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PHOTOGRAMMETRY IN ARCHAEOLOGY: MODERN TECHNOLOGIES OF DOCUMENTATION AND RECONSTRUCTION

The article explores the utilization of technology, specifically photogrammetry, for precise documentation of objects of varying sizes and the subsequent analysis of the digital replicas produced. In the realm of archaeology, modern digital tools offer enhanced accuracy and versatility in studying artifacts, providing not only detailed but comprehensive insights into the objects under examination. While photogrammetry has become a staple in archaeological research, its effectiveness is hindered by challenges such as the requirement for costly equipment and specialized expertise.

By focusing on three distinct objects — the 2022 excavation at the Ust-Teplaya monument in the Charyshsky district of the Altai Territory, a Turkic sculpture from the Biysk Museum of Local Lore, and a fragment of a mirror from the same museum — the article illustrates the practical application of this technology. The quality and precision of the final 3D model hinge primarily on the resolution of the photos capturing the object, necessitating a high level of pixel detail. Particularly with smaller objects containing intricate details, there is a heightened risk of relative distortions, demanding meticulous calibration of the camera and correction of any errors in distortion during the photography process.

The article briefly touches upon the diverse applications of the generated 3D model, including orthogonal computer visualizations devoid of perspective distortions and the enhancement of subtle embossed patterns. It concludes by underscoring the promising future of photogrammetry in archaeology, highlighting its potential to revolutionize the methods of researching and conserving archaeological artifacts. The article also considers various avenues for further development in this field, hinting at the transformative impact this technology could have on archaeological practices.

Keywords: photogrammetry, 3D-modeling, computer modeling, archaeological collections, archaeological site

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ФОТОГРАММЕТРИЯ В АРХЕОЛОГИИ: СОВРЕМЕННЫЕ ТЕХНОЛОГИИ ДОКУМЕНТИРОВАНИЯ И РЕКОНСТРУКЦИИ

В статье рассматривается вопрос технологии максимально точной фиксации объектов разного типоразмера с помощью фотограмметрии, а также возможности работы с полученной цифровой копией объекта. Современные цифровые технологии позволяют проводить более точную фиксацию и разностороннее изучение, получая при этом не только более детальную, но и более полную информацию об объекте исследования. Применение фотограмметрии в археологии уже стало неотъемлемой частью исследований, но, несмотря на свою эффективность, она сталкивается с такими проблемами, как необходимость наличия относительно дорогостоящего оборудования и специальных знаний. В статье рассмотрено применение такой технологии на примере трех объектов разного типа и размера — раскоп 2022 г. на памятнике Усть-Теплая в Чарышском районе Алтайского края, тюркского изваяния из Бийского краеведческого музея им. Бианки и фрагмента зеркала из Бийского краеведческого музея. В результате проведенных работ выявлено, что качество и точность конечной модели зависят в первую очередь от разрешения фотографии на данном участке объекта, которая должна содержать необходимый уровень пиксельной детализации. Отмечено, что, чем меньше предмет и чем больше он содержит мелких деталей, тем больше возможных геометрических искажений 3D-модели, поэтому необходимо более скрупулёзно подходить к процессу съемки, калибровке камеры и коррекции ошибок. Отдельно рассмотрены возможность ортогональных компьютерных визуализаций без перспективных искажений и выделение выбитых рисунков, в том числе малозаметных. В результате сделан вывод о том, что фотограмметрия в археологии имеет большие перспективы, которые могут существенно изменить способы исследования и сохранения археологических находок, а также рассмотрены некоторые из потенциальных направлений ее развития.

Ключевые слова: фотограмметрия, трехмерная фиксация, компьютерное моделирование, археологические коллекции, археологический раскоп

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Introduction

One of the main tasks of archaeological excavations is to record all the details and stages of the study of objects as accurately as possible. Fixation methods and tools are constantly being improved. One of such tools, which has become widespread in field archaeology over the last decade, is the photogrammetry method [Grushin, Sosnovsky, 2018]. Photogrammetry is a method of obtaining geometric information about objects and surfaces based on their photographs. In archaeology, this technique has already become an integral part of research, allowing you to create accurate three-dimensional models of both small archaeological finds and entire settlements.

Photogrammetry in archaeology begins with carefully shooting an object from various angles using a high-resolution digital camera or drone. These photos contain key information about the shape and structure of the object. Then special programs are used that analyze these photos, determine the position of each point of the object in three-dimensional space and build an accurate three-dimensional model of the object. This process allows you to create digital copies of archaeological sites with the highest degree of detail and clear advantages over classical methods.

The main advantages of using such technology are that photogrammetric methods allow you to achieve a high degree of compliance when creating three-dimensional models, which is important for accurate reconstruction of archaeological finds, they are highly efficient, allowing you to relatively quickly obtain data using modern cameras and drones and effectively document even large areas. The created three-dimensional models can serve as digital archives, storing information about the state of archaeological sites at a specific time and allow archaeologists to virtually explore and analyze finds without physical impact on them and, as a result, without the risk of damage or loss.

The study of the obtained 3D models allows us to obtain objective data on the geometry of archaeological artifacts of complex configuration — to make precise cuts in different planes, to make measurements, including curved surfaces, which is very difficult or impossible to do accurately enough when studying a real object, as well as to represent the object in an archaeological drawing. This problem of full-scale study of artifacts with curved profiles is acute when they are quantitatively processed using statistical methods [Kolobova et al., 2020: 242–244; Bondarenko, Kiryushin, Frolov, 2023: 133].

The next problem that 3D models can solve is the study of embossing and other traces of processing on stone sculptures and rock carvings with different depths of study of relief details and a high degree of surface destruction. In full-scale study, the fall of light from different angles and directions creates a certain play of shadows, in which the interpretation by visual methods of individual details of images consecrated in different ways is often subjective. The use of computer vision with subsequent processing and rendering, analysis of microrelief by digital intelligent methods, including using machine learning algorithms, allows us to obtain objective data on the features of such images [Kolobova et al., 2020: 242; Tishkin et al., 2020; Svoiskiy et al., 2021; Tishkin, Svoiskiy, Ziganshina, 2022; Tishkin, Bondarenko, 2023].

Another area of use of such digital copies is the possibility of computer reconstruction of individual artifacts with lost parts or deformed shapes, as well as large archaeological sites.

Reconstructions based on digital models have a greater degree of objectivity, since they are based on mathematical calculations to determine the shape and restore the missing parts of the artifact [Kolobova et al. 2020: 242, 243; Bondarenko S. Yu. 2023: 9–22].

Excavation photogrammetry, as a method of fixing, including the stages of the process, is increasingly trying to displace established methods in the form of hand sketches and photographs that do not meet modern requirements for accuracy and detail [Danilov, Fedorov, Bezvershenko, 2019; Starovoitov, Chernova, 2020].

The ongoing work on the creation of digital models of objects of various shapes and scales requires solving constantly emerging problems of both a technical and methodological nature, adapting the methodology and methodology of archaeological research to photogrammetry technologies. This publication presents an analysis of the issues that arise during the creation of digital copies of archaeological objects and artifacts and examines a number of approaches used to solve them.

Representation of archaeological sites and object in their area

Despite its effectiveness, photogrammetry in archaeology faces challenges such as the need for high-tech equipment and specialized knowledge. The correct conduct of photogrammetric studies requires a lot of experience and consideration of a large number of factors. As examples, we can consider photogrammetry objects of different scales. The first object to consider is a digital copy of the 2022 excavation of the archaeological expedition of the Altai and Kemerovo State Universities at the Ust-Teplaya memorial in the Charyshsky district of the Altai Territory [Grushin, Stepanova, Fribus, 2023]. In the excavation measuring 22 by 14 meters, mounds of the Pazyryk culture of the Early Iron Age (V–III centuries BC) and Afanasiev mounds of the Eneolithic era (XXXII–XXVIII centuries BC) were recorded. One mound was recorded at the stage of clearing the embankment, two — cleaning the burial.

Unfortunately, the printed format does not allow you to visually show all the possibilities of using a digital copy, for example — rotation, approximation, cross-sections, sizing any elements, determining heights, due to the dynamism of these functions. But Figures 1 and 2 show one of the functions of the drawing feature — the creation of various texture maps that preserve the colors and details of the surface of the finds. This provides additional features and is another separate type of data. A similar drawing (Fig. 2) it is obtained in fully automatic mode, without the human factor, allowing you to see the objective contours of objects, including very small ones.

However, such a resolution, as indicated on the render, is often not enough, the researcher needs more detailed information. Therefore, at the beginning of the work, the specialist must draw up a plan for photogrammetry, which allows to achieve the necessary detail of each site.

The quality of the final model and the factor of photogrammetry accuracy depends primarily on the quality of the shooting. The photos used must be of high quality and contain the necessary level of detail of the object. The clearer and more detailed the images, the more accurate the results will be. Also, the number of shooting points plays a role. The more of them there are, the easier it is for photogrammetry algorithms to accurately determine the three-dimensional structure of an object. This is especially important when shooting complex objects. Using control points — places or objects whose coordinates are known — also helps to link the virtual model to real coordinates, improving overall accuracy.

Fig. 1. Rendering of the top view of the excavation site
Рис. 1. Рендер вида сверху на раскоп

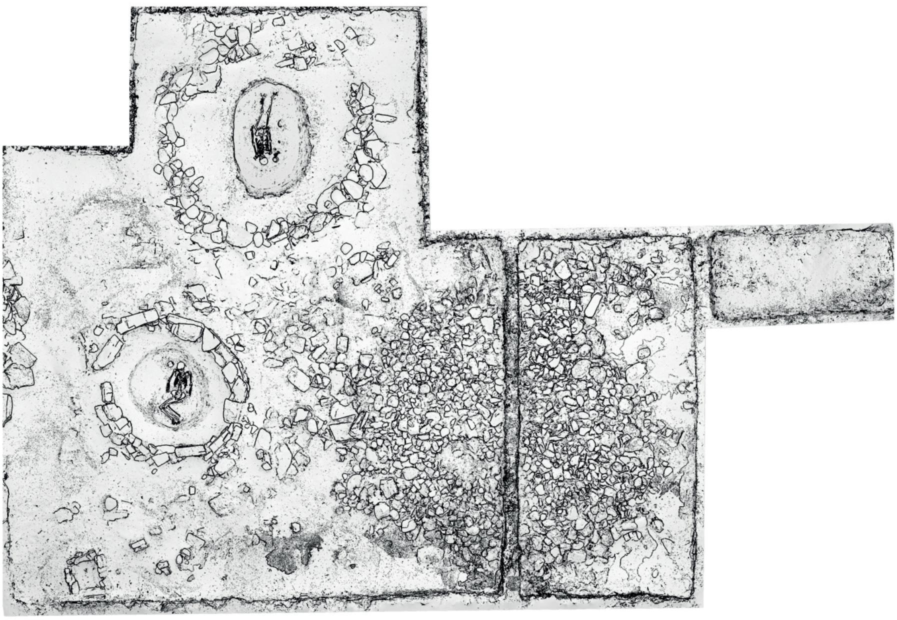

Fig. 2. Automatic drawing of the top view of the excavation site
Рис. 2. Автоматическая прорисовка вида сверху на раскоп

During the photogrammetry of this excavation, a Canon EOS 5D Mark IV camera with a high-power 35 mm lens was used. First, photographs of the entire excavation were taken, after which the burials themselves were photographed in more detail, which made it possible to increase their detail (Fig. 3).

Fig. 3. Rendering of the top view of the burial (texture rendering and autodrawing)
Рис. 3. Рендер вида сверху захоронения (текстурный рендер и автопрорисовка)

And after that, photogrammetry was performed inside the grave itself, in order to show the skeleton itself and the jug with the detail necessary for remote study (Fig. 4). The final model contained about 150 million polygons per 1 m^2 of surface, which allows you to clearly see objects about 1 mm in size.

Fig. 4. Rendering of the grave combined with drawing
Рис. 4. Рендер могилы, совмещенный с прорисовкой

Creating a digital copy of the sculptures

The second object that we would like to consider is a Turkic sculpture from the Biysk Museum of Local Lore named after V. V. Bianchi (BKM OF 73). The object was brought to the museum in 1926 by M. D. Kopytov. The documentation contains a description of the sculpture from the monograph by V. D. Kubarev. It says that the sculpture originates from the area "Kansk steppe" (Ust-Kansky district, Altai Republic) [Kubarev, 1984: 107, Table II.-18; Kubarev, 1997. P. 154–155; Leonov, 2021: 46].

The sculpture is made of a four-sided slab of coarse-grained gray granodiorite [Kubarev, 1984: 107]. The images are present on the front and back sides of the monolith. The upper edge of the head is slightly pointed and possibly imitates a pointed headdress. The head is separated from the body by a curved sharp-angled narrow groove, which models the neckline of the garment, and the neck and outlines of a narrow wedge-shaped beard are emphasized by it. The nose, eyebrows, eyes, and mustache are convex due to the deepening of the background around them. The eyes are almond-shaped. The indentations around the nose emphasize the wide cheekbones. Narrow and shallow grooves show highly raised arched eyebrows. Long narrow moustaches with raised tips are outlined with faintly relief narrow grooves. The mouth is highlighted by an arcuate notch. The part of the statue below the chest has not been preserved. Due to weathering, it is difficult to talk about the elaboration and arrangement of hands on the sculpture [Kubarev, 1984: 107, Table II.-18; 1997. P. 154–155]. On the reverse side of the sculpture there is a curved sharp-angled narrow recess — a groove that repeats the outlines of a similar stripe on the front of the product. This element is not typical for the design of sculptures of the Turkic period. It probably appeared as a result of several stages of work on the sculpture. Perhaps the master started working on the reverse side first, and only then chose a more even opposite surface. It should be noted that in the descriptions of the sculpture given by V. D. Kubarev, the relief on the reverse side is not specified. The possibilities of studying 3D-models of this sculpture allowed us to clarify additional details.

It should be noted that this approach to the publication of stone sculptures of the Turkic period is the most promising — based on 3D models, it is possible to compile catalog descriptions and make illustrations without serious distortions in different planes.

The experience of photogrammetry of stone sculptures is quite extensive [Tishkin et al., 2020; Svoysky et al., 2021; Tishkin, Svoysky, Ziganshina, 2022; Tishkin, Bondarenko, 2023; etc.] and the process of developing more and more optimal algorithms continues.

The process of creating a digital copy of the described sculpture from the Biysk Museum of Local Lore required a slightly different approach. Since the sculpture itself is small compared to the excavation and contains smaller details, any loss of the removed surface, incorrect angles, will result in a sharp drop in the quality and reliability of the digital copy. Therefore, the photogrammetry process required the creation of about 300 photographs of the object from different points and from different angles, as well as detailed frames to highlight smaller features. I would like to note that one of the possibilities of working with a digital copy is the ability to make orthogonal renderings of an object, without perspective distortions that are inevitable when photographing (Fig. 5).

Fig. 5. Rendering of orthogonal views of the statue
Рис. 5. Рендер ортогональных видов изваяния

Also, computer modeling can help to highlight embossed drawings on a stone, even those that are barely noticeable or noticeable only at a certain angle or in the right light (Fig. 6). However, such a task requires a special approach and the smaller the estimated size, the more qualified the specialist should be.

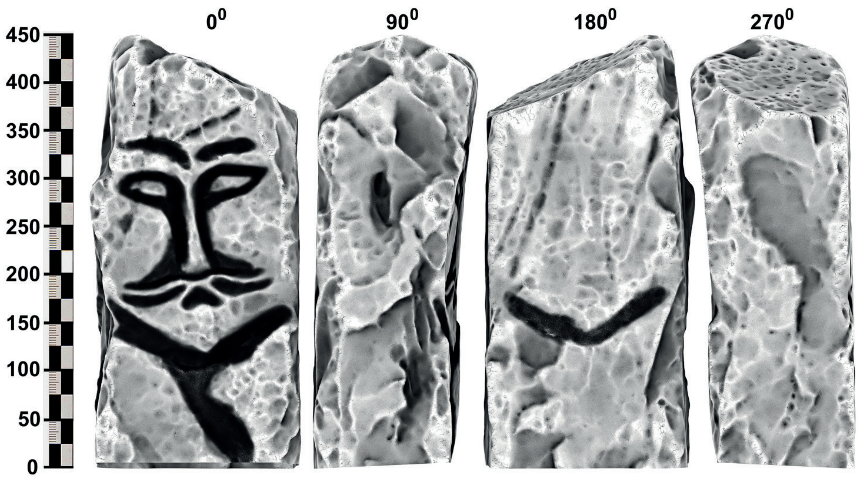

Fig. 6. Rendering of views with selected embossed contours
Рис. 6. Рендер видов с выделенными выбитыми контурами

Photogrammetry of archaeological objects

If we consider relatively small objects, an example is a fragment of a mirror from the collections of the Biysk Museum of Local Lore named after V. V. Bianchi (BKM A881, old inventory number). According to T. Masumoto, the object was discovered in sand dunes near

Biysk in the 1930-s [Masumoto, 1993: 251]. According to BKM employee L. I. Chagodaeva, the mirror could have been found in the vicinity of the village of Malougrenevo in the Biysk district of the Altai Territory.

The object is a fragment of a bronze mirror (about a quarter of it). On its reverse ornamented side, a part of the figure of a fantastic creature is visible — a winged sphinx, the remaining field is filled with a floral ornament. There is an Arabic benevolent inscription on the edge of the mirror. There is a hemispherical projection with a longitudinal hole in the center. Initially, the mirror had a diameter of 10.5 cm; the maximum thickness of the outer rim was 2.7 mm; the height of the protrusion-loop in the center was 8 mm. Entire copies of such mirrors depict two sphinxes placed in a heraldic pose with their backs facing each other (Fig. 7). The mirror from the Biysk Museum of Local Lore differs from the bulk of such products by a rather narrow outer border, where an Arabic inscription is placed and qualitatively elaborated details of the images.

Fig. 7. A fragment of a mirror from the Biysk Museum of Local Lore superimposed on a drawing of a mirror from the Tekeli mine [according to Baypakov K. M., Ternovaya G. A., Goryacheva V. D., 2007, fig. 221]

Рис. 7. Фрагмент зеркала из Бийского краеведческого музея, наложенный на рисунок зеркала из рудника Текели [Байпаков, Терновая, Горячева, 2007: рис. 221]

This type of mirror is found throughout the vast expanse of the Eurasian Steppe belt and in adjacent territories. Iran and Central Asia are considered as distribution centers for such products. In these territories, similar mirrors have been appearing since the end of the XI — beginning of the XII centuries. [Bogomolov, 2012: 163–164; Pugachenkova, 1961: 154]. In the western part of the Eurasian steppe belt, mirrors with paired sphinxes mostly date back to the XIII–XIV centuries. [Kvitnitskiy et al., 2019: 282; Pyankov, Raev, 2004: 244; Rudenko, Oborin, 2017: 147].

The product found in the vicinity of Biysk replenishes the eastern distribution zone of such mirrors. Even further east, similar objects were found in the Minusinsk basin and the Krasnoyarsk region [Lubo-Lesnichenko, 1975: 105, cat. 288, fig. 100; Borodovsky, 2023: 10–11, Fig. 1; Rudenko, Oborin, 2017: 146].

A large series of similar mirrors allows you to compare them with each other and trace the relative chronology, comparing the features of the casting of products and the details of the images. As a result, it is possible to trace in more detail the ways and chronology of their distribution. T. Masumoto also spoke about this when describing a mirror from Biysk [Masumoto, 1993: 251]. Unfortunately, the available publications do not allow for "remote" comparison of small details of products. But the high-quality publication of their 3D-models provides the basis for such a study. Presented on the Internet is a 3D-model of this mirror from Biysk will allow you to start this work (https://bolshoy-altay.asu.ru/museum/artifacts/zerkalo-fragment.html).

In order to carry out the correct photogrammetry of a mirror fragment from the collections of the Biysk Museum of Local Lore and obtain a relevant digital copy, it must be borne in mind that distortions unnoticeable in a larger object will inevitably lead to a noticeable distortion of this and therefore it is necessary to approach camera calibration and correction of distortion errors very scrupulously. Accurate calibration of a digital camera is an extremely necessary step. This includes determining the camera's internal parameters, such as focal length and radial distortion, which helps to correctly convert 2D-images to 3D-coordinates. When correcting errors, photogrammetry programs usually include algorithms for correcting distortions such as radial and tangential distortions, which helps to improve the accuracy of the result. And only the combination of these factors will allow us to achieve high accuracy in creating three-dimensional models with high accuracy of correspondence (Fig. 8).

Fig. 8. Rendering of mirror views
Рис. 8. Рендер видов зеркала

Conclusion

Photogrammetry, despite its long history and relative prevalence, is still a multifactorial technology with a well-known general technique, but fuzzy logic and the absence of an unambiguous set of rules by which good results could be achieved in any application for fixing both archaeological objects and artifacts of any size and geometry. Each object requires a separate approach with its own version of the technique for obtaining good fixation quality in an optimal way. Therefore, it requires special knowledge and experience, both in photo fixation and in processing the received data.

In general, the quality and accuracy of a digital copy depend on the level of photographic detail of the object, the number of shooting points and the use of control points. However, for large objects, if it is necessary to approach and examine parts of the object, for example, burial, it is necessary to photograph each element separately, creating a tiling model. For medium-sized objects, such as sculptures, photogrammetry from a single distance is required, as well as detailed shots of the knockout sites and small geometry features. For small objects, such as a bronze mirror, the first place is taken into account distortions, without which it is impossible to create a relevant digital copy. It should be noted that the study of the bronze mirror from the Biysk Museum of Local Lore named after V. V. Bianchi, once again showed that the creation of common databases of digital copies of archaeological artifacts is already an urgent need. You can start this work by organizing a single (unified) register of information about 3D models created by different researchers, their storage locations and access opportunities to them.

As a conclusion, it should be noted that photogrammetry in archaeology has great prospects that can significantly change the ways of researching and preserving archaeological finds. Some of the potential areas of development that are already being applied, although they have not found wide application, are the use of artificial intelligence, the integration of which methods into photogrammetry algorithms can speed up data processing, improve the accuracy of results and automate analysis processes, which will make photogrammetry even more effective. Continued advances in drone technology will allow archaeologists to capture images from more complex and hard-to-reach locations, expanding research opportunities. Photogrammetry can also become a key element in creating virtual and augmented archaeological environments that allow researchers and society as a whole to interact with reconstructed objects in virtual space. The use of cloud technologies allows for more efficient processing of large amounts of data, and collective processing can speed up the process of creating three-dimensional models and expand access to photogrammetry methods. The development of standards for photogrammetric data will allow for more efficient information exchange between researchers and scientists, which will support the collective development of the field. Taking into account these trends, photogrammetry will continue to evolve, providing archaeologists with new tools and opportunities for a deeper and more accurate study of the archaeological heritage.

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REFERENCES

Baypakov K. M., Ternovaya G. A., Goryacheva V. D. *Metal Art of the Krasnaya Rechka Ancient Settlement (the 6th — early 13th centuries)*. Almaty: Ғylym, 2007. 304 p. (in Russian).

Bogomolov G. I. Sphinx from Beshkubi: on the history of the image. *History of the Material Culture of Uzbekistan.* Samarkand: Institute of Archeology of the Academy of Sciences of the Republic of Uzbekistan, 2012. Vol. 38. P. 163–167 (in Russian).

Bondarenko S. Yu. Technology of Computer Reconstruction of Archaeological Finds, Similar to Objects of Rotation (on the Example of a Ceramic Vessel). *Theory and Practice of Archaeological Research.* 2023; no. 35 (3). P. 9–22. https://doi.org/10.14258/tpai(2023)35(3).–01

Bondarenko S. Yu., Kiryushin K. Yu., Frolov Ya. V. Presentation Possibilities of Three-Dimensional Registration of Archaeological Artifacts on the Example of a Pick from a Monument Firsovo — XI (Barnaul Ob). *Herald of Omsk University. Series "Historical Studies"*, 2023, vol. 10, no. 1 (37), P. 129–142 (in Russian). https://doi.org/10.24147/2312–1300.2023.10 (1).

Borodovskiy A. P. Another Find of the Eastern Mirror With Sphinxes on the Middle Yenisei. *Theory and Practice of Archaeological Research.* 2023, no. 2. P. 9–21 (in Russian). https://doi.org/10.14258/tpai(2023)35(2).–01.

Danilov V. A., Fedorov A. V., Bezvershenko L. S. The Comparison of the Methods of Photogrammetry and Laser Scanning for the Establishment of Three-Dimensional Models of Objects and Territories of Archeological GIS (on the Example of the Archeological Excavation of Uvek Hillfort). *Izv. Saratov Univ. (N. S.), Ser. Earth Sciences*, 2019, vol. 19, is. 2. P. 72–78 (in Russian). https://doi.org/10.18500/1819–7663–2019–19–2–72–78.

Grushin S. P., Sosnovsky I. A. Photogrammetry in Archaeology — Possibilities and Methods. *Theory and Practice of Archaeological Research.* 2018, no. 1. P. 99–105 (in Russian). https://doi.org/10.14258/tpai(2018)1(21).–08.

Grushin S. P., Stepanova E. V., Fribus A. V. Pazyryk headdress from the Ust-Teplaya burial ground (Northern Altai). *Transactions of the Institute for the History of Material Culture.* St. Petersburg: IHMC RAS, 2023. no. 29. P. 156–165 (in Russian). https://doi.org/10.31600/2310–6557–2023–29–156–165.

Kolobova K. A., Shalagina A. V., Chistyakov P. V., Bocharova E. N., Krivoshapkin A. I. Possibilities of using three-dimensional modeling for studying Stone Age complexes. *Siberian Historical Research.* 2020. No. 4. P. 240–260. https://doi.org/10.17223/2312461X/30/12.

Kvitnitsky M. V., Telnov N. P., Lysenko S. D., Razumov S. N., Sinika V. S. Golden Horde grave with a mirror with the image of sphinxes in the Lower Dniester Region. *In search of the essence: Essays in honourof Nicolai Russev on the occasion of his 60th birthday.* Chisinau: Stratum plus, 2019. P. 275–290 (in Russian).

Kubarev V. D. Ancient Turkic Sculptures of Altai. Novosibirsk.: Nauka, 1984. 230 p. (in Russian).

Kubarev V. D. Stone Statues of Altai. Short Catalog. Gorno-Altajsk: Ak-Chechek, 1997. 184 p. (in Russian).

Leonov A. S. Turkic sculptures of the Biysk Museum of Local Lore named after. V. V. Bianchi. *Collection of materials from the conference dedicated to the 100th anniversary of the Biysk Local History Museum named after. V. V. Bianki*. Biysk: BKM, 2021. P. 45–49 (in Russian).

Lubo-Lesnichenko, E. I. Imported mirrors of the Minusinsk Basin. To the question of the external relations of the ancient population of South Siberia. Moscow: Nauka, 1975. 166 p. (in Russian).

Masumoto T. On Bronze Mirrors Accidentally Discovered in Altai. *Protection and Study of the Cultural Heritage of Altai*. Part II. Barnaul: Izd-vo Alt. un-ta, 1993. P. 248–251 (in Russian).

P'iankov, A. V., Raev, B. Metal mirrors from the collection of the Don Museum (Novocherkassk). *Proceedings on the Archaeology of the Volga-Don Steppes*. Vol. 2. Volgograd: Volgograd State University, 2004. P. 219–250 (in Russian).

Pugachenkova G. A. Bronze mirror from Termez. *Ethnography of Soviet Union*. 1961. no. 1. P. 153–155 (in Russian).

Rudenko K. A., Oborin Yu. V. Mirrors with Fantastic Animals from Bulgar and Their Analogies. *Antiquities of Siberia and Central Asia*. 2017. no. 8 (20). P. 143–168 (in Russian).

Starovoytov A. V., Chernova I. Yu. Close-range photogrammetry as a reference method for making detailed all-level excavation plans. *Uchenye Zapiski Kazanskogo Universiteta. Seriya Estestvennye Nauki*, 2020, vol. 162, no. 2. P. 314–330 (in Russian). https://doi.org/10.26907/2542–064X. 2020.2.314–330

Svoysky Yu. M., Romanenko E. V., Ziganshina A. A., Tishkin A. A. The Use of Modern Digital Technologies for Documenting and Comprehensive Study of “Deer” Stones Stored in Museums of Russia. *Ancient Cultures of Mongolia, Southern Siberia and Northern China*. Abakan: IIMK RAN, 2021. P. 131–136 (in Russian). https://doi.org/10.31600/978–5–907298–19–4.131–136.

Tishkin A. A., Bondarenko S. Yu. “Deer” Stones Used by the Turks: a New Look at the Preserved Images (from the Materials of the Historical and Architectural Open-Air Museum of the IAET SB RAS) *Conservation and Study of the Cultural Heritage of Altai Krai*. 2023. Vol. XXIX. P. 239–247. https://doi.org/10.14258/2411–1503.2023.29.36.

Tishkin A. A., Svoisky Yu. M., Romanenko E. V., Ziganshina A. A., Iderkhangai T. New results of documenting “deer” stones near the village of Bayan zurkh (Mongolian Altai) *Proceedings of the VI (XXII) All-Russian Archaeological Congress in Samara*. 3 vols. T. III. Samara, 2020. P. 103–105 (in Russian).

Tishkin A. A., Svoisky Yu. M., Ziganshina A. A. “Deer” stones in Altai: the experience of modern documentation. *World of Central Asia — V*. Novosibirsk: SB RAS, 2022. P. 20–22 (in Russian). https://doi.org/10.53954/9785604788981_20.

БИБЛИОГРАФИЧЕСКИЙ СПИСОК

Байпаков К. М., Терновая Г. А., Горячева В. Д. Художественный металл городища Красная Речка (VI — начало XIII вв.). Алматы : Гылым, 2007. 304 с.

Богомолов Г. И. Сфинкс из Бешкуби: к истории сложения образа // История материальной культуры Узбекистана. Вып. 38. Самарканд : Институт археологии АН РУз, 2012. С. 163–167.

Бондаренко С. Ю., Кирюшин К. Ю., Фролов Я. В. Возможности технологии создания цифровых копий археологических артефактов на примере пешни с памятника Фирсово-XI (Барнаульское Приобье) // Вестник Омского университета. Серия: Исторические науки. 2023. Т. 10, № 1 (37). С. 129–142. https://doi.org/10.24147/2312–1300.2023.10(1).129–142.

Бородовский А. П. Еще одна находка восточного зеркала со сфинксами на Среднем Енисее // Теория и практика археологических исследований. 2023. Т. 35. № 2. С. 9–21. https://doi.org/10.14258/tpai(2023)35 (2).–01.

Грушин С. П., Сосновский И. А. Фотограмметрия в археологии — методика и перспективы // Теория и практика археологических исследований. 2018. Т. 21. № 1. С. 99–105. https://doi.org/10.14258/tpai(2018)1(21).-08.

Грушин С. П., Степанова Е. В., Фрибус А. В. Пазырыкский головной убор из могильника Усть-Тёплая (Северный Алтай) // Записки Института истории материальной культуры РАН. СПб. : ИИМК РАН, 2023. № 29. С. 156–165. https://doi.org/10.31600/2310–6557–2023–29–156–165.

Данилов В. А., Федоров А. В., Безвершенко Л. С. Сравнение методов фотограмметрии и лазерного сканирования для создания трехмерных моделей объектов и территорий археологических ГИС (на примере археологического раскопа Увекского городища) // Изв. Сарат. ун-та. Нов. сер. Сер. Науки о Земле. 2019. Т. 19, Вып. 2. С. 72–78. https://doi.org/10.18500/1819–7663–2019–19–2–72–78.

Квитницкий М. В., Тельнов Н. П., Лысенко С. Д., Разумов С. Н., Синика С. В. Золотоордынский погребальный комплекс с зеркалом с изображением сфинксов на Нижнем Днестре // В поисках сущности = In search of the essence: сборник статей в честь 60-летия Н. Д. Руссева. Кишинэу : Stratum plus, 2019. С. 275–290.

Колобова К. А., Шалагина А. В., Чистяков П. В., Бочарова Е. Н., Кривошапкин А. И. Возможности применения трехмерного моделирования для исследований комплексов каменного века // Сибирские исторические исследования. 2020. № 4. С. 240–260. https://doi.org/10.17223/2312461X/30/12.

Кубарев В. Д. Древнетюркские изваяния Алтая. Новосибирск : Наука, 1984. 230 с.

Кубарев В. Д. Каменные изваяния Алтая: краткий каталог. Новосибирск ; Горно-Алтайск: Ак Чечек, 1997. 184 с.

Леонов А. С. Тюркские изваяния Бийского краеведческого музея им. В. В. Бианки // Сборник материалов конференции, посвященной 100-летнему юбилею Бийского краеведческого музея им. В. В. Бианки. Бийск: БКМ, 2021. С. 45–49.

Лубо-Лесниченко Е. И. Привозные зеркала Минусинской котловины. К вопросу о внешних связях древнего населения Южной Сибири. М. : Наука, 1975. 170 с.

Масумото Т. О бронзовых зеркалах, случайно обнаруженных на Алтае // Охрана и изучение культурного наследия Алтая. Барнаул : Изд-во Алт. ун-та, 1993. Ч. 2. С. 248–251.

Пъянков А. В., Раев Б. А. Металлические зеркала из коллекции Донского музея (Новочеркасск) // Материалы по археологии Волго-Донских степей. Вып. 2. Волгоград : Изд-во ВолГУ, 2004. С. 219–250.

Пугаченкова Г. А. Бронзовое зеркало из Термеза // СЭ 1961. № 1. С. 153–155.

Руденко К. А., Оборин Ю. В. Зеркала с фантастическими животными из Булгара и их аналогии // Древности Сибири и Центральной Азии. Т. 8 (20). Горно-Алтайск : Горно-Алтайский государственный университет, 2017. С. 143–168.

Свойский Ю. М., Романенко Е. В., Зиганшина А. А., Тишкин А. А. Использование современных цифровых технологий для документирования и всестороннего изучения «оленных» камней, хранящихся в музеях России // Древние культуры Монголии, Южной Сибири и Северного Китая. Абакан, 2021. С. 131–136. https://doi.org/10.31600/978–5–907298–19–4.131–136.

Старовойтов А. В., Чернова И. Ю. Нестрогая фотограмметрия как базовый метод для создания высокоточных планов раскопа на всех уровнях вскрытия // Учен. зап. Казан. ун-та. Сер. Естеств. науки. 2020. Т. 162, кн. 2. С. 314–330. https://doi.org/10.26907/2542–064X.2020.2.314–330

Тишкин А. А., Бондаренко С. Ю. «Оленные» камни, использованные тюрками: новый взгляд на сохранившиеся изображения (по материалам Историко-архитектурного музея под открытым небом ИАЭТ СО РАН) // Сохранение и изучение культурного наследия Алтая. Вып. XXIX. Барнаул, 2023. С. 239–247. https://doi.org/10.14258/2411–1503.2023.29.36.

Тишкин А. А., Свойский Ю. М., Романенко Е. В., Зиганшина А. А., Идэрхангай Т. Новые результаты документирования «оленных» камней у поселка Баян зурх (Монгольский Алтай) // Труды VI (XXII) Всероссийского археологического съезда в Самаре: в 3 т. Т. III. Самара, 2020. С. 103–105.

Тишкин А. А., Свойский Ю. М., Зиганшина А. А. «Оленные» камни на Алтае: опыт современного документирования // Мир Центральной Азии — V. Новосибирск : СО РАН, 2022. С. 20–22. https://doi.org/10.53954/9785604788981_20.

Bondarenko S. Yu. Technology of Computer Reconstruction of Archaeological Finds, Similar to Objects of Rotation (on the Example of a Ceramic Vessel). Theory and Practice of Archaeological Research. 2023; no. 35 (3). P. 9–22. https://doi.org/10.14258/tpai(2023)35(3).-01.

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