Journal of Roman Archaeology 37 (2024), 215–240
doi:10.1017/S1047759424000084

The Roman siege system of Masada: a 3D computerized analysis of a conflict landscape

Hai Ashkenazi[1], Omer Ze'evi-Berger[2], Boaz Gross[3], and Guy D. Stiebel[3]

[1]Israel Antiquities Authority and Goethe University Frankfurt <haiashke@gmail.com>
[2]University of Bonn and Tel Aviv University <omer.zeev@gmail.com>
[3]Tel Aviv University <boazgros@tauex.tau.ac.il>, <guystiebel@tauex.tau.ac.il>

Abstract: The 1st-c. CE Roman siege system of Masada exhibits a high degree of preservation due to its remote location and the arid climate. However, unlike the thoroughly excavated Masada fortress, the siege system has not received due attention. This article is part of a research project aimed at advancing our understanding of the conflict landscape around Masada using contemporary archaeological methods. Following a comprehensive surface survey and photogrammetric 3D modelling, we show that the circumvallation wall stood to a height of 2–2.5 m and served several functions – as an obstacle, a means of psychological warfare, and a platform from which to mount counterattacks. Based on our measurements and workload estimations, we argue that the construction of the siege wall and the camps around Masada occurred fairly quickly.

Keywords: Early Roman period, siege warfare, conflict landscape, photogrammetric 3D modelling, Masada, Roman army

Introduction

The sheer cliffs surrounding the horst of Masada separate its elevated plateau from the Judean Desert Plateau to the west and the Dead Sea Plain to the east. Though the isolated mountain served as a refuge from the Chalcolithic to the Byzantine Period,[1] the site is best known for its role as the last stronghold of the First Jewish Revolt against the Roman Empire, dated to 66–73/74 CE.[2] The siege of Masada probably took place in 73/74 CE and was the final battle of this war. According to the contemporary account of Judeo-Roman historian Flavius Josephus, it ended with the Romans breaching the fortress's fortification walls, only to find that all its inhabitants had committed suicide to escape a future of slavery.[3]

During the battle over Masada, the Roman army built an extensive siege system around the fortress. This system included eight army camps, a siege wall (circumvallation),[4] and a large ramp approaching the fortress's wall. In addition, they either built or re-used a network of trails connecting the Judean Plateau and the eastern plain. The dry desert environment and the remote location allowed for the superb preservation of this system;[5] today, it is easy to identify its various architectonic features, from camp walls to tent

1 Mascher et al. 2016; Yadin 1965.
2 Cotton and Geiger 1989, 11; Netzer 1991, xv.
3 Ben-Tor 2009; Magness 2019; Yadin 1966.
4 See below and Campbell 2006, 192–95.
5 Stiebel 2007, 598.

bases, gates, towers, and a possible water cistern. Even the wood used for the construction of the siege ramp is still intact.[6]

Though the site of Masada has been comprehensively explored since its identification in the 19th c. and its top extensively excavated since the 1960s,[7] surprisingly little attention has been given to the siege system,[8] particularly the wall. To date, only Camp A,[9] Camp F, and the siege ramp[10] have been excavated and partially published, and as "the archaeological evidence for the Roman army at war is very slim,"[11] a new investigation into the Masada siege system was therefore due.

This present study was launched in 2017 with the intent of re-examining the site using modern archaeological field methods and research approaches. This paper is the first publication of comprehensive research aimed at studying the conflict landscape[12] around Masada using methodical surveys, photogrammetric 3D modelling, GIS mapping, and small-scale excavations. The paper summarizes the recording and study of the Roman wall. Together with a 3D analysis of the trails around the site (to be published soon) and future excavations in some of the Roman camps, it aims to demonstrate how the siege system was meticulously built in order to achieve the Roman army's aims. This paper also shows the potential of 3D modelling software as an analytic research tool and not simply for the 3D presentation of sites, as too often is the case.

Background

The First Jewish Revolt against the Romans started in 66 CE after years of political instability. One of the first acts in this war was the seizure of Masada from its Roman garrison by a group of Jewish rebels. At the beginning of the rebellion, the Jewish forces managed to defeat an army led by Cestius Gallus, the governor of Syria. Later, after suffering heavy losses in the field, and following the arrival in 67 CE of a second expedition led by Vespasian and his son Titus, the local militias usually avoided meeting the Roman forces in the field and took shelter in fortified towns and forts, most of which had been built during previous periods. This led to a war characterized mainly by Roman siege warfare. Several years of careful Roman advance culminated in the siege of Jerusalem in 70 CE, and though the Romans faced bitter resistance from the city's defenders, the city was conquered and destroyed within that same year. About three years later, the Romans followed the remaining rebels to their last stronghold – Masada.[13] The amount of effort invested by the Romans in chasing these last few hundred rebels to their final refuge in the middle of the desert may seem surprising. Some researchers argue that it was done in order to completely assert Roman rule over the country, to send a message to other potential rebels, and to "restore

---

6 Liphschitz and Lev-Yadun 1981.

7 Ben-Tor 2009; Magness 2019; Stiebel 2007; Yadin 1965.

8 Davies 2011.

9 Gutman 1965, 82–123.

10 Arubas and Goldfus 2008; Goldfus and Arubas 2002; Goldfus and Arubas 2010; Magness 1996; Magness 2009; Magness 2019.

11 Goldsworthy 2003, 12.

12 Coulston 2001, 42.

13 Berlin and Overman 2002; Cotton and Price 1990; Goldsworthy 1996, 84–90; Levithan 2013, 148–69; Netzer 1991; Roth 1991, 398–461.

the impression of Roman might";[14] others have recently claimed that the Romans' aim was to protect the valuable Balsam (*opobalsamum*) perfume production center at the nearby oasis of 'Ein Gedi.[15]

Circumvallation is the encirclement of a besieged town or fortress with a continuous line of fortification wall and other barriers.[16] By the time of the First Jewish Revolt, the Roman army was well trained in siege warfare. When advancing upon an enemy fort or fortified city, the Roman army usually built several army camps for housing the attacking soldiers, as well as a circumvallation line to surround the besieged site. When counterassaults (sorties) were expected, they added a variety of traps and obstacles in front of the siege wall. Subsequently, the attacking Roman force would attempt to bypass the defender's fortification wall by scaling it, sapping underneath it, or breaching it.[17] The circumvallation prevented the resupply or reinforcement of the besieged and protected the siege army from sallies or breakouts. The circumvallation wall sent a message to the besieged that consent was no longer an option and the assault was near. It might arouse feelings of desperation or lower morale among the defenders, and in some cases the construction of the circumvallation wall and siege ramp led to the surrender of the besieged (as was the case at the 152 BCE siege of Nergobriga, the 52 BCE siege of Vellaunodunum, the 57 BCE siege of Noviodunum, and the 66 CE siege of Narbata[18]). Circumvallation walls also increased the confidence of the besieging army; Levithan argued that the circumvallation built at a later stage of the siege on Jerusalem (70 CE) was intended to boost the soldiers' morale after failed attempts to breach the city's walls. The downside of building a circumvallation was that it demanded large amounts of time and labor, in effect delaying the assault itself.[19]

The first comprehensive methodological study of the siege system of Masada was conducted by Hawkes, whose analysis was based on aerial photos of the site taken by the British Royal Air Force.[20] Several years later, Schulten published the results of his 1932 survey of the siege system.[21] During the 1960s, Richmond published additional research based on aerial photography,[22] and Gutman and Yadin published studies based on their limited excavations in the Roman camps.[23] In 1995, Roth published a seminal theoretical study regarding the siege of Masada based on his review of historical sources and the available data on the siege system.[24] This study challenged the common paradigm of a years-long siege by suggesting that it only lasted between four to nine weeks. Arubas, Goldfus, and Magness excavated Camp F and the siege ramp and published several articles

---

14 Davies 2011, 68; Goldsworthy 2003, 161, 191.

15 Stiebel 2007, 598; Stiebel 2020.

16 Campbell 2006, 192–95.

17 Campbell 2006, 164–78; Davies 2006; Goldsworthy 2003, 186–97; James 2011; Levithan 2013.

18 Davies 2001, 71; Davies 2006, 95; Goldsworthy 2003, 193.

19 Levithan 2013, 63–65, 160.

20 Hawkes 1929.

21 Schulten 1933.

22 Richmond 1962.

23 Gutman 1965; Yadin 1966; Yadin 1967.

24 Roth 1995; Roth 1999.

discussing their results.[25] Based on their excavations and a geomorphological study of the ramp and the slopes of Masada, Goldfus and colleagues argued that erosion had only minimally degraded the siege ramp since its construction. Moreover, they claim the ramp was never finished and thus the siege ended in a different way than is presented in the historical narrative.[26] Recently, Hadas used this study to claim that Masada was conquered by Roman soldiers accessing it through the southern gate.[27] Davies and Magness rejected the conclusions of Goldfus and colleagues, suggesting that evidence of armed conflict on the western side of Masada shows that the Romans did break into the fortress using the ramp.[28] Other aerial photography-based research was conducted by Kennedy and Riley, Fowler, and, recently, Shmidov and Wiegmann.[29]

Most of the above studies were theoretical and based on aerial photos, brief visits to the site, or the historical record. The non-theoretical and ground-level research mainly concentrated on the Roman camps and on the siege ramp. The questions tackled by these scholars were usually concerned with the internal plan of the camps and estimations of the size of the besieging army. The siege system itself, however, did not get due attention, even in books dealing with Roman siege warfare.[30] Finally, in 2006 and 2011, a detailed study of the siege system and the wall based on a visit to the site was published by Davies,[31] who emphasized at the end of his work that many details remained lacking and further fieldwork and analysis was still needed.[32] Even basic technical details like the width of the circumvallation wall[33] or the number and locations of the towers[34] remained a matter of debate.

Researchers and historical sources dealing with the tactical objectives of the circumvallation around Masada note four possibilities: (1) protection of the besieging army from sorties,[35] (2) isolation of the mountain in order to control the blockaded area and to prevent infiltration and resupply (BJ 7.275–8),[36] (3) "busy works" to keep soldiers occupied (as the Roman army was large enough to isolate Masada merely by putting a ring of soldiers around it),[37] and (4) a performance of conspicuous consumption used to affirm Roman power and as a means of psychological warfare against the besieged.[38]

---

25 Arubas and Goldfus 2008; Goldfus and Arubas 2010; Goldfus and Arubas 2013; Magness 1996; Magness 2009.

26 Goldfus et al. 2016.

27 Hadas 2023.

28 Davies and Magness 2017.

29 Kennedy and Riley 1990; Fowler 2022; Shmidov and Wiegmann 2023.

30 E.g., Levithan 2013.

31 Davies 2006; Davies 2011.

32 Davies 2011, 82.

33 An average of 1.6 m in Ben-Tor 2009, 238; 1.5 to 1.8 m in Davies 2011; 1.5 m in Goldfus and Arubas 2010.

34 "Roughly 13" in Arubas and Goldfus 2008; 15 in Davies 2011; 14 in Richmond 1962.

35 Stiebel 2007, 598.

36 Arubas and Goldfus 2008, 1937; Stiebel 2007, 598.

37 Roth 1995, 101.

38 Davies 2001, 70–71; Davies 2011; Levithan 2013, 58–59; Trigger 1990.

The form and function of the wall and towers were also a source of debate. Hawkes claimed that the wall and the towers had wooden frames, breastworks, and superstructures.[39] Richmond argued that the towers, which project outwards from both the back and the front of the wall, were built to serve as firing bases and lookouts; he suggested that they were higher than the wall in order to provide a better view of the flat terrain, allowing the Roman soldiers to better repel breakouts from the eastern gate of Masada while also stopping deserters.[40] Davies, on the other hand, claimed that the towers along the eastern section did not rise above the wall and were intended to be firing platforms for light artillery with at least one of them serving as a "supplementary artillery position for a heavy catapult capable of indirect fire over the wall."[41]

Given that past research on the circumvallation has suffered from a lack of high-resolution information, our research aimed to better record and survey the circumvallation and to explain its form, construction, and function(s). Considering the impressive preservation of the siege system, it furthermore provided a uniquely favorable opportunity to study an early Roman-period conflict landscape that has remained nearly untouched since the 1st c. CE.

Research goals and methodology

Our research goals were to:

1. survey and document the siege system and especially the wall,
2. calculate the dimensions of the wall and its towers,
3. estimate the amount of work required for the construction of the siege system in order to allow a better appreciation of the duration of the siege, and
4. identify the exact function(s) of the circumvallation.

These goals were met using a methodological land survey of the siege system complemented by an aerial drone survey and high-resolution digital 3D photogrammetric modelling. Photogrammetric 3D modelling not only maps and presents a system, as is most frequently the ultimate implementation of such tools within archaeology,[42] but can also serve as a database for analysis and calculations of important variables, such as the height and volume of a siege system's features (walls, towers, etc.).

During 2017 to 2020, we surveyed and documented the siege system of Masada, with an emphasis on the wall and the built trails connecting it. A Trimble R2 Real-Time Kinematic (RTK) positioning system was used to record the exact coordinates of the different segments and features of the siege system and the artefacts found in their vicinity, and geodetic information was analyzed and processed with the assistance of ArcGIS version 10. 3D photogrammetric modelling was concentrated on the eastern section of the siege system due to its better preservation and the large number of towers and other features found there. A DJI Mavic Pro drone was used to take thousands of pictures of the siege system, which were then used to produce a high definition scaled photogrammetric model of

[39] Hawkes 1929.

[40] Richmond 1962.

[41] Davies 2011, 71.

[42] E.g., O'Driscoll 2019.

1,100 m of this wall section using Bentley ContextCapture modelling software. This model was used to calculate the wall's height, volume, and construction workload, using Bentley ContextCapture Viewer.

The study commenced with three main premises about the possible functions of the system:

a) defense and protection of the besieging army from the defenders' sorties, counterattacks, and long-range projectiles,
b) encirclement and isolation of the fortress, and/or
c) a means of psychological warfare/support: on the one hand, discouraging the besieged through a literal physical expression of their surrounded and encircled situation, in which escape seems impossible, and/or, on the other hand, encouraging the besieging soldiers through a manifest and collectively assembled representation of their superiority over the besieged.

Each of these functions may have been manifested in different ways in the architecture of the wall and camps: following best practice in fortification, an efficient defensive wall should be high enough to stop an attacking force while providing cover for its defenders in the form of breastworks or parapets. It should have firing platforms (such as towers) that protrude from the wall and are in locations where an attack is possible and where there is a need to eliminate blind-spots and allow enfilading fire on the attackers. The gaps between the towers should not exceed the range of the bowshot (or other projectiles), so that mutual covering fire is possible.[43] A wall intended to prevent a population from escaping and/or reinforcements from entering can be thinner, lower, and without cover, but it should have observation points and towers for watching the area, both to the front and to the back of the wall. A wall whose main aim is to send a message to the besieged population should only look impressive from the point of view of the besieged. With these things in mind, when analyzing the circumvallation of Masada, we should also consider the fact that the wall needed to be functional only for a short time and that the Roman army did not always adhere to best practice in fortification – for example, the ditches built in front of Roman army camps were fairly shallow[44] and sometimes the gates were positioned towards the enemy side.[45]

Results and observations

Based on the RTK survey and a careful reconstruction of the missing segments, a total length of ca. 4,300 m was estimated for the wall. This figure includes the camp walls that are incorporated into the wall (i.e., the fortress-facing walls of Camps A, D, E, G, and H). The camp walls that are not incorporated into the wall add an additional ca. 2,000 m for a total of 6,300 m of built wall (Appendix 1).

We divided the wall into seven sections based on their locations, construction methods, widths, and the features incorporated into them (Fig. 1). These sections are: (*1*) east (from Tower 1 to Camp D), (*2*) north (from Camp D to the base of the cliff west of Tower 15), (*3*)

43 Keeley et al. 2007.

44 Less than 90 cm in marching camps; Fields 2009.

45 As in Hadrian's Wall; Goldsworthy 2003, 157–59.

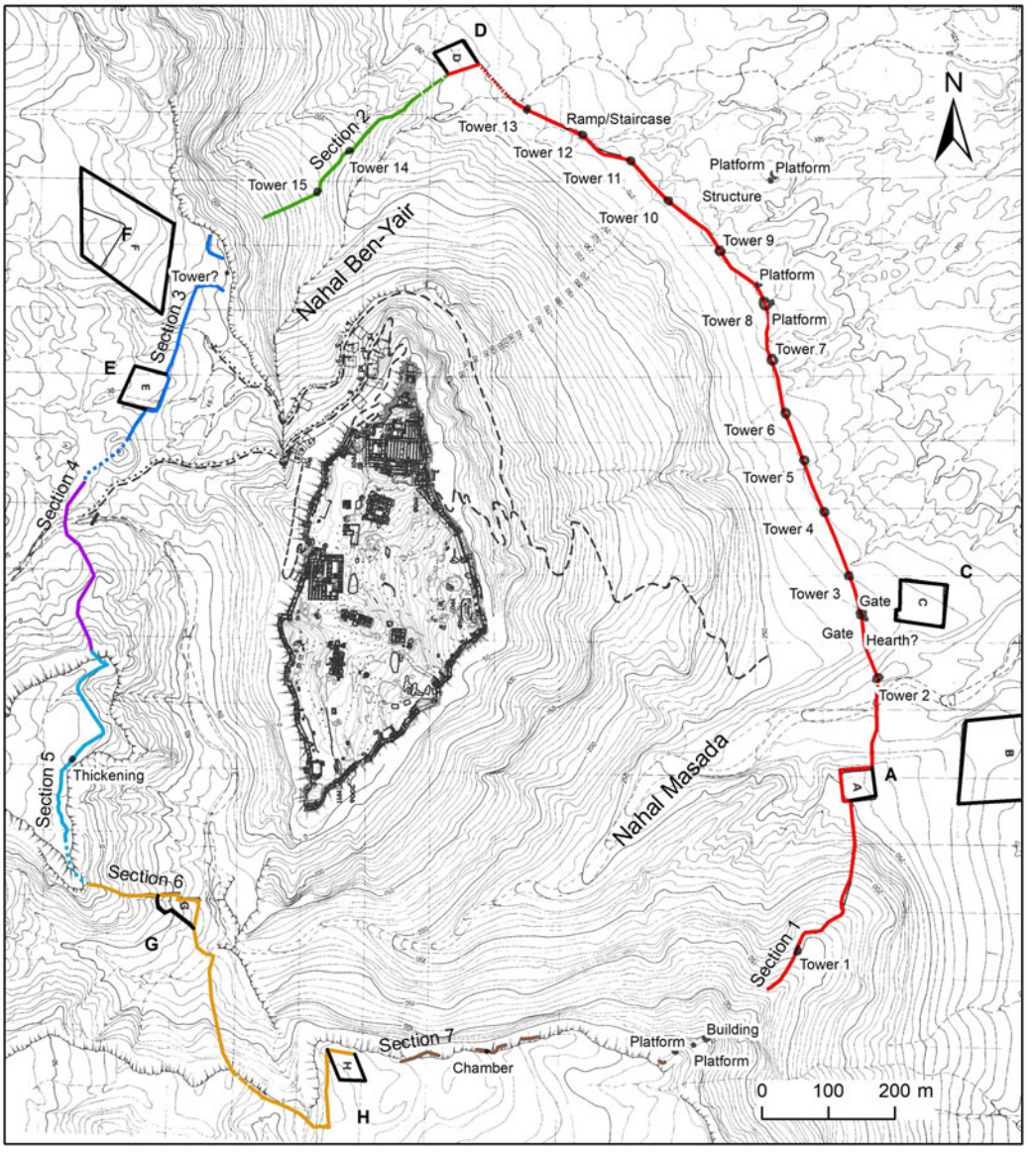

Fig. 1. *Masada circumvallation wall and its sections. (Drawing by H. Ashkenazi, Base Map after Netzer 1991, Plan A.)*

west (from the top edge of the cliff near Camp F to the "Zealots' Graves" hill,[46] located ca. 70 m south of Camp E), (*4*) central west (from the "Zealots' Grave" hill to the north side of the western plateau), (*5*) the western plateau, (*6*) the southwest section (from the western plateau to Camp H), and (*7*) the south section (Mount Elazar).

The siege system remains in a good state of preservation, with many of the built sections still standing to a considerable height and many of the various features built into or near

[46] The "Zealots' Graves" hill is the modern burial ground of the skeletons – controversially identified as the remains of the rebels – found during Yadin's excavations at Masada (see Ben-Tor 2009).

them still discernible. However, locations where both sides of the wall still stand and are not covered with colluvial sediment or collapsed stones are few, limiting our overall ability to measure the width of the wall. Nonetheless, exposed sections of the wall measured between 1.8 and 2 m in width. The most prominent features along the walls are 15 towers, incorporated into the eastern and northern sections of the circumvallation wall (Fig. 1 – *Sections 1* and *2*, Towers 1–15). Today, the towers mostly appear as large piles of rocks, though the outer faces and corners of several of them are still identifiable. These towers protrude about 0.9–1.5 m from the wall, from both the west face (looking towards Masada) and the east. Our observations differ from Gichon and Yadin's identification of 12 towers, Arubas and Goldfus's "roughly 13 watchtowers," and Richmond's 14 towers, and from the locations according to Davies.[47] The distances between towers from 2 to 13 range between 61 and 110 m as the crow flies, with an average gap of 90 m (Appendix 3).

SECTION 1 – The eastern section stretches from about 70 m south of Tower 1 to Camp D. It is about 1,800 m long and 1.8–2.1 m wide. The width of the wall can vary even along relatively short stretches of it, though most of the wall is ca. 2 m wide. Thirteen towers are incorporated into this wall section. Contrary to the observations made in previous studies,[48] only one tower was found to be built south of Camp A; our field observations showed that what Davies and Richmond identified in aerial photographs as a second tower positioned south of Camp A is actually an exposed stretch of bedrock. Most of the towers (2–13) are positioned in the relatively flat floodplain east of Masada. We noticed that all these towers are positioned near wadis and deep gullies originating from Masada's eastern escarpment (See Figs. 6 and 9 below). Tower 1, positioned high above the plain, overlooks Nahal Masada (*Wadi Sebbe*), the Snake Path (the ancient path climbing from the eastern plain to the eastern gate of Masada), and a small wadi flowing into Nahal Masada. A gate with two small towers or perpendicular walls on either side of it can be seen in front of Camp C (Fig. 2). Next to this gate an installation (possibly a hearth) was found (Fig. 3).

Many sections of the wall that were built in wadis and gullies are covered today by colluvial sediments. This is true for most of the sections between the eastern gate and Tower 7, and many of the sections between Towers 7 and 10 (e.g., segments of the wall that were covered in silt that distorted height calculations in Appendix 2).

A circular feature near Tower 7 (Fig. 4) was identified by Davies as a signaling position and a guard chamber.[49] Further north, two low stone platforms were identified – one next to Tower 8 and the other about 25 m north of it. Both were found on the eastern (external) side of the wall. During our survey, two grinding stone fragments were found about 10–20 m west of Tower 8 and the platforms. We also located two stone platforms and one stone structure on a small hill about 160 m east of Tower 10 (Fig. 1). The structure is ca. 3 × 4 m and the platforms are 2.5 × 5.5 and 2.5 × 4 m. A large number of Roman-period pottery sherds were collected in their vicinity.

About 20 m northwest of Tower 12, along the eastern face of the wall, a ramp or staircase foundation leads to the top of the wall (Fig. 5). Similar staircases were detected by us

---

47 Gichon 2000, 543; Yadin 1966, 215; Arubas and Goldfus 2008, 1937; Richmond 1962, Fig. 5; Davies 2011, Fig. 1.

48 Davies 2011; Richmond 1962.

49 Davies 2001, 71–72, Fig. 8. Davies marked this tower as "Turret 8," but the tower that appears in his Figure 8 is actually positioned between his "Turret 7" and "Turret 8."

Fig. 2. *The gate in front of Camp C (view to the east). (Photograph by O. Ze'evi-Berger.)*

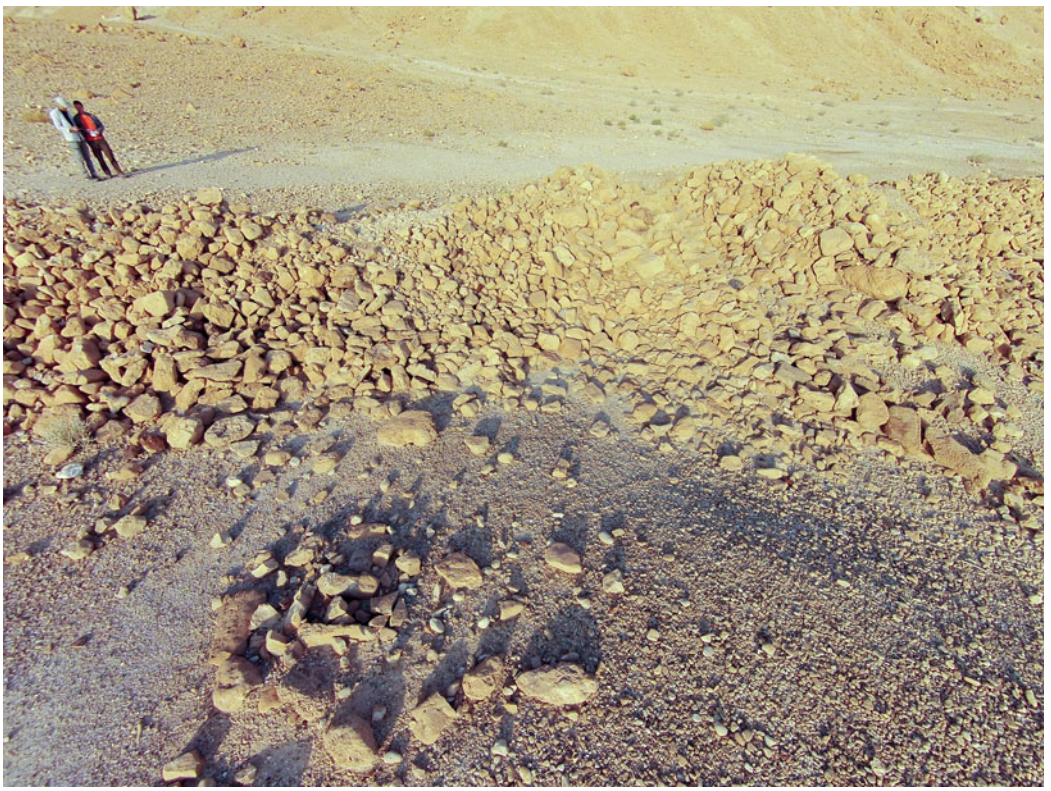

Fig. 3. *An installation (hearth?) near the eastern gate (view to the west). (Photograph by O. Ze'evi-Berger.)*

Fig. 4. *3D model of Tower 7 and the circular feature to its left (view to the west). (Photograph by H. Ashkenazi.)*

Fig. 5. *3D model of the ramp/staircase (view to the southwest). (Photograph by H. Ashkenazi.)*

at the southwest corner of Camp H, by Gutman at Camp A (see also below),[50] and by Yadin in the Herodian casemate wall of Masada.[51]

Davies claims that Tower 13 was superimposed onto the (already completed) wall.[52] This suggestion seems plausible, though some excavation and clearing of the collapsed

[50] Gutman 1965, 123.

[51] Netzer 1991, 526–27, 565–67.

[52] Davies 2011, 71.

Tower 3 (view to the east)

Tower 4 (view to the east)

Tower 7 (view to the east)

Tower 8 (view to the east)

Tower 9 (view to the northwest)

Tower 10 (view to the northeast)

Fig. 6. *Examples of towers positioned near wadis. (Photographs by O. Ze'evi-Berger.)*

stones would be needed to confirm it. Tower 10, on the other hand, was built prior to the wall, which abuts it (Fig. 7).

SECTION 2 – In its northern section, the wall continues from Camp D, up a spur, to the point where the cliff marking the eastern edge of the Judean Desert plateau is almost vertical. Two towers were built along this section: Tower 15 is positioned only 300 m from the lower part of Masada's Northern Palace. It is in an inferior low position but, on the other

Fig. 7. *Tower 10 and the wall abutting it (view to the east). (Photograph by H. Ashkenazi.)*

hand, situated at a good observation point, with clear views towards the upper part of Nahal Ben-Yair (*Wadi Nimre*) and the built trail leading from the palace to the water reservoirs to the northwest of the Masada horst (Fig. 1). Tower 14 was built down the same spur, in a position slightly less exposed to the Northern Palace, albeit with a worse view to Nahal Ben-Yair and the aforementioned trail. The wall in this section is badly preserved, and its width is only about 1.2 m.

SECTION 3 – The western section of the circumvallation starts from the Judean Desert plateau cliff, ca. 90 m above the point where *Section 2* ends. Following Ben-Tor, and contrary to Davies and Netzer,[53] we noticed that the northwestern section of the circumvallation wall was not built to form a continuous straight line, but rather to create a 40 m-wide "funnel" leading towards the cliff's edge (Fig. 1). Remains of a possible platform or tower at the end of this "funnel" may represent its purpose. A small opening in the wall is located at the southern side of the "funnel." From there, the circumvallation wall continues southwards. It forms the eastern wall of Camp E, and about 50 m south of the camp it disappears, likely due to erosion and recent human activity. This is why the *bauplatz* identified by A. Schulten[54] in the 1930s in this area cannot be discerned today. Except for the platform at the end of the "funnel," no towers were detected in this section.

[53] Ben-Tor 2009, Fig. 220; Davies 2011, Fig. 1; Netzer 1991, Plan A.

[54] Schulten 1933, 95.

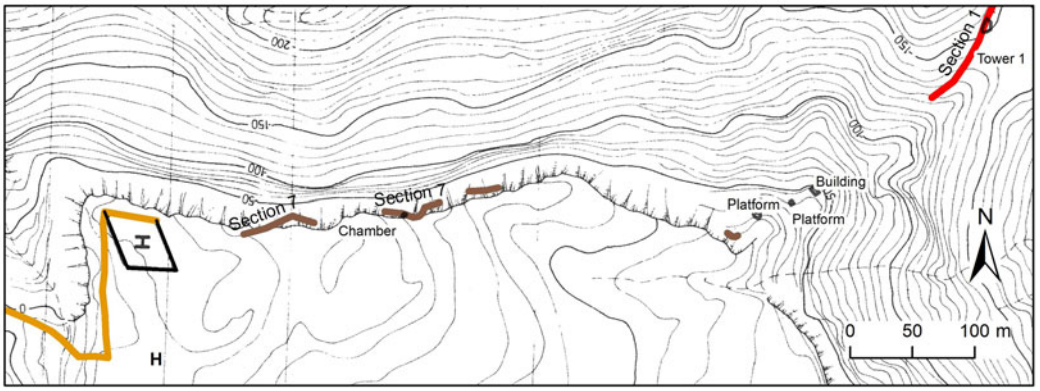

Fig. 8: *Southern part of the circumvallation. (Drawing by H. Ashkenazi, Base Map after Netzer 1991, Plan A.)*

SECTION 4 – The circumvallation wall can be discerned again on the spur leading to the western plateau. In this section, its width is 1–1.5 m. Here, it is either badly preserved or was originally poorly built. Its maximum preserved height is about 30 cm.

SECTION 5 – This section is built on the eastern side of the plateau positioned above the west bank of the upper Nahal Masada (see Fig. 1), where it provided a good overview of the western side of the Masada fortress for the soldiers stationed here. The wall in this section is roughly 360 m long and 0.85–1.05 m wide and is positioned directly above an almost vertical cliff more than 100 m high. Unlike the other sections of the circumvallation wall, which are built only of large and medium fieldstones, this section was constructed using two lines of stones with a fill of earth and gravel between them. A 1.3 m thickening at the center of this section (see position in Fig. 1) could mark the remains of a watch tower/platform. The southern section of the wall is built of large yellow stones ca. 50 × 60 × 35 cm in size; today, stones of this size and color are rare along the plateau, and therefore it is possible that the builders either used nearly all the stones available in the area or brought them from other places.

SECTION 6 – The southwest section includes the wall segment running from the western plateau to Camp H at the top of Mount Elazar. This section includes two camps and five openings. Here, the wall runs down the slope from the western plateau and joins Camp G, whose northern and eastern walls serve as part of the wall. From Camp G, the wall climbs up to Mount Elazar and can be identified nearly all the way up to the top of the steep slope below the cliff along the edge of the summit. On the top of Mount Elazar, it meanders around the gorge that leads to the summit and then connects to Camp H. Although *Section 6* is less than 800 m long, it has five openings in it: one positioned where the circumvallation wall joins Camp G from the west, two in the middle of the north and east walls of this camp, one on the lower slope of Mount Elazar, and another at the upper mouth of the aforementioned gorge. The poor preservation of the wall between the western plateau and Mount Elazar did not allow an accurate measurement of its width, but it is estimated to be ca. 1.5 m. The width of the wall on the top of Mount Elazar (west of Camp H) is 1.3–1.4 m.

SECTION 7 – The southern section of the wall (Fig. 8) is built along the northern edge of Mount Elazar, just above a sheer 200 m-high cliff overlooking Masada. Along a roughly 500 m stretch going east from Camp H, remains of the wall only appear where it passes through lower sections of the rocky cliff-edge (i.e., only in ancient wadi beds cut by the large canyon of Nahal Masada). Features encountered along this section include (from

west to east) a small chamber attached to one of the wall stubs, a 15 m-long terrace supporting a section of a trail, two platforms, and the remains of a 2 × 5 m building.

Size and workload calculations

In order to estimate the size of the wall and the amount of work needed for its construction, a 3D model was created using aerial pictures taken with a drone and image-based 3D modelling software (Fig. 9). The model can be viewed at https://iaapub.israntique.org.il/Archeaology/Masada_Expedition_TAU/North_Circ/App/index.html#%2F (the north section of the circumvallation: towers 7–13) and https://iaapub.israntique.org.il/Archeaology/Masada_Expedition_TAU/South_Circ/App/index.html#%2F (the south section: towers 2–8). Benefiting from the remarkable preservation of the wall, our aim was to model a section in which all the stones used in its construction can still be found in its vicinity and are not covered by sediments. We assumed that the desert environment, the relatively flat terrain, and the lack of human activity since the 1st c. CE allowed for most of the collapsed stones to remain near the wall.[55] The northern part of the eastern wall (*Section 1*) was the best candidate for this as it consists of the more exposed and preserved sections of the wall and towers. The results are detailed in Appendix 2 and Figure 11.

The height of the circumvallation wall was calculated in the following manner: the 3D model provided the volume of stones used for a certain segment of the wall and the length of that segment.[56] The width of the segment was calculated according to either the actual measurements taken or an assumed constant of 2 m (the most common wall width found along *Section 1*). The original height of every segment was calculated as volume / (width × length). The results show a weighted mean of 2.2 m (where weights are based on segment lengths); most of the segments were about 2 m high, a few were very low (and thus were not included in the average), a few were 1.5–1.6 m high, and a few were 2.4–2.5 m high (Appendix 2). Since the walls of the towers are covered with stones, we could not accurately estimate their widths and lengths. Based on our rough estimations, however, it seems that they were higher than the walls (Appendix 2).

The measured length of the circumvallation wall is 4,290 m. The camp fortifications add 1,980 m of walls for a total of 6,270 m. We assumed a width of 2 m and a height of 2.5 m for most of the circumvallation wall and camp walls, though some sections were thinner and lower (Appendix 1). The towers were estimated to be 3.5 m high (based on the highest towers recorded in Appendix 2). Their widths and lengths were either measured or estimated, based on the sizes of their preserved stone piles. The total volume of the stones needed for the wall, towers, and camps was about 26,700 m^3 (Appendix 1).

Many workload calculations are based on the pioneering work of Erasmus, who based his calculations on experiments using a five-hour workday relying on "voluntary and semi-festive labor."[57] He reached a figure of 6.5–8.5 workdays for one person to construct 1 m^3 of stone wall. Shelach et al. calculated a figure of 3.58 days for 1 m^3 (considering a mere 500 m as the distance over which the stones were transported) for the construction

[55] Goldfus and Arubas assumed the same when they estimated the heights of the structures in Camp F, and Gutman literally recreated it when restoring the walls of Camp A. See Goldfus and Arubas 2002, 208; Gutman 1965, 95–123.

[56] Bentley ContextCapture Viewer has a volume measurement function.

[57] Erasmus 1965.

of fortifications in China.[58] Helms reached a somewhat comparable number of 3.7 workdays per 1 m^3.[59] All these calculations are based on pre-state societies and semi-voluntary work; however, Roman army soldiers likely worked more hours and were more disciplined and better trained in construction. Additionally, stones are abundant in the area of Masada, so the effort to transport them would have been relatively low. Therefore, a figure of no more than 2–3 workdays per cubic meter may be more accurate for the construction of the circumvallation at Masada. Our estimation of 26,700 m^3 for the circumvallation (Appendix 1) leads to 50,000 to 80,000 workdays. Based on the above assumptions, 5,000 soldiers needed 11–16 days to build the wall and camps surrounding Masada (Appendix 4).[60]

Discussion

Our observations and findings show that the Roman siege system around Masada was carefully prepared and undertaken with great effort. The following discussion examines how it fulfilled various functions and aims, as well as the ways in which Roman military tactics and battlefield behavior are materialized in it and in the conflict landscape around it.

According to our model-based calculations (Appendix 2), we estimate that the wall in *Section 1* stood to a height of ca. 2–2.5 m. The inconsistency in height measurements may be due to different preservation conditions creating incorrect calculations for certain segments, or it could be the result of different methods or measurements being employed by individual work-groups/units during the wall's construction.[61] Gutman's figures for the reconstructed Camp A wall[62] and our measurements of the wall widths of the camps allow us to assume that parts of the western wall (*Section 3*) and the walls around the camps had similar dimensions. The other stretches of the wall were thinner and lower, measuring about 1–1.5 m wide and 1–2 m high (see Appendix 1 for maximal estimations).

Even along its widest (2 m) sections, the wall was too thin for a parapet made of fieldstones. It could have accommodated a wooden breastwork, but the lack of trees for timber in the area makes this option unlikely.[63] A 2–2.5 m-high wall made of fieldstones and lacking a parapet could not withstand a full-scale siege and is easily scalable, though it would serve as an effective obstacle against sorties and skirmishes by impeding the advance of the attackers. As it is higher than a person's stature, soldiers could not fight while taking cover behind it. Therefore, the wall could only effectively be used for fighting when mounted by Roman soldiers. Evidence from Camp A seems to reaffirm this; while reconstructing the walls of Camp A, Gutman found five staircases leading to the top of the defensive walls – two attached to the inner face of the back wall (i.e., the one which does not face

---

58 Shelach et al. 2011.

59 Helms 1981, 253.

60 The Roman army at Masada was estimated at about 8,000 strong (see Roth 1995, 92–93; Shatzman 1997). The figure of 5,000 soldiers working on the construction of the camps and wall was reached by assuming that only about 60% of the Roman force at Masada could work, as the others were assigned to other tasks, such as guarding the works and logistical lines, surveillance, and logistical and clerical jobs.

61 As in Hadrian's Wall, see Goldsworthy 2003, 146–47.

62 2.2 m high; Gutman 1965, 122.

63 Liphschitz and Lev-Yadun 1989.

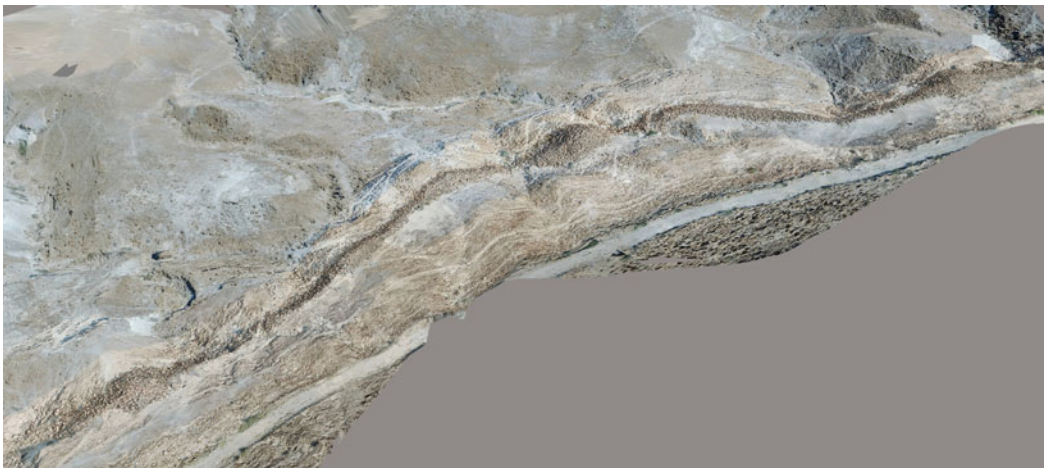

Fig. 9. *A section of the 3D model, showing Towers 7–9 (view to the east). (Photograph by H. Ashkenazi.)*

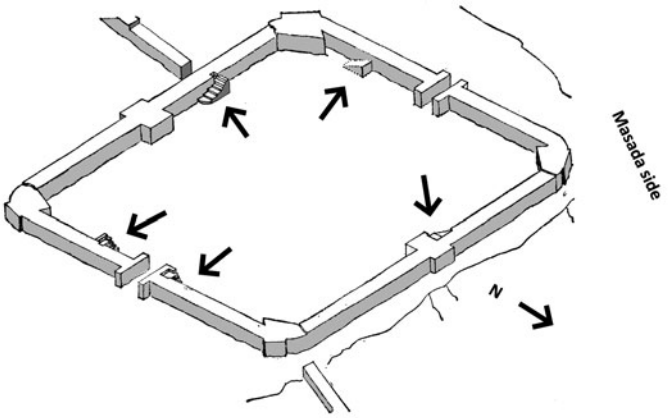

Fig. 10. *Camp A (arrows mark staircases). (After Gutman 1965, 109.)*

Masada) of the camp and one to each of the remaining three walls (Fig. 10).[64] This indicates that the Romans saw the walls as fighting platforms – the large number of staircases would have allowed soldiers to quickly man the walls in case of an attack. The second staircase along the back wall was likely built due to this location providing an enhanced degree of protection against projectiles shot by enemies advancing from Masada, while at the same time allowing a greater number of soldiers to ascend more easily.

As a general rule, the Roman army preferred taking the initiative and being on the attacking side to hiding behind walls, in most cases actively choosing to move onto the offensive.[65] The lack of parapets along the circumvallation wall and camp walls attests to this; the parapet-less walls did not offer much protection for the exposed soldiers standing on them. They were probably expected to defend themselves with their shields and mount an attack in an earlier phase of the battle.

---

[64] Gutman 1965, 123.

[65] Coulston 2013, 21–22; Goldsworthy 1996, 76–115, 246; Goldsworthy 2003, 89, 155.

The two rear staircases in Camp A are exhibitive of Roman attention to detail,[66] exemplary of how every feature in the siege system served a function. In this respect, we analyzed the towers of *Section 1*. These towers were relatively low, and most of them were positioned with gaps ranging from 61 to 110 m between them – a much greater distance than the traditional 31 m bowshot gap (which allows for mutual defense during an attack) but still within the range of catapults.[67] If it is assumed that this section was intended mainly for confronting sorties from Masada, then some of the towers were decidedly positioned in inferior locations, which provided neither wide firing angles nor good viewing angles (e.g., Towers 8, 11, and 12, which were positioned within concave sections of the wall), while locations that allowed better firing angles and eliminated blind spots (like bulging corners of the wall), were left without firing platforms. If examining *Section 1* as a wall intended to face a threat coming from the outside (the east), however, the locations of Towers 8, 11, and 12 become logical – they are not located in the concave parts of a wall directed towards Masada, but rather along convex portions of the wall, bulging outwards towards a possible infiltration of refugees, enemy reinforcements, or an attack coming from the wadis east of the circumvallation. This hypothesis is strengthened by Gutman, who first argued that the Roman army besieging Masada may have expected a threat from other sides. Gutman suggested that Camp H was too large to have been a surveillance post, as had been typically assumed. Also, for pure intelligence purposes, the western cliff offers a better view of the west and center of the fortress, while from Mount Elazar, only the south of Masada can be seen. Based on that, he argued that Camp H was positioned where it was in order to handle possible attacks from the south.[68] Further support for this extramural-threat defense hypothesis can be found in the placement of all *Section 1* towers near wadis and gullies; as these ravines could supply cover for enemies approaching from the east, there was a need for watchtowers/firing-platforms to be located next to them. Another possible explanation is that the towers were positioned to prevent escape attempts through these wadis and gullies.[69]

Davies's claim that some of the towers were used as firing platforms for light artillery[70] may be correct, as the distance between them fit the range of Roman catapults.[71] The lack of catapult bolts on the top of Masada and near the siege ramp[72] may be due to the fact that all of them were positioned on *Section 1*'s towers, against possible attacks from the east or north.[73]

In comparing the siege system of Masada to other sieges conducted by the Roman army, it becomes evident that when faced with a formidable threat from the besieged army or from the outside, the Roman army built different siege systems – at Numantia (133 BCE) and Alesia (52 BCE) they built daunting obstacles that included thick walls (up to

---

66 Gutman 1965, 128.

67 Holley 1994.

68 Gutman 1965, 128–30.

69 As the eight turrets positioned between Camps C and D in Machaerus; see Davies 2006, 81.

70 Davies 2011, 71.

71 Which was less than 400 m (Holley 1994; Shatzman 1997, 112).

72 Magness 2019, 15; Stiebel and Magness 2007, 31.

73 The eastern towers could not be used as firebases against Masada itself since the distance and elevation differences were too large (e.g., Tower 8 is more than 600 m from the closest point in Masada and more than 300 m lower, while the range of the artillery used during the siege did not exceed 500 m, see Holley 1994).

4.7 m wide), parapets, ditches, traps, and towers positioned within bowshot gaps (less than 31 m).[74] These siege fortifications were meant to withstand massive counterattacks from the besieged armies. The siege system at Masada, on the other hand, was not as elaborate. Therefore, we suggest that the Romans did not expect massive resistance, either from the fortress itself or from the outside.

The observations and evidence described above lead us to the conclusion that the circumvallation around Masada served several functions. The eastern section (*Section 1*) was aimed at repelling attacks from both Masada and the outside (though based on the locations and distances between towers and the lack of parapets, the Roman army did not seem to expect heavy fighting). In this respect, the platforms and structure found on a hill about 120 m east of Tower 10 may comprise an observation post meant for surveilling the gullied area east of the circumvallation. The lack of towers in other sections of the circumvallation wall may be explained by the lack of topographic advantage for the rebels; that is, the rebels could advance from the top of Masada eastwards towards the circumvallation without any major obstacles, while to their west they were funneled into a narrow area between the upper riverbed of Nahal Masada and the gorge of Nahal Ben-Yair. On top of that, *Section 3* was protected by Camps F and E and the intense activity connected with the construction of the siege ramp. *Section 4* was protected by the same siege ramp activity. *Sections 5* and *7* were protected by the sheer cliffs below them, and *Section 6* was defended by Camp G and Camp H.

The north section (*2*) – and in particular its towers – is unique in its proximity to Masada. Tower 15 is positioned ca. 300 north and practically at the foot of the Northern Palace of Masada – in a clearly inferior position – and may have served as an observation post towards Nahal Ben-Yair. Its proximity to the Northern Palace means that the defenders of Masada did not have artillery capable of reaching this range, and that the Romans knew this.

The wall built on the western plateau (*Section 5*) above a high vertical cliff and the southern section built above the 200 m-high cliff of Mount Elazar (*Section 7*) were not intended to serve as obstacles. The truncated sections of *Section 7*, found only in the lower areas of the northern cliff of Mount Elazar, are not the product of better preservation; as water erosion is higher in lower areas and wadi beds, we would have expected to find better-preserved sections of the wall along the higher areas of the cliff. Therefore, it seems safe to conclude that the situation today reflects the original construction, and that the walls built along these lower positions only served to present the defenders of Masada with the appearance of the flat top of a solid wall. We can therefore safely conclude that *Sections 5* and *7* were used for psychological warfare.

The southwest section (*6*), with its large number of openings, is intriguing. Davies suggested that one of them (on the lower slope of Mount Elazar) was to be used as a sally-port in the event of a flash flood in one of the tributaries of Nahal Masada.[75] We suggest that these gates, found along a section positioned in front of the southern access to the cliff of Masada,[76] were placed there in preparation for an optional direct Roman assault aimed towards this gateway.

Most of the various features found along the circumvallation may be connected to its function and use: the installation near the eastern gate may have been a small hearth;

---

[74] Campbell 2006, 127, 148–56; Levithan 2013, 115, 131–41.

[75] Davies 2011, 68.

[76] Ben-Tor 2009, 27; Gutman 1965, 128; Livne 1990, 179.

the platforms found near Tower 8 were probably the bases of tents used to shelter a small garrison in the middle of the long eastern section of the wall between camp C and D (the grinding stones found in close proximity may strengthen this hypothesis); the thickening in *Section 5* may have been another observation post, positioned as it is with a direct line of sight along the western side of Masada; the chamber found in the wall in *Section 7*, the platforms and building found along the eastern side of this section, and Tower 1 may have been used as surveillance and observation posts.

Our workload calculations show that 5,000 men could have built the siege system around Masada in 11–16 days. This figure is higher than the estimations of Ben-Tor and Roth, who claimed that the construction of the circumvallation could have been finished in fewer than 5 days,[77] though their estimations are based on a speech given by Hadrian to Roman soldiers in Africa, wherein he states that one soldier can build 1 m^3 of stone wall per day. We believe this figure to be exaggerated. During the 70 CE siege of Jerusalem, the Roman forces, five times greater in number than those at Masada, built 7 km of circumvallation wall and 13 camps in three days.[78] If we assume that the other parameters were similar (e.g., the wall widths and heights, the stones having been brought from the same distance), we may calculate the time required to build the Masada siege system in terms of the workdays needed to build the Jerusalem system multiplied by 5 (the workforce in Masada was 5 times smaller) and divided by 1⅔ (the siege system in Jerusalem was 1⅔ larger). This leads us to a figure of 9 working days, which is closer to our estimation than to Roth and Ben-Tor's.

Our observation that large parts of wall in *Section 1* are covered by colluvial sediments shows that substantial erosion has taken place on the east side of Masada since the 1st c. CE. This calls for an examination of Goldfus et al.'s argument that no erosion degraded the Roman siege ramp.[79] We thus support Davies and Magness in their doubts regarding this argument and the conclusions drawn from it.[80]

In this research we created a photogrammetric model of the eastern circumvallation wall and used it to measure the volume of the wall and the stone rubble next to it, and by that to estimate its height. The other recently published photogrammetric research on the Masada siege system was used to create viewshed analysis,[81] another example of how photogrammetric research can be a powerful tool. It is interesting to note that Shmidov and Wiegmann created a lower-resolution model of the whole site that allowed them to calculate lines of sight between the towers and the camps, while we created a high-resolution model of the eastern side only, in order to accurately calculate volumes.

Summary and conclusions

Our study aims to fill in some of the gaps in the research examining the conflict landscape around Masada and the circumvallation in particular. Namely, it serves to provide a better understanding of the circumvallation's function and usage during the siege.

---

77 Ben-Tor 2009, 238; Roth 1995, 100.

78 Shatzman 1997.

79 Goldfus et al. 2016.

80 Davies and Magness 2017.

81 Shmidov and Wiegmann 2023.

Our analysis, based on a thorough survey, ground-level recording, and a digital photogrammetric 3D model, shows that the construction of both the wall and the camps around Masada took about two weeks. This supports Roth's argument for a four-to-nine-week siege.[82]

The wall was built to fulfil several functions. Overall, it was an obstacle intended to slow approaching enemies, deserters, or infiltrators. This 2–2.5 m high wall lacked parapets, and therefore could only serve in a limited way as a fighting platform; in the case of an attack – either from Masada or from the back – the soldiers standing on it were expected to quickly take the initiative and counterattack. The eastern section (*Section 1*) was the more elaborate obstacle in the circumvallation and was built to counter small-scale attacks – especially from the deep wadis to the east – as well as sorties from Masada. The northern part of the western section (*Sections 3* and *4*) was built for a similar reason, only without towers as the rebels did not have a topographical advantage on this side and the camps and the soldiers working on the siege ramp protected the area. The openings found in the circumvallation wall near Camp G, were probably placed there to enable a possible direct attack via Masada's southern approach. The circumvallation was also built as a means of psychological warfare against the besieged. In fact, the sections above the south and west cliffs were built only to lower the defenders' morale and to function as a symbol of Roman might.[83] The audience for the psychological warfare may also have been the Roman soldiers themselves – Levithan showed that the Roman legions besieging Jerusalem only a few years prior were not an unstoppable war-machine; in fact, their commanders did not have full control over them, as soldiers avoided dangerous circumstances and officers had to persuade them to volunteer for more dangerous missions.[84] The impressive circumvallation around Masada probably helped the Roman army's morale by boosting soldier confidence – an important factor in ancient warfare.[85]

Based on our observation that large sections of the eastern wall are either missing or covered by colluvial sediments, we argue that substantial erosion has taken place on this side of Masada since the 1st c. CE. We see it as further strengthening Davies and Magness's argument that the thesis of Goldfus et al. is inaccurate and the siege on Masada did end with the breach of its western wall by the Roman siege engines.[86]

In this research we showed how a computerized 3D model, together with a ground survey, can contribute to archaeological research as an analytical tool. We created a photogrammetric model of the eastern wall and used it to measure sizes and volumes of the wall and the stone rubble next to it. These measurements allowed us to calculate the original height of the wall and the time needed for its construction. In addition to the circumvallation, the conflict landscape around Masada also includes the siege ramp, the Roman army camps and the trails connecting it. This research is the first part of a long-term project aimed at studying all the components of this landscape.

---

82 Roth 1995.

83 Davies 2001, 70.

84 Levithan 2013, 152–69.

85 Goldsworthy 2003, 175.

86 Davies and Magness 2017; Goldfus et al. 2016.

Appendices

APPENDIX 1: CIRCUMVALLATION WALL SECTIONS, LENGTHS, AND VOLUME CALCULATIONS

Circumvallation wall sections	*Length (m)*	*Width (m)*	*Calculated/ estimated max. height (m)*	*Volume (m^3)*	*Remarks*
Section 1 (east)	1,806	2.00	2.5	9,028	
Section 2 (north)	364	1.20	2.0	873	
Section 3 (west – Camp F to hill)	454	2.00	2.5	2,272	
Section 4 (west – from hill to cliff)	287	1.25	2.0	718	
Section 5 (west cliff)	445	0.95	1.0	423	
Section 6a (southwest – from west cliff to top of Mount Elazar)	459	1.50	2.0	1,376	
Section 6b (west of Camp H)	333	1.35	2.0	898	
Section 7 (south cliff)	143	0.70	1.0	100	
Towers (extra volume on top of the wall)				1,295	
Camp A	82	2.00	2.5	409	Only sections that are not part of the circumvallation wall
Camp B	548	2.00	2.5	2,740	
Camp C	273	2.00	2.5	1,365	
Camp D	129	2.00	2.5	646	Only sections that are not part of the circumvallation wall
Camp E	149	2.00	2.5	746	Only sections that are not part of the circumvallation wall
Camp F	582	2.00	2.5	2,911	
Camp G	85	2.00	2.5	426	Only sections that are not part of the circumvallation wall
Camp H	131	1.35	2.5	443	Only sections that are not part of the circumvallation wall
Circumvallation wall total	**4,290**			**15,687**	
Camp wall total	**1,980**			**9,686**	
Towers total				**1,295**	
Total:	**6,270**			**26,668**	

APPENDIX 2: CIRCUMVALLATION WALL VOLUME MEASUREMENTS AND HEIGHT CALCULATIONS IN NORTHERN PARTS OF SECTION 1

Segment ID	*Type*	*Area*	*Volume*	*Length*	*Width*	*Width According to*	*Calculated Height*	*Remarks*
1	Wall	103.64	62.99	12.42	2.00	Measurement	**2.5**	Wall is on a slope, volume may be too high
2	Tower 13	80.10	88.94	5.50	5.50	Measurement	**2.9**	Tower is on a slope; volume may be too high
3	Wall	128.77	102.93	21.11	2.00	Measurement	**2.4**	
4	Wall	70.37	31.88	10.12	2.00	Measurement	**1.6**	
5	Wall	20.00	14.24	2.90	2.00	Estimation	**2.5**	
6	Wall	24.00	17.25	4.35	2.00	Estimation	**2.0**	
7	Wall	56.85	41.31	10.03	2.00	Measurement	**2.1**	Width 2–1.9 m
8	Wall	30.58	15.69	5.37	2.00	Estimation	**1.5**	
9	Wall	27.17	19.31	4.77	2.00	Estimation	**2.0**	
10	Wall	33.74	23.33	5.54	2.00	Estimation	**2.1**	
11	Wall	58.82	34.84	8.46	2.00	Estimation	**2.1**	
12	Wall	56.38	24.08	11.59	2.00	Estimation	**1.0**	W side may be covered in silt
13	Tower 12	97.24	106.51	5.50	5.50	Measurement	**3.5**	
14	Wall	36.00	25.86	5.06	2.00	Estimation	**2.6**	
15	Wall	79.00	33.55	11.43	2.00	Estimation	**1.5**	
16	Wall	27.54	8.78	6.23	2.00	Estimation	**0.7**	W side may be covered in silt
17	Wall	35.73	10.49	6.68	2.00	Estimation	**0.8**	W side may be covered in silt
18	Tower 11	79.78	48.66	5.00	5.00	Measurement	**1.9**	
19	Wall	115.68	68.47	19.55	2.00	Estimation	**1.8**	W side may be covered in silt
20	Wall	92.08	61.79	12.81	2.00	Estimation	**2.4**	
21	Tower 8	131.18	248.79	10.00	7.00	Estimation	**3.6**	

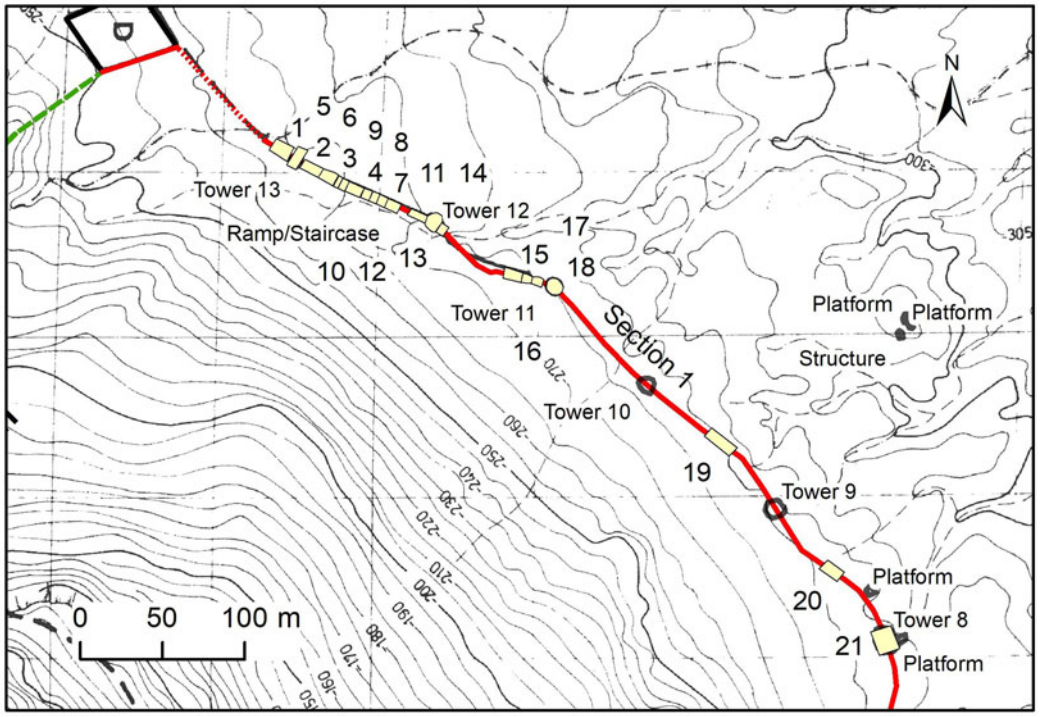

Fig. 11. *Locations of sections measured in Appendix 2. (Drawing by H. Ashkenazi, Base Map after Netzer 1991, Plan A.)*

APPENDIX 3: TOWER VOLUME ESTIMATIONS AND AERIAL GAPS

Tower	*Aerial distance to next tower in table*	*Width*	*Length*	*Approximated Height*	*Volume*	*Tower volume w/o wall volume*	*Remarks*
1	265	6.0	4.0	3.5	84.0	60.0	Approximate width and length
Camp A	162						
2	98	5.0	6.0	3.5	105.0	85.0	Approximate width and length
Gate		2.0	6.0	3.5	42.0	34.0	Approximate width and length
Gate	61	2.0	6.0	3.5	42.0	34.0	Approximate width and length
3	103	5.0	5.0	3.5	87.5	67.5	Approximate width and length
4	84	5.0	5.5	3.5	96.3	76.3	Approximate width and length
5	76	5.5	5.5	3.5	105.9	83.9	Approximate width and length
6	83	6.0	5.0	3.5	105.0	81.0	Approximate width and length
7	86	5.0	6.0	3.5	105.0	85.0	Approximate width and length
8	104	10.0	7.0	3.5	245.0	205.0	Approximate width and length
9	110	5.0	5.0	3.5	87.5	67.5	Approximate width and length
10	82	5.0	5.5	3.5	96.3	76.3	Measured width and length
11	84	5.0	5.0	3.5	87.5	67.5	Measured width and length
12	92	5.5	5.5	3.5	105.9	83.9	Measured width and length
13	114	5.5	5.5	3.5	105.9	83.9	Measured width and length
Camp D	190						
14	77	5.0	4.0	3.5	70.0	50.0	Approximate width and length
15		4.0	5.0	3.5	70.0	54.0	Approximate width and length
Total						**1,295**	

APPENDIX 4: WORKLOAD CALCULATIONS

	Workdays per m^3	*Total workdays*	*Duration in days, workforce of 5,000 soldiers*	*Duration in days, workforce of 4,000 soldiers*	*Duration in days, workforce of 3,000 soldiers*
Extremely efficient workers	2	53,336	11	13	18
Very efficient workers	3	80,004	16	20	27
Efficient workers[87]	3.58	95,471	19	24	32
Inefficient workers[88]	7.5	200,009	40	50	67

References

Arubas, B., and H. Goldfus. 2008. "The Roman siege works." In *The New Encyclopedia of Archaeological Excavations in the Holy Land*, Vol. 5, ed. E. Stern, 1937–40. Jerusalem: The Israel Exploration Society and Carta.

Ben-Tor, A. 2009. *Back to Masada*. Jerusalem: Israel Exploration Society.

Berlin, A. M., and J. A. Overman. 2002. "Introduction." In *The First Jewish Revolt: Archaeology, History, and Ideology*, ed. A. M. Berlin and J. A. Overman, 1–14. London and New York: Routledge.

Campbell, D. B. 2006. *Besieged: Siege Warfare in the Ancient World*. Oxford: Osprey Publishing.

Cotton, H. M., and J. Geiger. 1989. *Masada II: The Yigael Yadin Excavations 1963–1965, Final Reports. The Latin and Greek Documents*. Jerusalem: Israel Exploration Society.

Cotton, H. M., and J. Price. 1990. "Who conquered Masada in 66 CE, and who lived there until the fortress fell?" *Zion* 55: 449–54.

Coulston, J. 2001. "The archaeology of Roman conflict." In *Fields of Conflict: Progress and Prospect in Battlefield Archaeology*, ed. P. W. M. Freeman, and A. Pollard, 23–49. BAR International Series 958. Oxford: Archaeopress.

Coulston, J. 2013. "Courage and cowardice in the Roman imperial army." *War in History* 20: 7–31.

Davies, G. 2001. "Siege works, psychology and symbolism." In *TRAC 2000: Proceedings of the Tenth Annual Theoretical Roman Archaeology Conference, London 2000*, ed. G. Davies, A. Gardner, and K. Lockyear, 69–79. Oxford: Oxbow Books.

Davies, G. 2006. *Roman Siege Works*. Stroud: Tempus.

Davies, G. 2011. "Under siege: The Roman field works at Masada." *BASOR* 362: 65–83.

Davies, G., and Magness, J. 2017. "Recovering Josephus: Mason's *History of the Jewish War* and the siege of Masada." *Scripta Classica Israelica* 36: 55–65.

Erasmus, C. J. 1965. "Monument building: Some field experiments." *Southwestern Journal of Anthropology* 21: 277–301.

Fields, N. 2009. *The Roman Army of the Principate 27 BC–AD 117*. Battle Orders 37. Oxford: Osprey.

Fowler, M. J. F. 2022. "The archaeological potential of KH-9 HEXAGON satellite photographs: The Roman temporary camps and siege works at Machaerus and Masada." *AARGnews* 64: 37–53.

Gichon, M. 2000. "The siege of Masada." In *Les légions de Rome sous le Haut-Empire*, ed. Y. Le Bohec and C. Wolff, 541–54. Collection du Centre d'études romaines et gallo-romaines. Nouvelle série 20. Lyon: De Boccard.

Goldfus, H., and B. Arubas. 2002. "Excavations at the Roman siege complex at Masada – 1995." In *Limes XVIII: Proceedings of the XVIIIth International Congress of Roman Frontier Studies held in Amman, Jordan (September 2000)*, ed. P. Freeman, J. Bennet, Z. T. Fiema, and B. Hoffmann, 207–14. BAR International Series 1084. Oxford: Archaeopress.

Goldfus, H., and B. Y. Arubas. 2010. "Masada from the Roman point of view – In light of new excavations at the siege-works." In *OR LE-MAYER: Studies in Bible, Semitic Languages, Rabbinic Literature, and Ancient Civilizations, Presented to Mayer Gruber on the Occasion of his Sixty-Fifth Birthday*, ed. S. Yona, 19–32. Beer Sheva: Ben Gurion University of the Negev Press.

Goldfus, H., and B. Arubas. 2013. "Masada." In *The Encyclopedia of Ancient History*, ed. R. S. Bagnall, K. Brodersen, C. B. Champion, A. Erskine, and S. R. Huebner, 4338–41. Malden: Blackwell Publishing.

Goldfus, H., Y. Avni, R. Albag, and B. Arubas. 2016. "The significance of geomorphological and soil formation research for understanding the unfinished Roman ramp at Masada." *Catena* 146: 73–87.

Goldsworthy, A. K. 1996. *The Roman Army at War: 100 BC–AD 200*. Oxford Classical Monographs. Oxford: Clarendon Press.

Goldsworthy, A. K. 2003. *The Complete Roman Army*. New York: Thames and Hudson.

Gutman, S. 1965. *With Masada*. Tel Aviv: Hakibbutz Hemeuchad Publishing House. (Hebrew)

Hadas, G. 2023. "From where did the Romans breach into Masada?" *Jerusalem Journal of Archaeology* 4: 137–54.

Hawkes, C. 1929. "The Roman siege of Masada." *Antiquity* 3, no. 10: 195–213.

Helms, S. W. 1981. *Jawa: Lost City of the Black Desert*. London: Methuen.

Holley, A. E. 1994. "The ballista balls from Masada." In *Masada IV: The Yigael Yadin Excavations, 1963–1965: Final Reports*, ed. J. Aviram, G. Foerster, and E. Netzer, 347–65. Jerusalem: Israel Exploration Society.

James, S. 2011. "Stratagems, combat, and 'chemical warfare' in the siege mines of Dura-Europos." *AJA* 115: 69–101.

Keeley, L. H., M. Fontana, and R. Quick. 2007. "Baffles and bastions: The universal features of fortifications." *Journal of Archaeological Research* 15: 55–95.

Kennedy, D., and D. Riley 1990. *Rome's Desert Frontier From The Air*. London: B. T. Batsford.

Levithan, J. 2013. *Roman Siege Warfare*. Ann Arbor: The University of Michigan Press.

Liphschitz, N., S. Lev-Yadun, and Y. Waisel. 1981. "Dendroarchaeological investigations in Israel (Masada)." *IEJ* 31: 230–34.

Liphschitz, N., and S. Lev-Yadun 1989. "The botanical remains from Masada: Identification of the plant species and the possible origin of the remnants." *BASOR* 274: 27–32.

Livne, M. 1990. "The trails leading to Masada – their location and discovery." In *The Dead-Sea and the Judean Desert 1967–1990*, ed. M. Naor, 173–82. Jerusalem: Yad Ben-Zvi Press. (Hebrew)

Magness, J. 1996. "Masada 1995: Discoveries at Camp F." *Biblical Archaeologist* 59: 181.

Magness, J. 2009. "The pottery from the 1995 excavations in Camp F in Masada." *BASOR* 353: 75–107.

Magness, J. 2019. *Masada: From Jewish Revolt to Modern Myth*. Princeton and Oxford: Princeton University Press.

Mascher, M., V. J. Schuenemann, U. Davidovich, N. Marom, A. Himmelbach, S. Hübner, A. Korol, M. David, E. Reiter, S. Riehl, M. Schreiber, S. H. Vohr, R. E. Green, I. K. Dawson, J. Russell, B. Kilian, G. J. Muehlbauer, R. Waugh, T. Fahima, J. Krause, E. Weiss, and N. Stein. 2016. "Genomic analysis of 6,000-year-old cultivated grain illuminates the domestication history of barley." *Nature Genetics* 48, no. 9: 1089–93.

Netzer, E. 1991. *Masada III: The Yigael Yadin Excavations 1963–1965, Final Reports*. Jerusalem: Israel Exploration Society.

O'Driscoll, J. 2019. "Picture perfect: Using drone technology and photogrammetry techniques to map the western stone forts of Ireland." *JFA* 44: 126–46.

Richmond, I. A. 1962. "The Roman siege-works of Masada, Israel." *JRS* 52: 142–55.

Roth, J. 1991. "The Logistics of the Roman Army in the Jewish War." PhD Diss., Columbia University.

Roth, J. 1995. "The length of the siege of Masada." *Scripta Classica Israelica* 14: 87–110.

Roth, J. P. 1999. *The Logistics of the Roman Army at War (264 B.C. – A.D. 235)*. Columbia Studies in the Classical Tradition 23. Leiden: Brill.

Schulten, A. 1933. "Masada: die Burg des Herodes und die römischen Lager." *ZDPV* 56: 1–185.

Shatzman, I. 1997. "The Roman siege of Masada." In *The Story of Masada: Discoveries from the Excavations*, ed. G. Hurvitz, 109–30. Provo: BYU Studies.

Shelach, G., K. Raphael, and Y. Jaffe 2011. "Sanzuodian: The structure, function and social significance of the earliest stone fortified sites in China." *Antiquity* 85: 11–26.

Shmidov, Y., and A. Wiegmann. 2023. "Photogrammetric documentation and visibility analysis of the Roman siege works at Masada." In *New Studies in the Archaeology of the Judean Desert: Collected Papers*, ed. O. Sion, J. Uziel, A. Ganor, and E. Klein, 419–49. Jerusalem: Israel Antiquity Authority.

Stiebel, G. D. 2007. "Masada." In *Encyclopaedia Judaica*, 2nd ed., ed. F. Skolnik and M. Berenbaum, 593–99. Detroit: Thomson Gale.
Stiebel, G. D. 2020. "What have the Romans ever done for us?" *Scripta Classica Israelica* 39: 175–82.
Stiebel, G. D., and J. Magness 2007. "The military equipment of Masada." In *Masada VIII: The Yigael Yadin Excavations 1963–1965, Final Reports*, ed. J. Aviram, G. Foerster, E. Netzer, and G. D. Stiebel, 1–94. Jerusalem: Israel Exploration Society.
Trigger, B. G. 1990. "Monumental architecture: A thermodynamic explanation of symbolic behaviour." *WorldArch* 22: 119–32.
Yadin, Y. 1965. "The excavation of Masada—1963/64: Preliminary report." *IEJ* 15: 1–120.
Yadin, Y. 1966. *Masada: Herod's Fortress and the Zealots' Last Stand*. New York: Random House.
Yadin, Y. 1967. "Masada and the Limes." *IEJ* 17: 43–45.