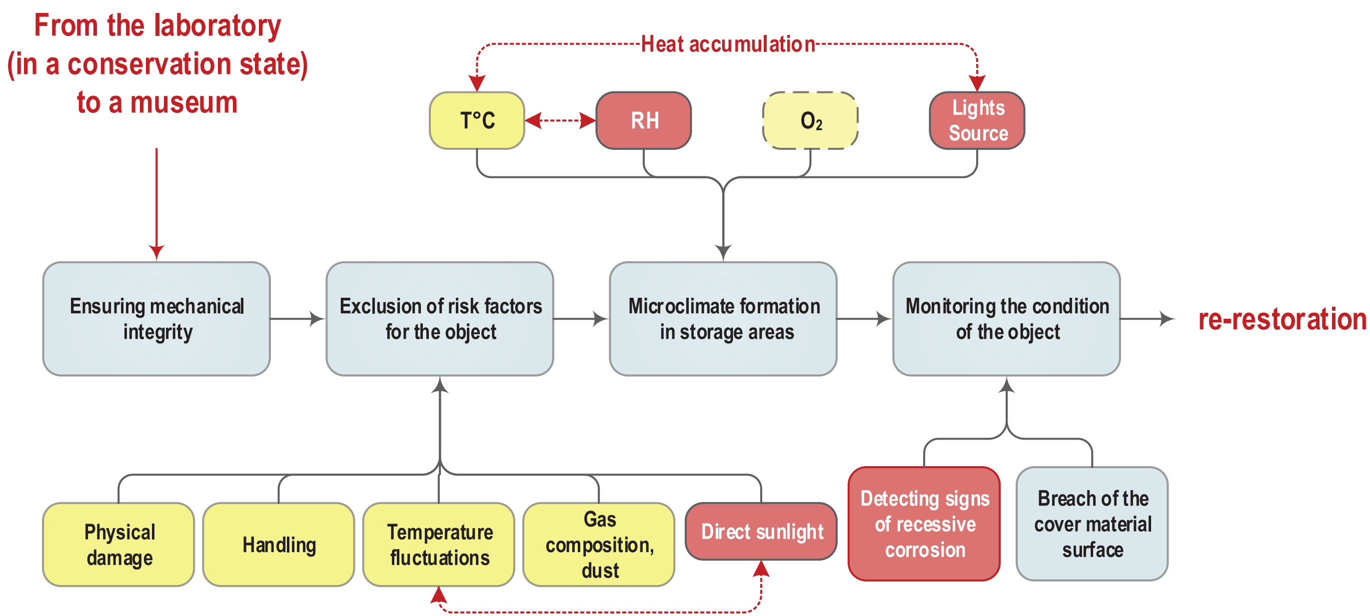

Fig. 7. Iron archaeological objects basic procedures conducted in a museum for long-term storage

CONCLUSION

The analysis of the scientific literature shows that the contemporary theory of deterioration and preservation of finds has been formed, and the traditional approaches to the processing of objects common in the world practice are relatively simple and available for implementation. The whole route of an object from the moment of its extraction from the ground to the moment of transferring the object for storage to a museum can be realized in practice without the need for expensive equipment. The central resource consumed in the process is time. Conservation of objects requires an enormous amount of time since it does not accept rushing at its core.

The analysis with the generalization of the contemporary theory of the deterioration of iron finds points to the central place in the complex deterioration of processes of physical and chemical nature. It is impossible to preserve an iron object in the state in which it is at the time of its extraction from the ground by methods that do not involve the removal of an aggressive reagent from the volume of the material. At the stage of *"in-situ"* conservation, the destruction mechanism (electrochemical corrosion in the presence of electrolytes saturated with chlorine compounds) is indicated by its external signs of corrosion activity, formation of a continuum of chlorine iron and oxyhydroxide compounds. Thus, active destruction processes can be timely diagnosed and partially eliminated (partial opening of the material with the washing in aqueous solutions). However, a review of traditional and alternative methods used in processing iron finds under laboratory conditions indicates the difficulty of their complete or partial transfer to field conditions, especially for an organized tent-type laboratory.

The preservation of iron archaeological finds is a complex and labor-intensive set of activities in which the field *"in-situ"* preservation phase is particularly important. When developing a preservation strategy for iron finds, the most desirable way to organize the work is to shorten the time interval between removing the object from its environment (breaking its quasi-stable state of natural preservation) and beginning its stabilization (dechlorination). The worst-case scenario is to postpone the beginning of the preservation process indefinitely, including in conditions of unsuitable packaging (without ensuring mechanical integrity and forming a suitable microclimate) or its absence.

The optimal variant of the organization of *"in-situ"* conservation in the field is presented in a mobile field laboratory format. The field laboratory work is integrated into the model of the optimal complex of conservation measures, consisting of three stages (field conservation, laboratory conservation, long-term storage). And allows the development of approaches with suitable conservation techniques in the field, thanks to a flexible process flowchart and technical-technological recommendations.

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КОНСЕРВАЦИЯ АРХЕОЛОГИЧЕСКОГО ЖЕЛЕЗА: ТЕОРЕТИЧЕСКИЕ ОСНОВЫ РАЗРУШЕНИЯ НАХОДОК, ОРГАНИЗАЦИЯ И СОПРОВОЖДЕНИЕ КОНСЕРВАЦИОННЫХ МЕРОПРИЯТИЙ

И.Ю. Буравлев, А.В. Балагурова

В статье рассматриваются теоретические основы разрушения археологического железа на различных этапах «жизненного цикла» артефактов (период использования, период пребывания в грунте, этап раскопок), организация и сопровождение мероприятий *"in-situ"* консервации в полевых условиях на примере экспедиции на бохайском (698—926 гг.) археологическом памятнике в Краскино (юг Дальнего Востока России), а также основные этапы построскопочных процедур обращения с железными археологическими объектами (лабораторная стабилизация, консервация и долговременное хранение). Описанный в статье опыт даёт возможность увеличить количество эффективных способов решения указанной проблемы и расширяет методологию полевой консервации при сопровождении всего цикла сохранения археологических железных объектов.

Ключевые слова: консервация, полевая консервация *"in-situ"*, археологическое железо, Краскинское городище, Государство Бохай (698—926 гг. н.э.).

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