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# PHOTOGRAMMETRIC MODELING AND THE CENTRAL RAVINE OF THE SANCTUARY OF THE GREAT GODS, SAMOTHRACE

Vincent Baillet, Ioannis Poularakis, and Andrew Farinholt Ward

## Abstract

A seasonal torrent, bounded by retaining walls integrating Greek and Roman phases, runs through the middle of the Sanctuary of the Great Gods on the island of Samothrace. This central ravine was the subject of study in 2016, inspired by the American mission's current focus on the question of how ancient visitors navigated the sanctuary. A key aspect of this study was the accurate, but selective, documentation of the ravine's anthropogenic elements, and the delineation these integrated premodern and modern phases. Rather than using laser scanning or another technologies more often used for large features, the project generated a high definition photogrammetric model and associated vector drawings by a modified protocol using a hand held camera. The value of this low-resource methodology was evident after a series of storms between 2017 and 2020 caused extensive damage., and this paper evaluates its efficacy in light of newer techniques and technologies.

## Keywords

Greek archeology, Water Management, Digital archaeology, Photogrammetry, 3D modelling.

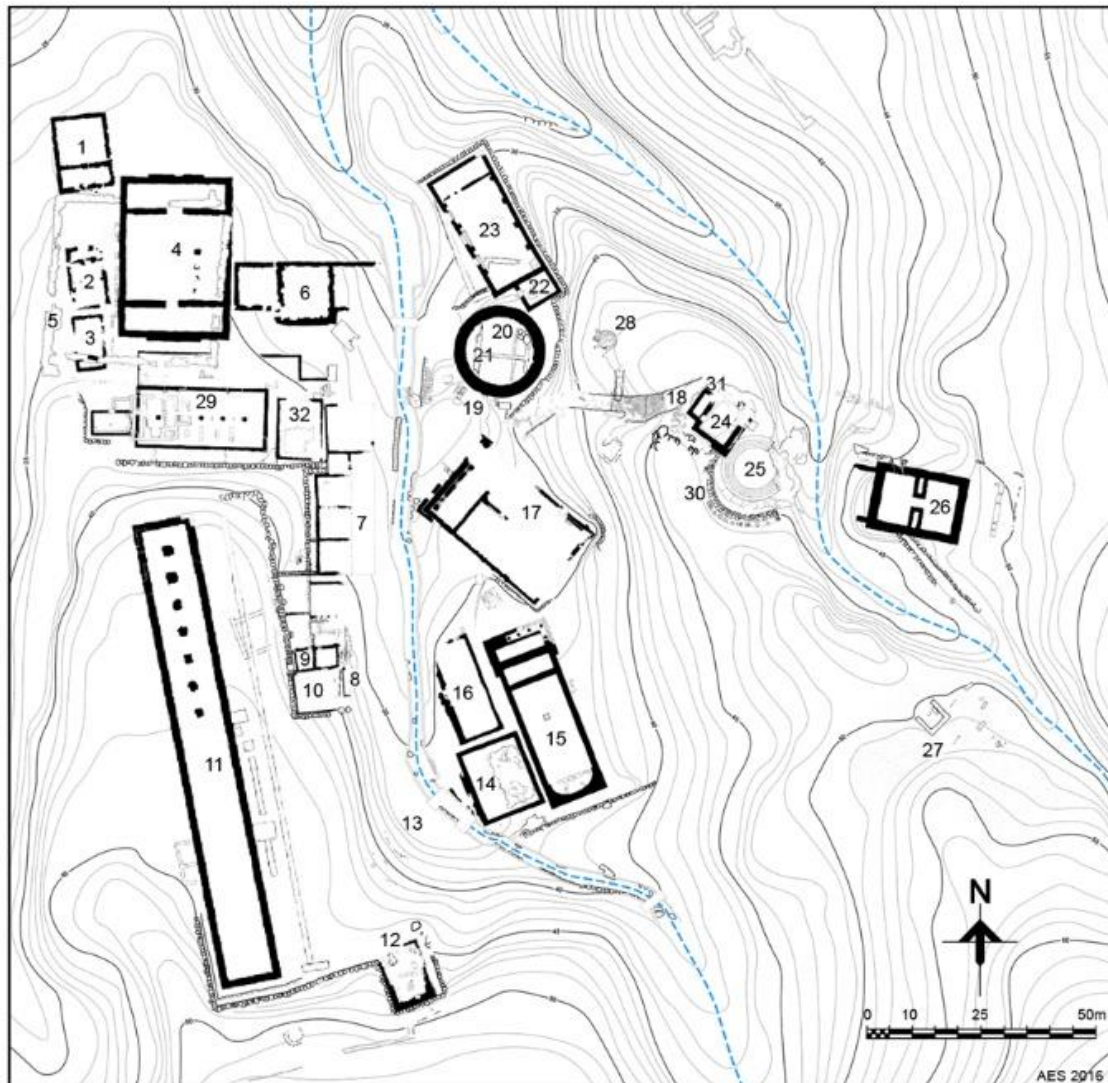
## 1.1 Samothrace and the Sanctuary of the Great Gods

The island of Samothrace (Fig. 1) in the North Aegean, settled by Greek migrants between the eighth and sixth centuries BCE (Graham 2002: 231-260), is dominated by Mount Saos. The mountainous topography of the island shaped not only the development of the principle urban center perched on the steep flanks of the Agios Georgios ridgeline, but also, by the end of the Archaic period, a sanctuary to the settlement's west.



**Fig. 1.** The North Aegean, with the island of Samothrace indicated. (© American Excavations Samothrace).

Sited in a valley flanked on either side by ridges, the Sanctuary of the *megaloí theoi*, or Great Gods, the space was natural catchment for seasonal rain and snow-melt runoff. In spite—or perhaps in some ways because—of this harsh topography, the sanctuary would gain international prominence and be elaborated with a number of innovative monuments under the patronage of the Macedonian royal family and their Hellenistic successors, remaining in use through the Roman Imperial period (Fig. 2; Lehmann 1966; Matsas 1998).



**Fig. 2.** Sanctuary of the Great Gods, Samothrace. Restored plan of the of the sanctuary's major monuments: 1, 2, 3 Unidentified Late Hellenistic buildings; 4 Unfinished Early Hellenistic building (Building A); 6 Milesian Dedication; 7, 8, 10 Dining rooms; 9 Archaistic niche; 11 Stoa; 12 Nike Monument; 13 Theater; 14 Altar Court; 15 Hieron; 16 Hall of Votive Gifts; 17 Hall of Choral Dancers; 18 Sacred Way; 20 Rotunda of Arsinoe II; 22 Sacistry; 23 Anaktraon; 24 Dedication of Philip III and Alexander IV; 25 Theatral Circle; 26 Propylon of Ptolemy II; 27 South Nekropolis; 28 Doric Rotunda; 20 Neorion; 30 Stepped Retaining Wall; 31 Ionic Porch; 32 Hestiatorion. (© American Excavations Samothrace).

The core rite by at least the fifth century BCE was a two-stage initiation into the cult's mysteries (Dimitrova 2008: 246ff). Ancient literary sources are understandably vague on the nature of the rituals and their meaning (Burkert 1999), but topography clearly played a role in ritual activity, with initiates, descending down into the sanctuary and crossing over two water channels all while following a path that carefully curated their viewing experience. Under the direction of Bonna Wescoat of Emory University, the American Excavations Samothrace mission has focused both on the full publication of the sanctuary's many monuments (e.g., Wescoat 2018), and investigation into how this interaction between the built and natural environments shaped an ancient visitor's experience (Wescoat 2017; Wescoat et al. 2020). Such a shift falls in line with wider trends in archaeological practice, which seek to broaden what we conceive of and study within a landscape (Thomas Fisher and Thurston 1999).

## 1.2 The Central Ravine Project

This new approach has in turn led to the reevaluation of a prominent, but in some ways understudied, feature: the so-called central ravine (Fig. 3). As it exists today, the watercourse runs roughly south-north through the sanctuary's central valley, channeling seasonal waters from beyond the site's fence to a streambed to the north all while weaving through and dividing a number of important ancient buildings. The "term" ravine is in some ways a misnomer, as in its current state parts of its path are completely lined with concrete and stone, while in other areas the ravine's sides are retained still by ancient walls. In many ways the ravine typifies the idea of an architectural palimpsest (Van Ooijen 2019), holding within itself a complex interplay of coexisting ancient and modern attempts at channeling the seasonal waters. The sheer length of the ravine, though, and this combination of anthropogenic and geologic elements, has made it difficult to study effectively as a cohesive archaeological feature using traditional survey methods.



**Fig. 3.** Plan of the Sanctuary of the Great Gods with the modern course of the Central and Eastern Ravines indicated as dashed blue lines (left); Aerial view of Central Ravine (right). (© American Excavations Samothrace).



Its size and complex assemblage of phases might make it seem that the ravine had always existed as it does today, but that is not the case. Early excavators on the site, including the French expedition of G. Deville and E. Coquart in 1866 and the Austrian mission led by Alexander Conze in 1873 and 1875, documented sections of ancient walls alongside and occasionally in a torrent that could change course season to season (Deville and Coquart 1867: 278; Conze, Hauser, and Benndorf 1880: 31-32). During the Lehmann excavations in the 1950s, the ravine bed was deepened, a channel suggested by those ancient walls, recognized by the excavators as part of the ancient water management system (Lehmann 1951: 8-9). Two phases of ancient retaining walls were identified. Sections made of dry-laid basalt boulders consistent with Greek construction practices were concentrated primarily to the south, originally attributed to the Archaic period but more likely associated with the site's monumentalization in the Hellenistic period. Meanwhile, more extensive sections of limestone and concrete walls presumably of a Roman date survived through the heart of the sanctuary (Fig. 4). Although the new route excavated in the 19750s roughly followed the course of this ancient channel, the route's primary function would be as the site's first tourist path. Over the following years, though, the intensity of seasonal rains would see the retransformation of the path back into a watercourse, with necessary repairs following particularly catastrophic winters.



**Fig. 4.** Central Ravine. Intact section of Greek-phase boulder retaining walls (left); Intact section of Roman-phase concrete and limestone retaining walls (right). (© American Excavations Samothrace).

Motivated by the interests outline in section 1.1, in 2016 the first full documentation of the central ravine's anthropogenic features, in all their complexity, was attempted. Working within a long-running archaeological mission, the desired end products included a traditional scale plan illustrating the distinct phases, as well as a digital model to integrate into a sanctuary-wide model maintained by the mission in 3dsMax. After reviewing the wide range of technologies and methods available in 2016 to generate these products, photogrammetry with a handheld device, increasingly common among archaeologists (c.f. Andersonn 1982; Delevoie, 2012; Sapirstein and Murray 2017) and cultural heritage specialists (McCarthy 2014), was deemed the most appropriate. While far from a novel methodology, the irregularity of the central ravine,

the intense climate of an Aegean island in the summer months, and labor and financial considerations presented challenges that had to be addressed, leading to a revised protocol that had many benefits, intended and unintended, which may be instructive to other archaeological projects.

### **1.3 Project Formation**

To understand this complex feature, and how it related to the surrounding sanctuary, an effective and efficient means of documentation and modelling was needed. While archaeological questions might have instigated the project, modern excavation projects are necessarily multidisciplinary, requiring a wider range of visual and quantitative data. Therefore, a suite of final products was necessary, which included both a georeferenced, highly detailed, and textured three-dimensional digital model, as well as a set of detailed two-dimensional elevation and plan drawings, with clear definition and delineation between visible stones and mortar groupings.

A major consideration during project formation was scale, inherent to any study of landscape. The area of the ravine to be modeled included slightly less than 111 meters of a total ravine length within the archaeological park of roughly 164 meters. This area of investigation included all of the visible sections of ancient retaining wall, comprised of a southern section running 75.80 and a northern section measuring 35.16 meters. Along that length, two distinct elevations to the east and west (height: 1.45 – 3.60 meters), and the ravine bed itself (width: 2.25 – 10.50 meters) had to be surveyed, for an intimidating total of ~1.000 m<sup>2</sup> of detailed measurements. By means of traditional manual measuring, this task would require hundreds of work hours, requiring a major reorientation by the entire archaeological mission to finish the project in over two brief summer seasons.

Terrestrial laser scanning (TLS) has become increasingly popular for documenting complex heritage objects with high data density. The highly irregular course and varied surfaces and textures of this sort of feature, however, were a concern, as well as the costs associated with bringing in outside specialists. Meanwhile, aerial laser scanning, more practical for large-scale features such as the central ravine (Harmon, Leone, Prince, and Snyder 2006), required several additional permits due to restrictions on aerial photography on an island with a military base. 3D scanning can create errors in the generation of edges (Boehler and Marbs 2005), accurate renderings of colors for individual stone, or the texture of concrete aggregate, all of which are crucial for the archaeological component of the project, as subtle differences in the stones could differentiate phases.

While the combination of laser scanning and Structure from Motion (SfM) photogrammetry has proven effective for complex standing structures (Alshawabkeh et al. 2020), for the unique challenges of the ravine a protocol was developed in order to use hand-held camera photogrammetry as the sole method for data capture for the generation of a 3D model and resultant orthophotos and traditional line drawings. The methodology developed by the small study team is outlined in the coming pages.

The advantages of photogrammetry for such projects are well known (Manferdini and Galassi 2013), and for highly irregular monuments the benefits of more expensive equipment are not always clear (Costa et al. 2016). There were, though, further unforeseen benefits of completing this documentation in parallel with archaeological and architectural study of the extant anthropogenic features of the ravine. While the team faced certain challenges requiring modifications to the initial protocol, this integrated process proved to be very time efficient, with a 3D model and complete phase plan generated over two brief summer campaigns in 2016 and 2017.

## **2.1 Evaluating Photogrammetric Methods**

The task of approaching a highly reliable model of the ravine using photogrammetry, especially in the center of a rich archaeological site, proved to be challenging methodologically and epistemologically. The need for a high degree of accuracy in the final product was clear, as was the use of orthophotography as the bridge between data-gathering and modelling. Beyond this, though, a series of choices needed to be made, as the unique demands of the context required slight adjustments to the standard 3D capture technique of photogrammetry through the practice of dense correlation.

While photogrammetry has become increasingly popular across academic and professional disciplines in the past decades (Pierrot-Deseilligny, 2011), the word ‘photogrammetry’ is in fact quite old. First used by Albrecht Meydenbauer in 1893 in a very different sense (Wolfgang, 2006), the term even today can refer to a broad range of techniques which all use photography to determine the shape and position of an object in space (CLIF, 1997). Conventionally, the term now refers to a technique based on a rigorous modelling of mosaics of images in order to reconstruct an exact – or as faithful as possible – three dimensional reproduction of the subject. Nevertheless, even this definition obscures a great deal of methodological choice that is often omitted in the publication of final products.

Once consensus was reached on using photogrammetry as the primary method of data-capture to create orthographic pictures of the central ravine, an obvious question remained. What tool could be used to gather the necessary data for this three-dimensional model? Several tools nowadays make it possible to carry out a photogrammetric survey (Pamart, 2019). As discussed in section 1.2, 3D scanning, more commonly known as lasergrammetry, has suitable features for digitization (Chayani, 2016). Yet, this technique is not the best for environments like that encountered on Samothrace.

On the one hand, a 3D scanner is not selective in the construction of a digital model, including absolutely everything in the view of the laser during the revolution of the device. Thus, trees, shrubs, rocks and other existing obstacles outside the boundaries of the central ravine will be included in the dense cloud points. If 3D scanning was chosen, the most time intensive task would ultimately be the correct definition of the scan positions, in order to ensure a sufficient coverage of the objects to be scanned.

On the other hand, if this technique was adopted, the volume of data could very quickly reach tens of gigabytes, making the processing and manipulation of the data with standard processors more difficult (Dubois, 2017). Even if one takes care to position scanning stations properly, the inclusion of the aforementioned extraneous data would further increase the size of the model. In post-production, such a model would require tedious manual cleaning before it could be used for applications related to archaeological survey (Landes, 2011).

An aerial drone equipped with a high-resolution digital camera is another device usually suitable for these types of projects (Cailloce, 2015). Unfortunately, most of the sanctuary's ravine is lined with tall trees leading to low visibility from high altitudes. While it is possible for a drone to navigate below tree cover, even with precautions taken it is difficult to avoid potential collisions with other vertical elements.

An additional context-specific concern arose in the intense winds characteristic of the Aegean area, which makes data gathering using aerial drones unwise (Goustard, 2013). As a result, the risk to the equipment was deemed unreasonably high.

## **2.2 Evaluating Photogrammetry with Manual Shooting**

This process of elimination led to the ideal solution: Structure from Motion photogrammetry, using a high-resolution handheld digital camera in order to create a model of the Central Ravine. This method met the project's needs and works well in the unusual context of the ravine. The decision was facilitated by the fact that an entire model of the central ravine was not needed, and could be obtained fairly easily later on through the combination of lasergrammetry and aerial photography UAVs. The principle objective here was instead the generation of high-quality orthographic pictures of areas of surviving ancient retaining walls.

A large photo sensor was used to achieve this. A large-sized sensor reproduces the light signal received on its sensitive surface more accurately. Thus, it offers better resolution, as well as better definition by presenting more details on the high and low-light areas through greater management of the signal/noise ratio (Pamart, 2019). In this case, a *Reflex NIKON D7100* camera was used with the *Nikkor 18–140 mm DX VR* as a lens.

It is commonly recognized that the full frame camera is much more adapted to realize a photogrammetric survey (Grussenmeyer, 2003). However, the camera used offers a good resolution/definition compromised with very correct resolutions with a 24.1 megapixel sensor and it can produce RAW images in 6000 by 4000 pixels. As mentioned above, using a large sensor will be preferred in photogrammetry, as it will have a direct impact on the quality of the image. A sensor of large dimensions reproduces more precisely the light signal received on its sensitive surface. It thus offers a better resolution, but also a better definition by presenting more details in the high and low light areas by a better management of the signal / noise ratio. The lens used was largely sufficient because the goal of this research was to have a complete



survey of the Central Ravine with an accuracy estimated to the centimeters. Actually, the use of more efficient equipment depends on the requirements of a study that motivated the digital survey. The most important aspect for the team was to guarantee technological, technical and methodological consistency in relation to the constraints imposed by the archaeological context.

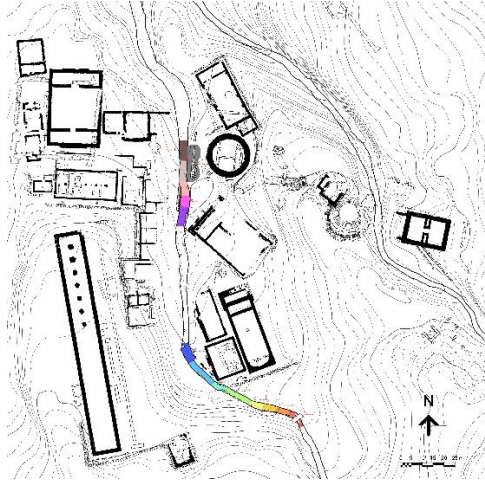
While this technique of digital capture takes longer to prepare, on the whole it turns out to be more efficient than the remote devices described in sections 1.3 and 2.1, because of its adaptability. Thus, it provides the camera user with more control in the shooting and a broader control in the photographic path, which is necessary to recreate the three-dimensionality of the central ravine.

With the chosen methodology's effect on data capture considered, the next question to be solved was that of data processing. How might a traditional excavation team create exploitable three-dimensional files using computers, which are not necessarily capable of processing all of the data generated by an archaeological feature as large as the central ravine?

Considering the broad dimensions of the ravine, as well as surviving parts of the ancient channel's retaining walls that exist outside of the modern torrent, the model would need a surface of  $\sim 1000 \text{ m}^2$ . To lessen the quantity of data processed at any given time, the ravine's northern and southern areas were subdivided into sections of a length not exceeding 15 meters. This subdivision, by reducing the number of images, had the added benefit of reducing computation time required to generate point clouds – essential during the short seven week seasons between 2016, 2017 and 2019. While this sectioning requires more work in post-production to stitch together the sections' models, it settles the problem of rendering the models in a reasonable size. Moreover, this approach makes it possible to overcome many obstacles (Dubois, 2017) associated with photogrammetric surveys, and to set in motion all the actors involved in the development and the use of archaeological data concurrently.

## **2.3 Data Capture Protocol**

Having established these elements, the first digital survey campaign in July 2016 was initiated. In collaboration with the director of the research program, as well as the geospatial referencing team, fourteen sections of the torrent were selected of archaeological interest (Fig. 5), grouped within three main areas of the sanctuary. The first section begins just before the Rotunda of Arsinoe II and continues until the southwestern corner of the Hall of Choral Dancers. The second area begins just before the Altar Court and captured the channel as it wraps through the space between the Altar Court and theater. A final section, contiguous to the second, continues upstream to the southern border of the sanctuary. Once these sections were well established, they were demarcated in the field with temporary but weather resistant physical markers (Fig. 6).



**Fig. 5.** Central Ravine. Area of investigation during the 2016-2017 photogrammetric campaigns, with section divisions. (© American Excavations Samothrace).

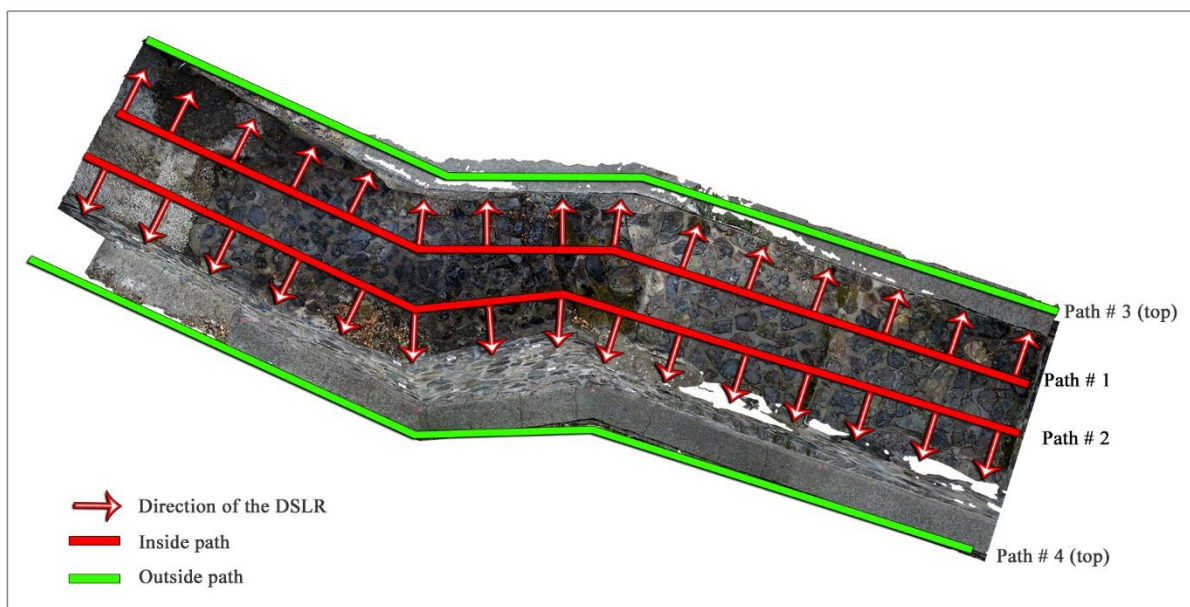


**Fig. 6.** Division between Sections 8 and 9. East wall of the Central Ravine, facing southeast. (© American Excavations Samothrace).

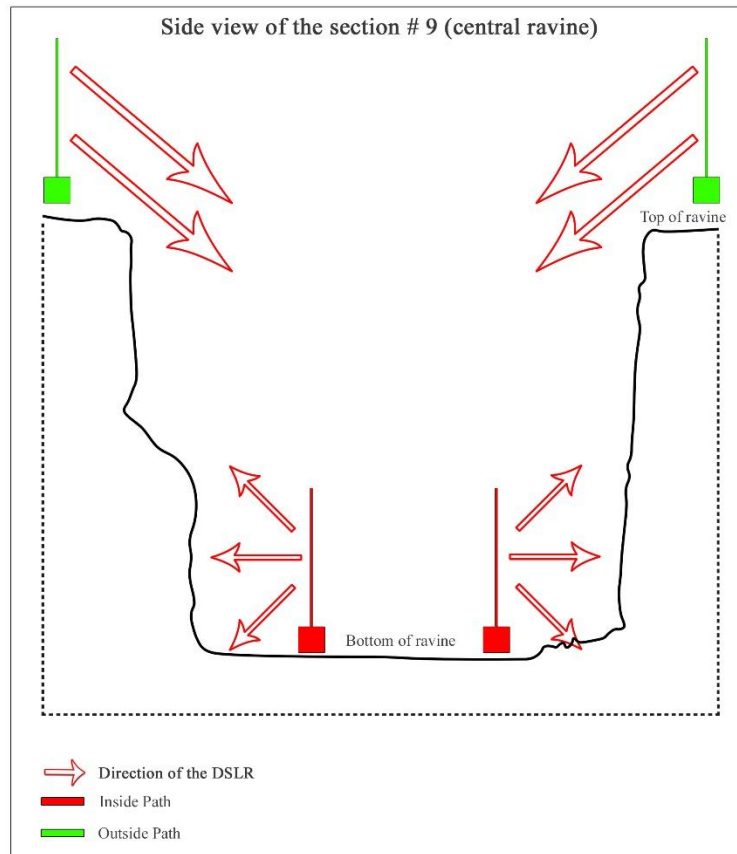
Prior to all data-capture sessions, between 20 and 30 coded ground control points were fixed on the walls of the ravine in each segment to allow for geo-referencing of the generated digital model. While essential for the generation of the orthographic photos, these markers also facilitate rescaling the numerical model, locating it in space, and correctly orienting the x, y,

and z axes. Ideally, a line of four to six targets was placed and spaced at regular intervals (about 1 meter) at two to three different elevations within the ravine. In reality, the number of targets as well as their layout depended on the accessibility of the photographed walls, the length of the segment, and the overall complexity of the area.

Following this setup, the digital capture process of the central ravine began. In July 2016, the protocol included four photographic paths. Two paths (Path #1, 2) were followed by a single photographer within the torrent, during which they faced outward towards the side walls of the ravine (Fig. 7). This was followed by two further paths (Path #3, 4) that required walking along the embankments and walls flanking the torrent. From these upper elevations, the camera lens was pointed downwards at a series of angles, allowing the capture of the ravine bed (Fig. 8). This protocol generated 300 high-quality photographs per five-meter segment.



**Fig. 7.** Paths taken during photographic capture. Central Ravine, Section 9. (© American Excavations Samothrace).

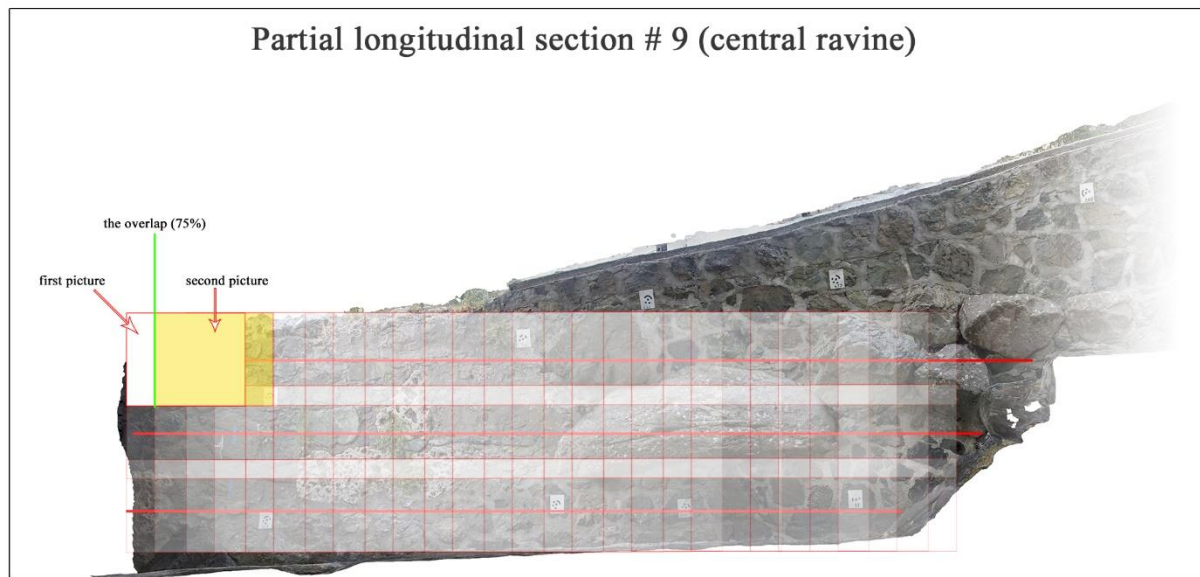


**Fig. 8.** Graphic demonstrating paths for effectively overlapping photographs. Central Ravine, Section 9. (© American Excavations Samothrace).

A superimposition rate of 75% for data capture was found to be the most effective for the later processing (Fig. 9). Furthermore, each of the chosen paths taken by the photographer incorporated groups of multiple shots at different heights, and at regular intervals, to provide as much information as possible to the software. As is well known, a greater variety of heights and angles of view increases the accuracy of 3D models, and this need was magnified by the many internal elevations, curved surfaces, and vegetal elements within the ravine. Such accommodations required 321 photos and 19 discrete ground control points within the first segment, which may appear excessive. Nevertheless, due to the constraints related to the limited time of the mission and the heavy post image processing, as well as the long computing time, it seemed essential to use more images, in order to ensure the quality and the authenticity of the photogrammetric model.

Obviously, it is quite conceivable to recalculate the models after the mission, by removing photos in the photogrammetry software, which would have the effect in optimizing calculation times. Also, it is important to specify that no segment perfectly followed the protocol described above, requiring a unique photographic path for each.

Concerning technical details during the shooting, a fixed focal length of 18 mm has been used. Meanwhile, due to certain specificities of the samothracian landscape for instance difficulties of access, rugged terrain, the focal length could vary from 24 to 27 mm.



**Fig. 9.** Graphic demonstrating superimposition protocol for effectively overlapping photographs. Central Ravine, Section 9. (© American Excavations Samothrace).

## 2.4 Data Processing Protocol

Having captured the necessary data in the field, the information was then synthesized and processed through several readily available pieces of software (Pamart, 2019). As the settings and general use of these software are well known, a few methodological points might be highlighted that may be of use for archaeological missions planning photogrammetric campaigns with similar limitations in terms of available technology and time.

All images were taken in RAW format, as the compression rate of JPEG and PNG formats ultimately damages the image irreparably and is therefore inadvisable for data that might be published or archived (Reznicek, 2016). The RAW format is also more flexible, allowing for manipulation *prior* to calculating the photogrammetric model.

Taking a RAW photograph captured in the first ravine segment as an exemplum (Fig. 10), the shutter speed's parameter was set to 1/100 s, with an aperture of f/10, at an ISO sensitivity of 1600. Obviously, this configuration doesn't reflect the parameters used in the entire photogrammetric survey. This image was taken in the early evening when lighting conditions minimized the shading of nearby architectural and vegetal elements. While that choice in the data capture stage mitigated one problem, it created another, and so it was also necessary to counterbalance this weak lighting by having a high ISO.





**Fig. 10.** Raw photograph. Section 1 of the Central Ravine, facing east. (© American Excavations Samothrace).

Despite these parameters, some photos appeared overexposed and unnatural (Fig. 11). Thanks to the RAW format, many photographs' parameters could be adjusted to obtain more accurate rendering for each of the images taken in the field. The contrasts between the two figures demonstrates the importance of following rigorously this preparatory step before launching the calculation of the point cloud. The goal is to significantly improve the parameters of the picture without altering the final rendering through the idealization of colors or the general lighting of the images, so as not to betray the original material. Moreover, it is preferable to have a lower ISO ranging from 100 to 600, with a constant aperture (f/11), as well as a faster shutter speed. In the case of section 1, due to the ambient luminosity, it was mandatory to make compromises. The ultimate goal was to obtain the clearest possible pictures and in the same time, to respect a coherent overlap between each pictures, in order to validate a rigorous metrology of the 3D model.



**Fig. 11.** Overexposed photograph. Section 1 of the Central Ravine, facing east. (© American Excavations Samothrace).

To avoid this trap in processing, it is crucial to adjust basic settings, through software supporting RAW formats (Fig. 12). This improvement goes through several steps beginning with exposure adjustment. A well-exposed image, as the case here after the adjustment, will have a bell-shaped histogram. Then the light and dark tones must be revised, in order to prevent the loss of data through the accentuation of shadow. The final correction is in terms of colorimetry. Lacking vibrancy and saturation, these parameters are relatively easily achieved in most software.



**Fig. 12.** Adjusted settings for overexposed photograph. Section 1 of the Central Ravine, facing east (© American Excavations Samothrace).



The resulting image is then converted into a readable format by photogrammetry software (Fig. 13), and the calculation of the photogrammetric model is begun. This task was carried out during the central ravine project by using Agisoft Photoscan Professional v 1.5.



**Fig. 13.** Comparison of images with and without colorimetric correction. (© American Excavations Samothrace).

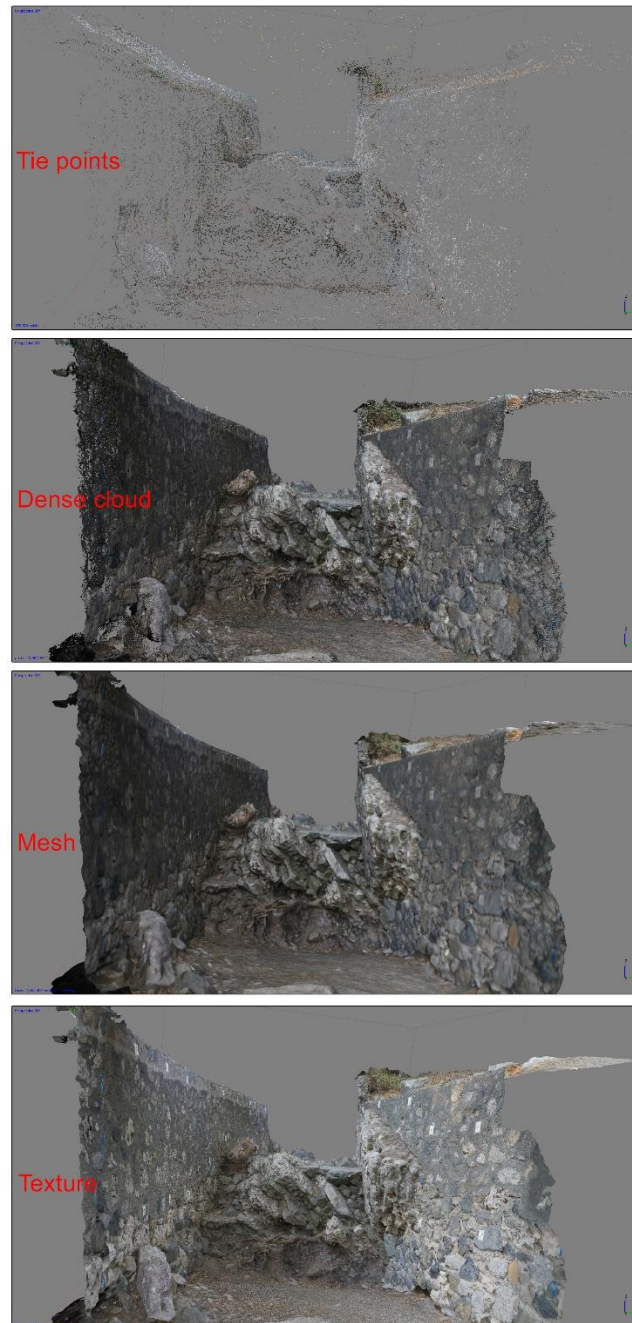
Given the widespread use of this software for both cultural heritage documentation and active excavation (Seguin, 2017), and the lack of adjustments to the standard protocol during the generation of the model for the central ravine, a quick visual summary of the process using the first ravine segment will suffice (Fig. 14). The model is generated first through the calculation of tie points, which creates the base model through the alignment of photographs,<sup>1</sup> followed by the generation of a medium-quality dense cloud.<sup>2</sup> While these are not the highest settings available on the software, it is not necessary to have a high-quality model to obtain a high-quality orthographic picture. When considered alongside the limitations on time inherent to an excavation season, some level of compromise must be made between quality and time. At the end of this new calculation phase, a model with increased readability was obtained. The three-dimensionality is created but the volume is still lacking. A mesh model is made next.<sup>3</sup> While

<sup>1</sup>Accuracy: High; Pair preselection: Disabled; Key point limit: 40,000; Tie point limit: 1000.

<sup>2</sup>Quality: Medium; Depth filtering: Moderate.

<sup>3</sup> Typical surface: Arbitrary; Source data: Dense Cloud; Face count: High (2,693,460); Interpolation: Enabled; Point classes: All.

volume is present, colorimetric composition is added only through the final step which adds a photorealistic texture applied to the 3D model,<sup>4</sup> generating a completed photogrammetric model of ravine segment [Note to editor – here we would like to include link to video, attached as per instructions as a separate file to this submission].



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<sup>4</sup>Mapping mode: Generic; Blending Mode: Mosaic; Texture size/count: 8192 x 1 (the higher the value, the greater the quality).

**Fig. 14.** Section 1 of the Central Ravine, facing south: Model at alignment stage; Model at mesh stage; Model without colorimetric corrections; Completed photogrammetric model (© American Excavations Samothrace).

This dense correlation photogrammetric model can then be integrated into community engagement and research visualizations using 3DSmax and other software.<sup>5</sup> In order to make the model usable by all of the project's researchers, orthographic pictures of the central ravine of Samothrace must then be generated. To create these orthographic pictures, digital markers are first inserted to match the ground control points, with the geodata generated by the mission's survey team then added. With this, an orthographic image is easily created (Fig. 15).<sup>6</sup>



**Fig. 15.** Georeferenced and orthorectified image. Section 1 of the Central Ravine, west wall. (© American Excavations Samothrace).

## 2.5 Utilizing the Photogrammetric Model

As the orthophotos were generated, they were imported and used as an underlayer for the tracing of vector drawings in Adobe Illustrator. To control the drawings' scale, and to identify any distortions, on-site measurements were taken for each section. The drawings were then matched with their geospatial data gathered by the project's surveyors, resulting in high fidelity plans that could be integrated into the variety of geospatial databases utilized by an archaeological mission.

The plans were then color coded by chronologic phase, by transferring the notes and observations from the notations of the team's archaeologist. Continuous outlines of stone walls and mortars, which form regions that belong to the same chronological period, were drawn in

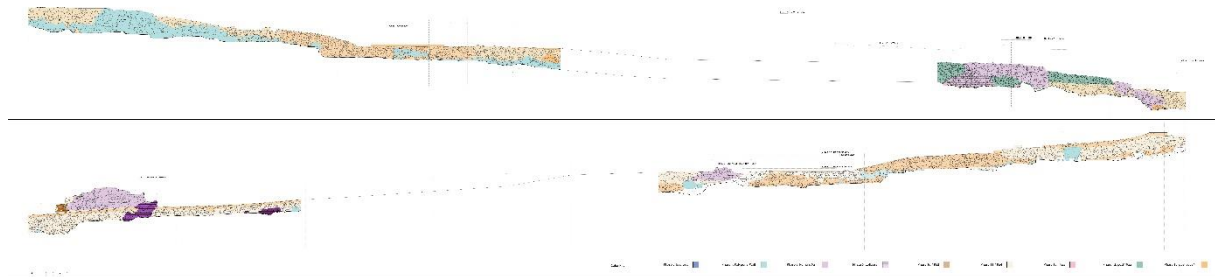
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<sup>5</sup> For further discussion of the *Passage and Perception* project, see: <https://samothrace.emory.edu/passage-and-perception-in-the-sanctuary-of-the-great-gods-samothrace-visualization-and-animation/>

<sup>6</sup>Type: Planar; Projection Plan: Markers; Horizontal Axis: orient markers along the feature in question; Max dimensions (pixel): 8192.



Illustrator, and grouped in layers for easier future referencing. The final product of this work was a set of 2D color-coded drawings (Fig. 16), to supplement and aid in the interpretation of the textured 3D model described in the preceding section.



**Fig. 16.** Central Ravine. Elevations of western retaining wall (above) and eastern retaining wall (below), with major construction and repair phases indicated. (© American Excavations Samothrace).

Performing this process in tandem with the creation of the photogrammetric model's remaining segments had several benefits. Unlike laser scanning or other more remote data capture methods, using a handheld camera encouraged autopsy, the close inspection of individual elements of the overall feature, during data capture. The angles and distances required to construct an accurate model of such a large and irregular feature required proximity and a constant viewing from unusual angles. Meanwhile, producing the plans by tracing over orthophotos, rather than using an algorithm, required interpretation and discussion. As has been raised elsewhere (Morgan and Wright 2018), traditional drafting is incredibly useful as a cognitive and interpretive act, and our methodology proved to maintain these benefits while also taking advantage of the accuracy and general rapidity of photogrammetric modelling. Close looking by all members of the team encouraged dialogue, which in turn encouraged new observations.

One obvious result of this project was a far clearer understanding of the ravine's many phases. The Greek polygonal boulder wall was noted to be not only in the southern area of the sanctuary, but to have survived throughout the channel's length. The Roman concrete phase, in turn, was recognized to be even more extensive; it was at times built on top of, and at other times built in front of, the prior phase. In turn, the "modern" repairs could be separated into five distinct phases (1953, 1954, 1955, 1966-1975, and 2003-2004).

A combination of autopsy, and the ability to consider the ravine in its entirety resulted in another, arguably more important, discovery. As has been noted previously, modelling is crucial in situating archaeological data into bigger pictures (Tsiafaki and Michailidou 2015: 39-40), and the placement of certain surviving boulders suggested that the ancient channel's course was different, and at least further to the west between the Hall of Choral Dancers and the south

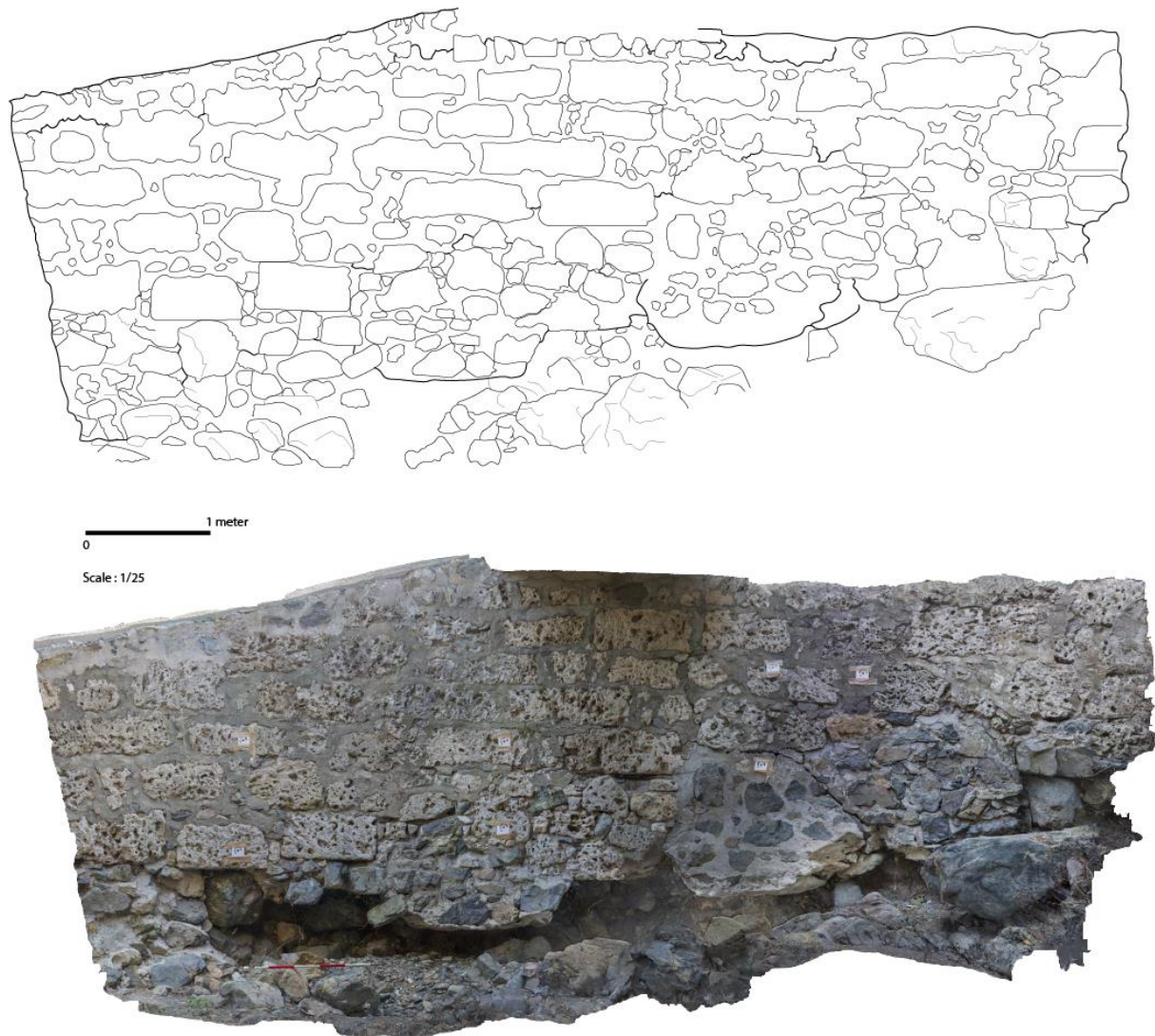
end of the Hall of Votive Gifts. Posited during the modelling project, the hypothesis would ultimately inform new excavations.

### **3.1 Static Models, Dynamic Objects**

The efficacy of this project was, unfortunately, validated following a series of catastrophic storms beginning in 2017. Severe storms and associated flooding is not uncommon, and portions of the modern retaining wall had been rebuilt and their height raised between 2003 and 2004 after a previous storm in 2000. Yet, the severity of the storm cycle has escalated in recent years. The effects of these storms have been compounded by overgrazing by the island's goats and resulting deforestation (Fischer-Kowalski et al. 2011; Mier 2019). During July 2017, storm flooding caused a section of the western side of the modern retaining wall to collapse, and a more powerful storm and subsequent flooding in September 2017 undercut the ravine's walls and led to the destruction of large sections of the Greek boulder retaining wall near the southern boundary of the sanctuary and the area of the theater, as well as the collapse of the modern walls and bridge near the Rotunda of Arsinoe II. Flooding had caused more catastrophic damage outside the sanctuary: burying many parts of the town of Chora, collapsing infrastructure including the Kamariotissa-Lakkoma bridge, and impacting life on the island in ways both obvious and subtle. This severity has continued unabated, with a storm in March of 2020 leading to the destruction of a section of modern wall, which had rested on a section of Greek boulder retaining wall that had been destroyed in 2017, and the displacement of the concrete bridge at the south boundary of the sanctuary.

Having a full model of the architectonic elements of the ravine has been essential in identifying what sections are missing, and where they now are. The dynamism of these natural forces is such that a massive basalt boulder might be found almost one hundred meters from its original placement. More subtle changes like ground level changes could also be noted thanks to the model, and changes that were seemingly insignificant in 2017 often presaged more significant changes in the following two seasons.

The ease of the photogrammetric process, and the modular approach taken to the documentation of the ravine allowed the project team to integrate these changes to the ravine on an annual basis (Fig. 17). On the one hand, this tracking allows for informed decisions in terms of site management. Missing sections can be tracked, weak points highlighted, and the various modern and ancient phases' differing capabilities for resisting damage analyzed. On the other hand, the ability of a digital file to include multiple phases (an undamaged section in 2016, its change in 2017, and its presumed future repair) allows for the coexistence of multiple points in time contemporaneously – allowing archaeologists to create a digital stratigraphy of a monument which is losing, rather than gaining, mass.



**Fig. 17.** Central Ravine. Section of damaged eastern retaining wall showing undercutting following 2017 storm. (© American Excavations Samothrace).

While the accuracy of the project's documentation has been a boon, what has proven to be most essential was the speed and low costs of the project, which allowed it to document a feature whose value is only being fully appreciated as it faces systemic loss. While on Samothrace the increased risk to site stability is largely due to local issues, the increasing impact of climate change globally suggests that methodologies requiring minimal planning but allowing for accurate modelling will be of value.

## 4.1 Conclusion

Photogrammetry by dense correlation thus seems, in the case of the central ravine in the Sanctuary of the Great Gods on Samothrace, to have been an ideal choice. The goal of this paper is in no way to suggest that data capture with handheld cameras is the best method for

data capture in all cases. Rather, that a very high degree of accuracy may be achieved through a careful and well-thought set of protocols, achieved in a manner achievable by archaeological and cultural heritage missions without access to more specialized equipment and trained personnel.

The project has also—in no small part because of the methodology selected—affected our understanding of the ancient channel as its own entity within the sanctuary, rather than something to simply cross over. Integrating the disparate sections of retaining walls from both the Greek boulder and Roman concrete phases into a single model emphasized how truly monumental this water management project was – with few parallels in sanctuaries of the ancient Mediterranean. The creation of the model also allowed for closer comparison of the modern ravine’s course and the extant sections of the ancient ravine, suggesting that the ancient ravine actually ran slightly more to the west through much of the sanctuary. This hypothesis was ultimately confirmed through excavation in the summer of 2019, when collapsed sections of the ancient channel were found beneath the tourist path on the embankment to the west of the modern ravine (Wescoat et al. 2020).

The storms and the resultant damage to the ravine brought all these points into focus. The central ravine as it existed in 2016 now only exists in the photogrammetric model. No matter what decisions are made in terms of site restoration, that state is unrecoverable.

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