PHOTOGRAMMETRY IN ARCHEOLOGY ACCORDING TO VERIN NAVER BURIAL GROUND AND THE SHENGAVIT SETTLEMENT

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ABSTRACT:

Photogrammetry is a non-destructive, three-dimensional modeling technique that has been widely adopted in archaeology. Archaeological monuments are particularly vulnerable to natural and anthropogenic activities, such as destruction, weathering, and erosion. Therefore, precise fixation and documentation of the monument are essential for preserving cultural layers for future generations. Digital technologies, especially photogrammetry, enable us to obtain better results for the photogrammetric survey. In recent years, this method has been employed in the excavation sites of Shengavit settlement and Verin Naver tombs, demonstrating its effectiveness in archaeological research. To obtain a better view of the stratigraphy of the site, the data was merged with archival drawings of previously collected information. This integration of data has allowed for a more comprehensive understanding of the site's history and evolution.

1. INTRODUCTION

Photogrammetry has been used for many years to create maps, 3D models, visual representations objects to research and survey the world around us. The origins of photogrammetry can be traced back to the 19th century, just after invention of photography and it has had a significant impact on generating the mapping using photos.

In the late 1800s, when French engineer and scientist Alphonse Bertillon developed a system for using photographs to measure human bodies. This system was used by authorities to identify criminals based on physical characteristics such as height, weight, and facial features. Bertillon also developed a method for using aerial photographs to create accurate topographic maps. He was taking overlapping photographs of the terrain from a hot air balloon or kite, and then using principles of photogrammetry to create a three-dimensional model of the landscape. He also developed methods for using aerial photographs to measure distances and calculate elevations, which made it possible to create highly accurate maps and topographic models.

But the pioneers of using photography to measure distances was Albrecht Meydenbauer (lbertz, J., 2001), an architect who had an idea to develop a method of using photographic images to measure the height of buildings and other structures. The method was taking two photographs of a building from different angles and distances, and then using the principles of perspective to calculate the height of the building. By knowing the distance between the two camera positions and the angles of the two images, he could calculate the height of the building using simple trigonometry. This system was a significant in the development of this field and it becomes very key tool for scientific measurements and analysis and has had a lasting impact on the field of architectural documentation and preservation.

Photogrammetry continued to evolve and improve. During World War I, photogrammetry played a critical role in the military efforts of many nations. The technology was used to create detailed maps of enemy territory, as well as to identify potential targets for artillery and other weapons. The aerial photography was achieved using cameras mounted on aircraft. The cameras were manually operated by the photographer, who would take a series of overlapping photographs by leaning out of the aircraft and snapping pictures at regular intervals. Photogrammetry continued to evolve after World War I and was used extensively in World War II. It was used to create highly detailed maps of the terrain, as well as to identify enemy positions and movements. One of the most significant advancements in photogrammetry during World War II (Brugioni Dino A., 1984) was the development of stereoscopic imaging techniques. By taking two overlapping aerial photographs of the same location from different angles, analysts could create 3D images of the terrain which allowed for even more accurate mapping and targeting. After World War II, photogrammetry continued to advance and was used for a wide range of applications in various fields, including cartography, geology, and engineering.

With the advent of digital cameras and computer processing, it became easier and faster to obtain accurate measurements and create detailed models from photographs. Today, photogrammetry is used in a wide range of fields, from engineering and architecture to archaeology and cultural heritage preservation.

2. PHOTOGRAMMETRY IN ARCHAELOGY

Photogrammetry has become an important tool in archaeology in recent years. It allows to create detailed and accurate 3D models of archaeological sites, structures, and artifacts, which can then be analyzed and studied in detail. Traditional methods of archaeological recording, such as hand-drawn plans and sections, often focus on specific features or areas, while ignoring others. Photogrammetry, on the other hand, can capture an entire site from multiple angles, providing a complete record of the site. One of the advantages of photogrammetry is its ability to capture more detailed and accurate data. While hand-drawn plans and

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sections are often limited by the skill and experience of the specialist. Photogrammetry, on the other hand, can capture detailed 3D models of sites and artifacts, which provide a more accurate and comprehensive record of the object or site.

Another advantage of photogrammetry is the speed and effectiveness. Hand-drawn plans and sections can be unproductive and laborious, mainly for larger sites or more complex structures. Photogrammetry, quickly and efficiently can capture data, allowing researchers to document the site in less time. Though there are also limitation in photogrammetry which are the specialized equipment, such as aerial cameras, professional ground-based camera, GPS receiver, photogrammetry software, computer hardware, which can be expensive and time-consuming to set up and operate.

In addition, on site works requires lighting and weather conditions, which can be limited in the environment.

Although the result and 3D model will provide valuable data not only for archeologist but preserve it virtual for future generation.

3. RESEARCH OF THE MONUMENT’S HISTORY

Favorable climate conditions of Armenia (food and water resources, specific temperature of the continental zone, the presence of metal minerals, particularly copper and high-quality raw materials for the stone tools, the effective relief of residence and protection, as well as acting as a bridge between Eurasian Steppe and ancient Near Eastern civilizations and other circumstances) had an important role in the formation of ancient civilizations in Armenian highlands. In the Republic of Armenia, according to official data, in every 1 sq. km archaeological and architectural heritage sites have been fixed. For the researchers the huge number of ancient archaeological sites, the relatively large population, the constructional and economical activities, brings many complex problems, and the important point is the use of precise modern technologies for the preservations and compound study of ancient cultural sites. Documentation of archaeological sites with photogrammetric methods is becoming more and more important for the geometrical survey of the monuments, detecting their locations, positions, and exact dimensions.

In this report are presented two different sites: the Shengavit settlement (early bronze age town) and Verin Naver tombs (middle bronze age necropolis).

4. THE PRINCIPLES OF COMBINING ARCHIVAL THEODOLITE DATA AND AERIAL SURVEY

The development of digital technologies has brought significant change in the research and geometrical survey of the monuments. The key point is accurate selection and combination of survey methods. Comparison of previously performed conclusions begins with focal studies on the spot, in the field. Some basic contents (road, structure, strataigraphy, etc.), which are still in their original position and size are detected. With the use of modern survey devices (laser distance meter, theodolite, tachometer, etc.) are fixed the reference objects in the site and the distance between them. The more key points and their geometrical data, the more accurate is the matching. After collecting the necessary data, the survey with a drone must be done. Based on the characteristics of the site, it is essential to choose a flight height and make a photo survey from that level.

The survey needs to be done both in the vertical position of the camera and at different angles to get high-quality data for the future model. All collected materials (archival, aerial photos, and data with the geometrical survey instruments) are uploaded to the computer. Required software for photogrammetry and imported data allows to obtain a three-dimensional accurate model of the terrain. We can merge the key points of different archival maps to complete the stratigraphy, and from three-dimensional model we can easily create the orthophoto plans of the site. This type of operation has been done in Shengavit settlement and Verin Naver burial ground (could be for sure applied in other archaeological monuments) and it allows us to study the stratigraphy of the site and the changes of the landscape in time.

5. THE PHOTOGRAMMETRIC METHOD OF DOCUMENTATION IN ANCIENT SETTLEMENTS ACCORDING TO THE RESEARCH CASE OF THE SHENGAVIT SETTLEMENT

The primary theodolite survey carried out in 1936, 1980, 2000 and 2022 in the Shengavit settlement with combination of photogrammetric method are an important basis for the accurate replacement in the drawings of the dwellings and buildings, defensive walls, storage and cultic pits excavated by different archaeologists and in different periods (Simonyan H., Rothman M. S., 2023). It allows us to map the archaeological artifacts in the excavation sites, to recreate practical character of the place and to identify the urban development processes. Particularly it is significant to get the precise documentation of the defensive structures, cultic buildings, cereal store-pits, crafts sector (jewelers, stone-masons, farmers, blacksmiths and etc.), correct documentation of the tomb-fields and recreate the picture of the settlement's urban life, which will be possible only by combining the geometrical survey, stratigraphic research, and photogrammetric method (Simonyan H., 2013).

Aerial photos are important source of data for photogrammetry. There are several factors that can affect the accuracy of height measurements obtained through photogrammetry, including the quality of the aerial photos, the angle of the photos and the scale of the photos.

Since 2020, photogrammetry has been used to collect data in the excavation sites of Shengavit settlement. The archaeological site has been divided into squares, which serve as ground control points for photogrammetry and are helpful for mapping features. In 2022, the focus of the archaeological excavation in the settlement of Shengavit was mainly on four squares, each measuring 10 x 10 meters.

The site documentation and mapping were carried out using aerial surveys conducted several times during the excavation. The most recent and detailed survey was conducted on November 23, 2022. Aerial surveys can provide valuable non-destructive identification and documentation of archaeological features and sites. To ensure optimal results, we selected appropriate equipment with a high-resolution camera, specifically the DJI Mavic 3 drone with Hasselblad camera and a 20-megapixel 1-inch CMOS sensor capable of shooting 4K video. After identifying our objectives and equipment, we carefully planned our flight path to ensure full coverage of the site. Although specialized software can be used to plan the flight path and ensure

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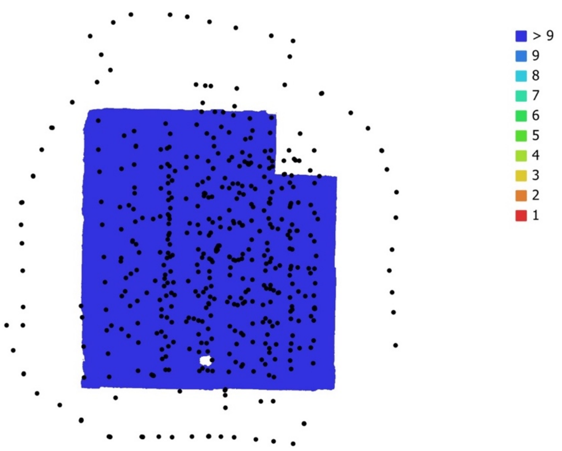
adequate image overlap, we decided to manually capture the photos. Before flying the drone, we conducted a site survey to identify any potential hazards or obstacles that could interfere with the flight or data collection. As the settlement of Shengavit is located in close proximity to an airport, flights near the controlled airspace required prior approval from the authorities to ensure the safety of air traffic.

Once the photos were captured, the next step was to process them and generate a 3D model. The initial step was to import the photos into photogrammetry software and generate a point cloud. There are several software options available for photogrammetry, each with their own unique features. We opted to use Agisoft Metashape, which enabled us to create high-quality 3D models and maps from the aerial photos we had taken. This included the ability to generate dense clouds, create meshes and textures, and generate orthomosaics.

On the day of capture, we were able to take 503 photos with a flying altitude of 6 meters from the base point. The coverage area of the overlapping images was 586 square meters, as detailed in Figure 1. The reprojection error for this dataset was 0.653 pixels, indicating the average distance between observed image points and their corresponding projections onto the 3D model. This means that, on average, the projections of the 3D model onto the 2D images have a distance of 0.653 pixels. A lower reprojection error is generally more desirable as it indicates a more accurate reconstruction. However, the acceptable range of reprojection error depends on the specific application and the quality of the input data. In some cases, a reprojection error of up to 1-2 pixels may be acceptable, while in other cases, a reprojection error of less than 0.5 pixels may be required.



Number of images:	503	Camera stations:	503
Flying altitude:	6 m	Tie points:	140,574
Ground resolution:	2.4 mm/pix	Projections:	1,064,113
Coverage area:	586 m²	Reprojection error:	0.653 pix

Camera Model	Resolution	Focal Length	Pixel Size	Precalibrated
L2D-20c (12.29mm)	5280 x 3956	12.29 mm	3.36 x 3.36 μm	No

Figure 1. Shengavit settlement, survey data, camera locations

Once the photos were aligned, the software allowed us to select specific points and expand or reduce the selection to optimize the model, which improved the quality and accuracy. To reduce the reprojection error, we attempted to improve the camera calibration, increase the number of tie points, optimize the alignment process, and use higher quality images. By taking these steps, we were able to achieve a lower reprojection error and improve the overall quality of the 3D model (Figure 2).
Once the images were aligned the next step was generation of dense point cloud by triangulating position of each feature in the overlapping images. After generation of dense cloud we created mesh from the points. The essential step in creating 3D model is texture mapping from 2D images.

Post-processing is the next crucial phase for finalizing the 3D model and ensuring that it is of the highest quality possible which involves cleaning up the model, removing any noise, adjust brightness, contrast and saturation and enhancing the visual quality of the final output.

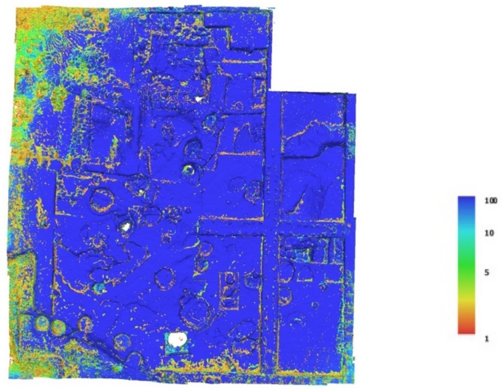
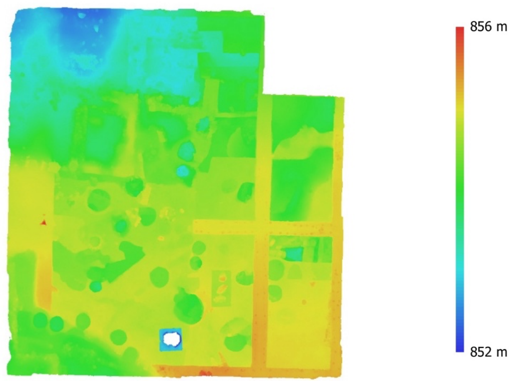


Figure 2. Shengavit settlement, confidence range



Resolution:	4.79 mm/pix
Point density:	4.35 points/cm²

Figure 3. Shengavit settlement, survey data, camera locations

The software allows us to reconstruct digital elevation model (DEM) which is a representation of the surface topography of a terrain or area, created through photogrammetry. DEM are often used in geographic information systems (GIS), urban planning, land management, environmental monitoring. (Figure 3) The accuracy and resolution of a reconstructed DEM depend on the quality and resolution of the input data, the accuracy of the camera calibration, the accuracy of the ground control points.

Weather conditions are critical factors to consider when it comes to aerial photography. Direct sunlight can cause harsh shadows and overexposure in aerial images. It's best to shoot the hour after

sunrise or before sunset to capture softer, more pleasant lighting. Despite in we did the survey early in the morning there were still shadows especially in the pits. To improve the shadows and overexposure can significantly enhance the visual quality of the model. Agisoft De-Lighter is a tool within Agisoft Metashape that is used to remove the lighting information from images. We import 3D model into the software carefully removed the lighting information from the model. And in result we improve the quality and consistency of the texture get better 3D model. (Figure 4)
After creation of the model it can serve as a basis for creation drawings, plans, sections, by using appropriate drawing software, which will be the next step of the survey.

Figure 4. Shengavit settlement, orthophotos of excavation site, with natural light and after removing shadows

8. DOCUMENTATION IN THE TOMBS OF VERIN NAVER

The necropolis of Verin Naver is a vast area covering approximately 150 hectares, containing hundreds of kurgans from the Middle and Late Bronze Ages, as well as tombs from the Urartian periods. Discovered in 1975, the monument was excavated between 1976 and 1990, and again from 2010 to 2022. Topographical surveys of the site were conducted in 1973, 1977, 1980, and 2003, using measurements taken not only from the site itself but also from the four points of the tombs. The resulting data provided a reliable foundation for confirming the absolute values of the kurgans (Simonyan H., 2006).

These topographical surveys are essential in merging with photogrammetric data to create accurate maps of the site and place all the tombs with artifacts, enabling the identification of concentration of burials from different social levels and periods. By classifying cultic structures and sacrifices, as well as identifying the development of burial processes, researchers can gain a better understanding of the social and cultural practices of the time.

In 2021, extensive construction work commenced in the vicinity of the Verin Naver necropolis, with plans for a winery and vineyard in the area. The construction was located in close proximity to the necropolis, which raised concerns about potential damage to the site. As a result, a project was initiated to establish a new protection zone for the necropolis, and excavation works were organized in 2021-2022 to assess any potential impact of the construction on the archaeological site.

These excavation works were critical in providing a thorough understanding of the site and identifying any potential risks to its preservation. With the new protection zone in place, the Verin Naver necropolis can be safeguarded for future generations, ensuring that its rich archaeological history remains intact. This project is a testament to the importance of preserving our cultural heritage and ensuring that development and progress are balanced with the protection of our valuable archaeological sites.
In 2021, multiple tombs were excavated in both the central and northern sections of the Verin Naver necropolis, revealing further insights into the rich history of the area (Figure 5): The following year, in 2022, archaeological work continued in the northern part of the site. At the same time the protection zone of the site was formed.

During the archaeological survey has done geometrical survey of the tombs using the method of photogrammetry. In the archaeological site we established 5-6-meter-wide squares or a circle of diameter 5-6 meter to ensure that each excavation unit was accurately positioned and recorded. The distance between fixed points, azimuth and altitudes measured by hand tools. Connecting the fixed points to other points in the area, such as an electric pole or road corner, was the following step in the surveying and mapping process. The excavation process of the tombs captured with photo camera canon EOS 60D. photo-taking positions were selected along the perimeter of the excavation area, at a distance about 0.5 meters from each other. This indicates that a systematic approach ensuring that all areas of the site were adequately covered. 3-4 photos captured from each position, from a height of about 1.5 meters, which allows for a detailed and comprehensive record of the site. For each archaeological unit we obtained about 150-200 photos. The collected data of the geometrical survey were imported to the software such as AutoCAD and the stationary points generated in their precise positions. The photos taken during the excavation process were downloaded into the Agisoft Metashape program, which analyzed the images and reconstructed a 3D model of the site. Orthographic plans and sections from the 3D model obtained which were downloaded into specialized software to get more accurate plan and section drawings.

By combining these two types of data 3D model of the of the necropolis and topographical data obtained bases for the protection zone project.

To obtain precise coordinates of the tombs and stationary points, the Trimble rover GPS was utilized during the surveying process. Additionally, the entire area of the necropolis was captured using a DJI Mavic Air 2 drone, which captured more than 200 images from a height of 50-100 meters above the highest point of the site, providing detailed and accurate 3D models of the protection zone.

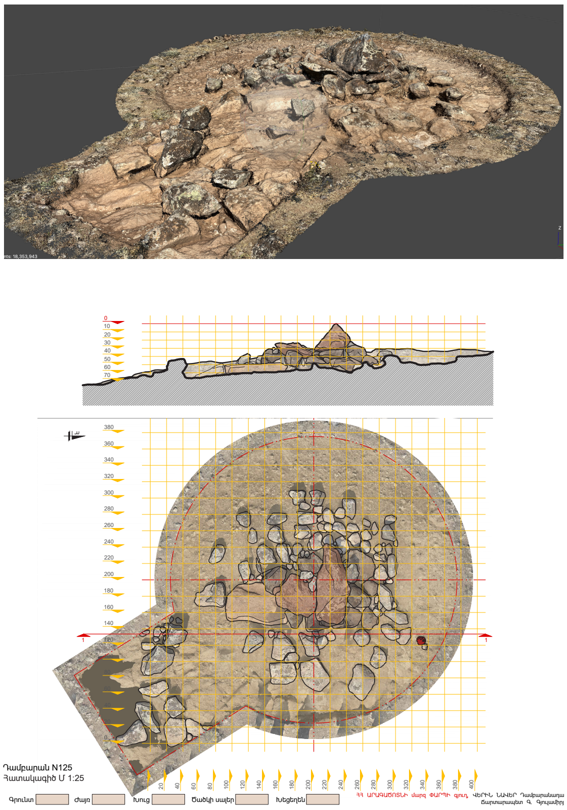


Figure 5. Verin Naver, tomb 125, dense point cloud, drawing according to orthophoto

Using the orthographic plan of the site obtained from the 3D model, combined with data taken by the Rover GPS, a detailed and accurate map of the site was created. This map was instrumental in analyzing the distribution of the tombs, as well as identifying patterns and relationships between the tombs and other features of the site.

The resulting data and documentation allowed for the generation of a new, more detailed project for the protection zone of the necropolis. Overall, the use of modern technologies such as GPS and drones, along with specialized software, enabled researchers to accurately document and analyze the site's features and layout, contributing significantly to ongoing research and preservation efforts.

9. CONCLUSION

Topography and photogrammetry are both invaluable tools in the field of archaeological research, each with its unique strengths and limitations. Topography provides a comprehensive view of a site's surface features, allowing archaeologists to map out its elevation, contours, and structures. This technique is particularly useful for identifying architectural elements and changes in terrain that may indicate past human activities.

On the other hand, photogrammetry enables researchers to create highly detailed 3D models of artifacts or sites using photographs taken from different angles. This technique is ideal for capturing intricate details that may be difficult to measure with traditional surveying techniques.

Both topography and photogrammetry require specialized equipment and expertise to use effectively. The choice of which technique to use will depend on the specific research questions being asked and the nature of the site under investigation. By combining these two techniques, archaeologists can gain a more complete understanding of the archaeological record and shed new light on the activities and practices of past societies.

The ability to visualize and analyze 3D models generated from photogrammetry also offers exciting possibilities for public engagement and education, allowing people to explore archaeological sites in new and immersive ways. Ultimately, the use of topography and photogrammetry in conjunction with other archaeological methods can provide a more nuanced and multidimensional understanding of the past, enriching our knowledge of human history and cultural development.

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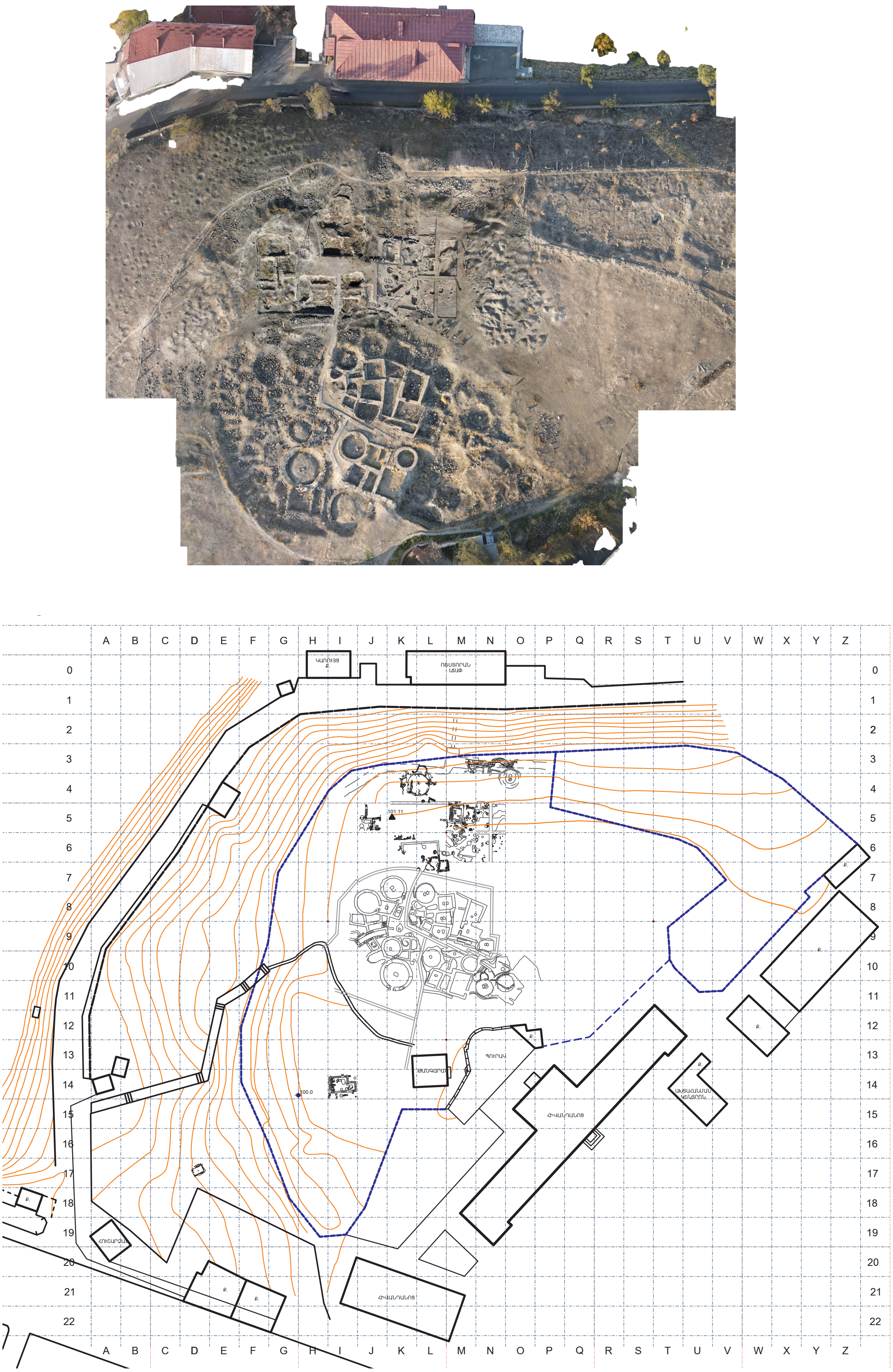
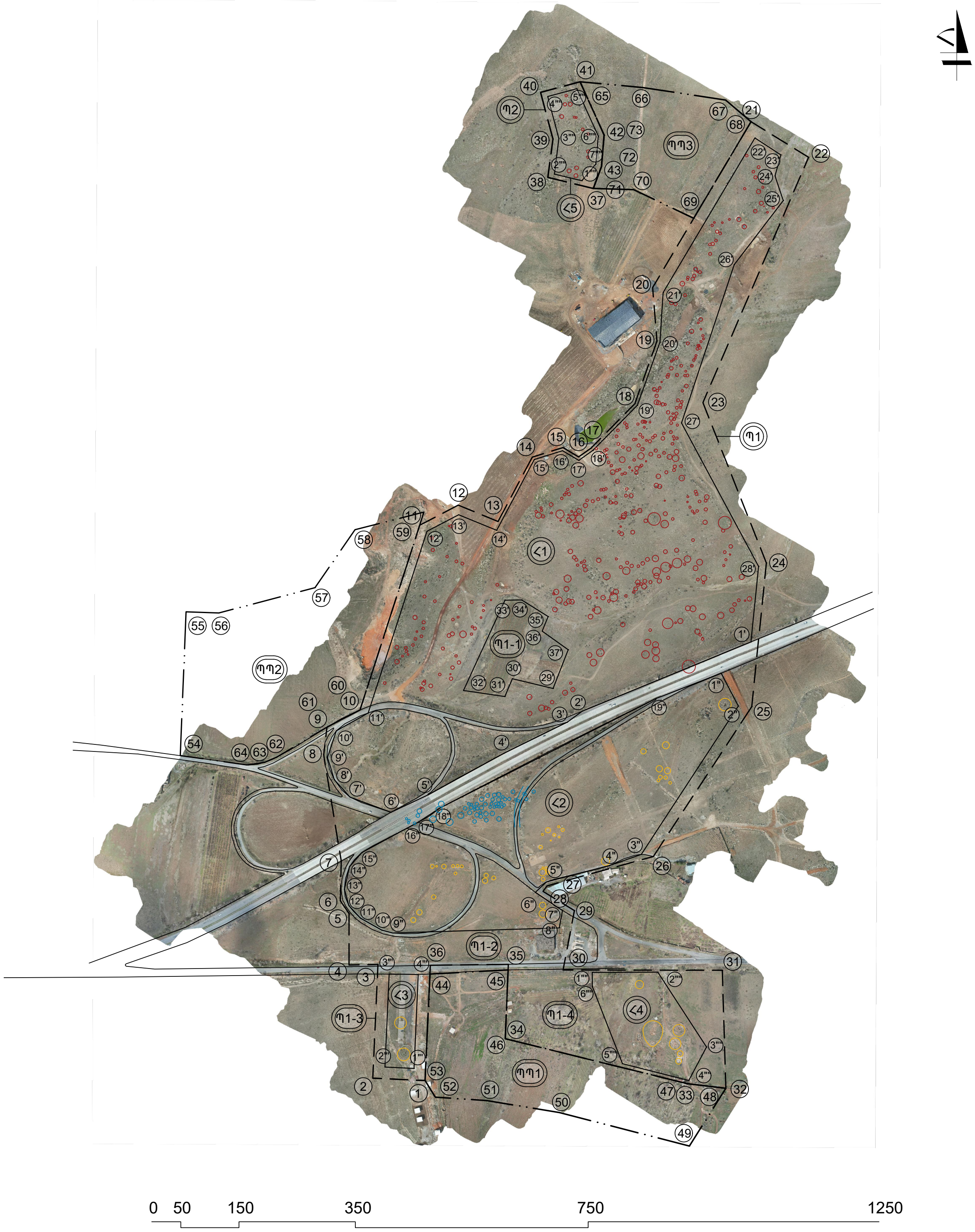


Figure 6. Shengavit settlement, combination of archival drawings, merged according orthophoto



LEGENDS

Core zone of the monument

Protection zone of the monument

Zone marked to be excavated

Survey with digital theodolite made in 2021 (the inaccuracy is minimum)

Survey in 2010, with primary theodolite (there has been a decline in the northern area surveyed, there are some inaccuracy in distance between tombs and diameters)

Tombs marked with use of aerial photography (there are some inaccuracy)

Figure 7. Verin Naver, monument protection zone according to the topographic surveys in 2010, 2021, merged with orthophoto