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3 **Study and enhancement of the heritage value of**  
4 **a fortified settlement along the Limes Arabicus.**  
5 *Umm ar-Rasas (Amman, Jordan) between remote*  
6 *sensing and photogrammetry*

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19  
20 **ABSTRACT** 

21 The Limes Arabicus is an excellent laboratory for experimenting with the huge potential of  
22 historical remote sensing data for identifying and mapping fortified centres along this sector  
23 of the eastern frontier of the Roman Empire and then the Byzantine Empire. Remote sensing,  
24 combined with modern surveying techniques and tools such as photogrammetry and laser  
25 scanners, now makes it possible to identify, document and study ancient settlements in the  
26 area, as well as to develop site valorisation programmes, including the design of real and  
27 virtual routes for better use of archaeological areas. We offer here a preliminary contribution  
28 to the site of Umm ar-Rasas (Amman, Jordan), a fortified town on the Via Traiana Nova.  
29 Since the early 1800s, certain explorers have recorded this location, which is marked by the  
30 presence of a tetrarchic castrum and a Byzantine settlement to the north. It has been the  
31 subject of archaeological study since the second half of the 1980s. The excavations, carried  
32 out by the Studium Biblicum Franciscanum of Jerusalem (Piccirillo and Alliata 1994) and the  
33 Swiss Max van Berchem Foundation (Bujard 2008), involved a portion of the castrum and, in  
34 particular, the settlement north of this fortified site, bringing to light precious mosaic floors  
35 that have made Umm ar-Rasas famous. From 2013 to 2019, the Italian National Research  
36 Council's Institute of Heritage Science (CNR-ISPC) conducted topographic and 3D surveys of  
37 the Saint Stephen, Bishop Sergius, and Saint Paul Churches in the inhabited area north of the  
38 castrum, in collaboration with the Jordanian Department of Antiquities (DOA) and co-  
39 financed by the Italian Ministry of Foreign Affairs and International Cooperation (MAECI), in  
40 order to both document the status of conservation of the mosaic floors and prepare for better  
41 tourist access to the area (Gabrielli, Portarena, and Franceschinis 2017). Beginning in 2021,  
42 the CNR-ISPC investigations concentrated on the castrum and the region to the north and  
43 east of the Byzantine village.

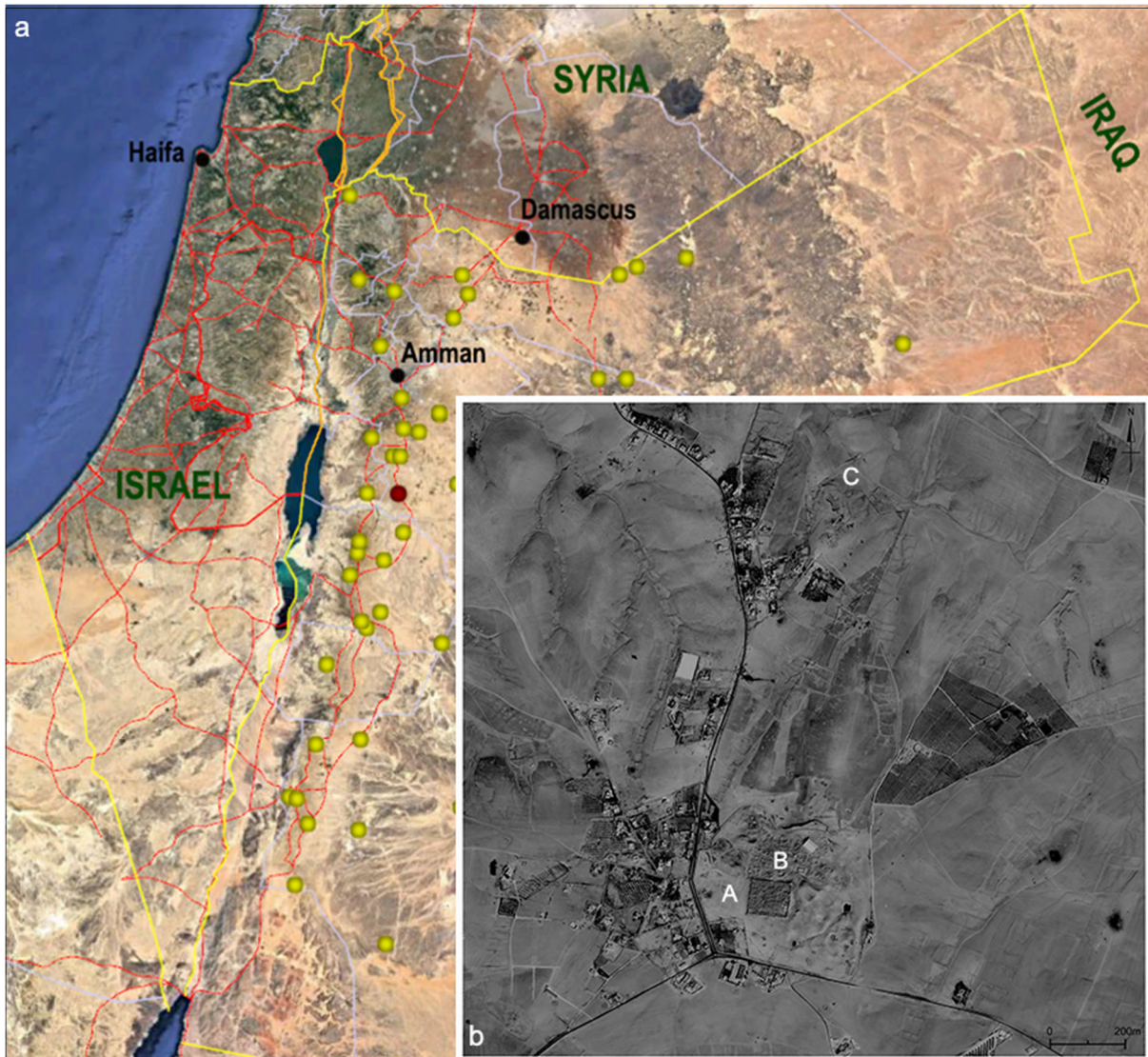
44 Topographical and architectural surveys were carried out to confirm on the ground the crop  
45 marks discovered through the study of historical and modern remote sensing images, as well  
46 as to document the fortification's construction phases. An examination of multitemporal  
47 remote sensing documents obtained from aerial and satellite platforms preceded the field  
48 studies. To begin, historical aerial photographs taken by Sir Marc Aurel Stein in 1939 and  
49 space photos acquired by the Corona KH-4B and Hexagon KH-9 satellites throughout the  
50 1960s and 1970s were georeferenced, processed, and interpreted. The analysis of aerial  
51 photos taken from 600 to 1200 feet in altitude and space photos with spatial resolutions  
52 ranging from 1.8 to 0.60 m allowed for the documentation of preserved structures as well as  
53 the identification of archaeological crop, dump, and shadow marks linked to buried ancient  
54 features. This research endeavour enabled the design of ground checks for the investigation  
55 and reconstruction of the site's ancient topography and historical landscape. Furthermore,  
56 the panchromatic and multispectral data from two very high-resolution satellite images, a  
57 Pléiades 1B from 2020 (max. spatial resolution 0.5 m) and a Pléiades Neo from 2022 (max.  
58 spatial resolution 0.3 m), were processed to identify other marks associated with buried  
59 ancient remains and to generate orthorectified images used as base maps during field  
60 surveys. Finally, the archaeological elements acquired from multitemporal recording  
61 improved the site's archaeological map when combined with comprehensive plans of the  
62 castrum and excavated sectors of the inhabited area made during recent topographic surveys  
63 or previous studies. The castrum walls were recently topographically surveyed and 3D  
64 architecturally surveyed using the following techniques: terrestrial photogrammetry with a  
65 Canon 5D Mark II (24 MPixel) and laser scanner survey with two laser scanners, Faro 120 and  
66 Faro 330 x. Ad hoc systems were created with the goal of finishing the high-resolution  
67 documentation of the masonry; specifically, photogrammetry techniques were applied with  
68 multiple pictures to acquire a higher chromatic definition of the surfaces and better  
69 photographic detail. Instead, a correct description of the distorted walls was achieved  
70 through the capture of 97 laser scanner scans, which showed substantial irregularities. Many  
71 relevant and credible facts relating to the building phases and subsequent alterations of the  
72 castrum's walls, as well as its state of conservation, have been collected and archived over  
73 the course of two years. An initial mapping of the locations of stone material extraction, water  
74 reserves, canalization systems, and the organisation of cultivated land around the community  
75 was completed. The data are being combined into an archaeological map that will be put into  
76 a GIS platform to document the ancient topography of Umm ar-Rasas and will serve as a  
77 knowledge foundation for the site's valorization initiatives. With the collapses that hide much  
78 of the interior of the castrum, it is impossible to identify a construction phase of the Severian  
79 age, which has been hypothesised based on items found in earlier excavations. It is hoped  
80 that future missions will be able to complete the aerial laser scanner surveys and conduct  
81 geophysical prospecting, allowing for the acquisition of elements on the topography of the  
82 area inside the walls of the tetrarch fortification and the highlighting of any pre-existing  
83 structures, with the goal of creating a more updated castrum plan.


84  
85 **Keywords:** Limes Arabicus, remote sensing analysis, high-resolution satellite images, laser scanner  
86 survey, photogrammetry, historical landscape.

87

89 Umm ar-Rasas, Amman's current governorate, is located about 30 kilometres southeast of Madaba  
 90 (Fig. 1a). It is an archaeological site best renowned for the beautiful Byzantine mosaics that characterise its  
 91 churches, which were excavated between the second half of the 1980s and the early 2000s.

92 The presence of three settlement units characterises the site: the castrum (A), which dates back to the  
 93 end of the third and beginning of the fourth centuries AD; the Byzantine-Umayyad village, which is directly  
 94 to the north (B); and the Stylite tower complex, which is about 5 miles to the north (C) (Fig. 1b).  
 95



96  **Figure 1 - a)** Site location. **b)** Framing of the archaeological area: castrum (A); Byzantine-Umayyad  
 97 village (B); Stylite tower complex (C).

98

### *State of art*

99 Umm ar-Rasas in Arabic means “mother of lead”. The toponymy probably refers to the size and colour  
 100 of the stones that distinguish the castrum. It was the destination of all explorations since 1800 (Burchardt  
 101 1822; Irby and Mangles 1823; Buckingham 1825; Robinson 1837; Seetzen 1854, Palmer 1871; Tristram  
 102 1874; Layard 1887; Vailhé 1896; Germer-Durand 1897; Clermont-Ganneau 1898; Lagrange 1898; Wilson  
 103 1899; Brünnow and Domaszewski 1905; Musil 1907; Glueck 1934; Savignac 1936; Saller and Bagatti 1949).  
 104 In 1986, two inscriptions discovered on two mosaic floors, in the Lion Church and St. Stephen's Church,



105 permitted the site to be linked to the biblical and historical KASTRON MEFA. Mefaat was the city of the  
106 Ruben tribe (Gs. 13, 18; 21, 37; 1Cr. 6, 64; Ger. 48, 21), the φρούριον mentioned in the Onomasticon of  
107 Eusebius (Onomasticon 128, 21) and the Roman camp of Equites Promoti Indigenae mentioned in the  
108 Notitia Dignitatum (NotitiaDignitatum, p. 81, n. 19).

109 In 1939, the site was explored from the air by Sir Marc Aurel Stein. Between 1986 and 2006, the  
110 Studium Biblicum Franciscanum of Jerusalem excavated the churches of the Byzantine village immediately  
111 north of the castrum (Abela and Acconci 1997; Abela and Pappalardo 1998; 2002; 2004; Piccirillo 1986;  
112 1987; 1988; 1989; 1991; 1992; 1995; 1996; 1997; 1999; 2001; 2002; 2003; 2006; Piccirillo and Alliata 1994;  
113 Piccirillo and Attiyat 1986; Piccirillo, Abela and Pappalardo 2005; 2007). Finally, the Swiss Max van Berchem  
114 Foundation (1988-2000) studied a tiny portion of the castrum. The gates, particularly the east gate, as well  
115 as the south-east portion of the walls, comprising the twin churches, were explored (Bujard 1992; Bujard  
116 2008; Bujard and Joguín 1995; Bujard and Haldimann 1988). In 2004, Umm ar-Rasas was designated a  
117 UNESCO World Heritage Site (Abu Dayyeh 2002).

## 118 *Kastrum Project*

119 In 2013, Roberto Gabrielli began a project aimed at documenting, enhancing, and musealizing the  
120 archaeological area of Umm ar-Rasas. Seven successful missions incorporating the churches of the Saint  
121 Stephen complex and the Stylite Tower were carried out between 2013 and 2019 (Cozzolino et al. 2019;  
122 Gabrielli et al. 2016; Malinverni et al. 2019). Various topographic reliefs were undertaken throughout those  
123 years, as well as 3D surveys on structures and mosaic floors utilising GPS, photogrammetry, and laser  
124 scanners. Several tests have been carried out over the years in order to establish a method that would  
125 allow for the comprehensive documentation of the mosaic flooring in high resolution utilising  
126 photogrammetry techniques with a significant number of pictures and approximately thirty scans for the  
127 church (Gabrielli et al. 2017).

128 Since 2021, the already multidisciplinary study team has expanded even more, and research on the  
129 castrum and its surrounds has resumed, utilising remote sensing analyses and surveys (architectural,  
130 archaeological, photogrammetric, and laser scanners).

## 131 **Methods and tools**

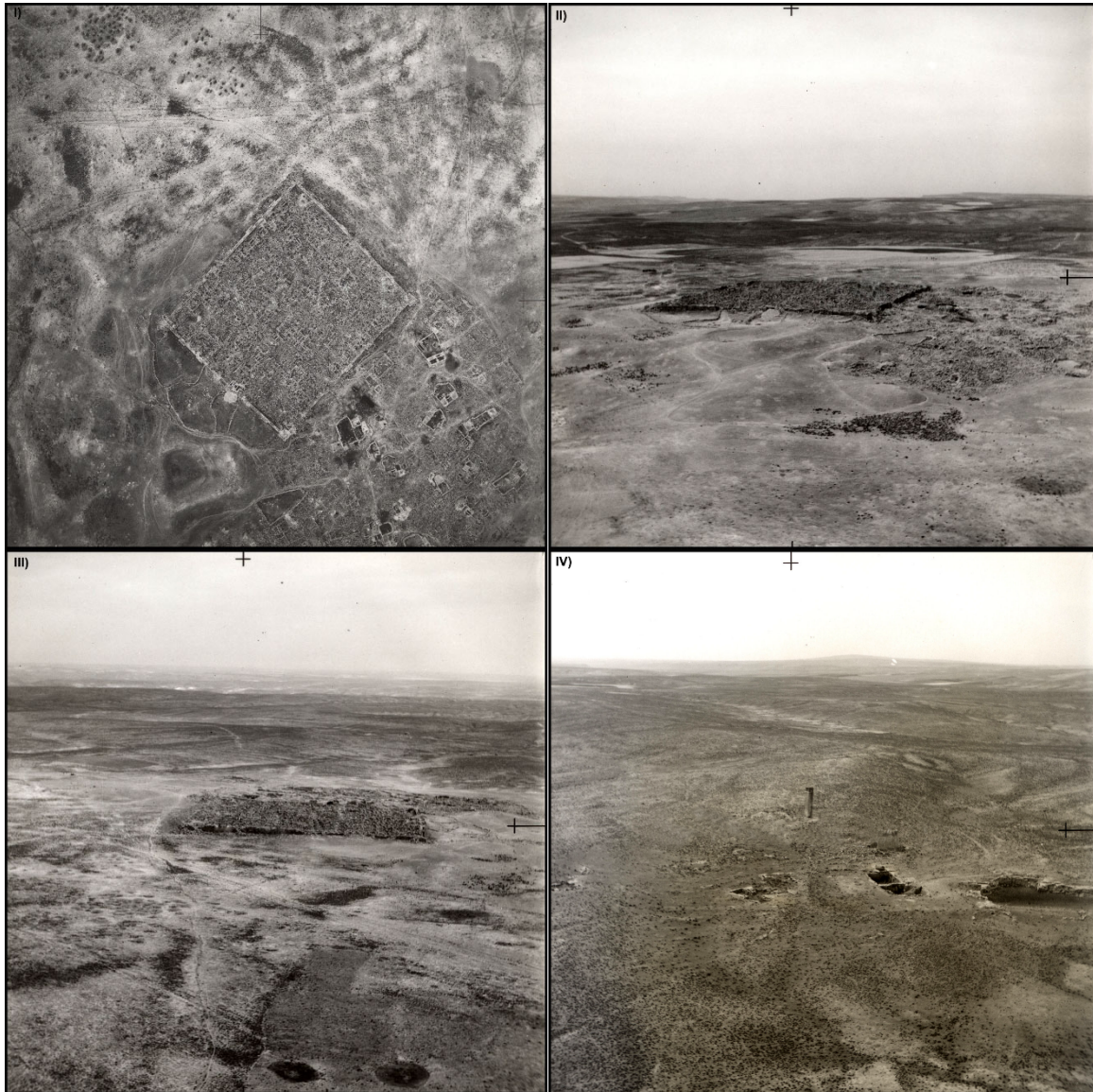
132 This section presents the methods and tools used during the last two years of remote sensing and  
133 fieldwork at Umm ar-Ras. The research has focused on the study of Umm ar-Rasas (castrum and  
134 settlement) and its surroundings, using mostly unpublished historical and recent remote sensing data.  
135 Research has also focused on ground, architectural, photogrammetric and laser scanning surveys. In  
136 particular, photogrammetric and laser scanning surveys were carried out on the walls of the castrum, and  
137 all features were verified on the ground using remote sensing analysis.

## 138 *Remote sensing analysis*

139 Starting with remote sensing analysis, the main research tools have been: historical aerial photographs  
140 taken by Sir Marc Aurel Stein in 1939 during a flight over Umm ar-Rasas; satellite panoramic camera  
141 photographs taken by Corona KH-4B, but especially the recently declassified Hexagon KH-9, which have  
142 been important in contextualising the site; and finally, recent high and very high resolution satellite images,  
143 which have allowed us to record the current state of preservation of the traces and also to discover new  
144 ones.

145 Sir Marc Aurel Stein was a Hungarian-born, naturalised English explorer of late 19th and early 20th  
146 centuries. In the late 1930s, he conducted significant aerial and ground surveys of the Roman Eastern  
147 Frontier between Iraq and Jordan, following the work of Father Antoine Poidebard in Syria (Poidebard  
148 1934). Stein left the Sinjar in the spring of 1938 and completed the mission in May of 1939. On his journey,  
149 he used the Kirkut-Haifa oil pipeline and then explored the archaeological sites of the Eastern Roman Limes

150 to the Aqaba Gulf (Stein 1938;1940). In May 1939, Stein flew to Umm ar-Rasas and made four aerial  
151 photographs, one vertical and three oblique, at heights of 1200 and 600 feet, respectively (Fig.2).



152 **Figure 2** - Umm ar-Rasas May 6th, 1939. The aerial photographs taken by Stein. **I)** a vertical view of  
153 the castrum from 1200 feet above ground; **II-III)** oblique views of the castrum and village from the  
154 northeast and south, respectively, at a height of 600 feet; **IV)** an oblique view of the Stylite complex  
155 from the north, also at a height of 600 feet.

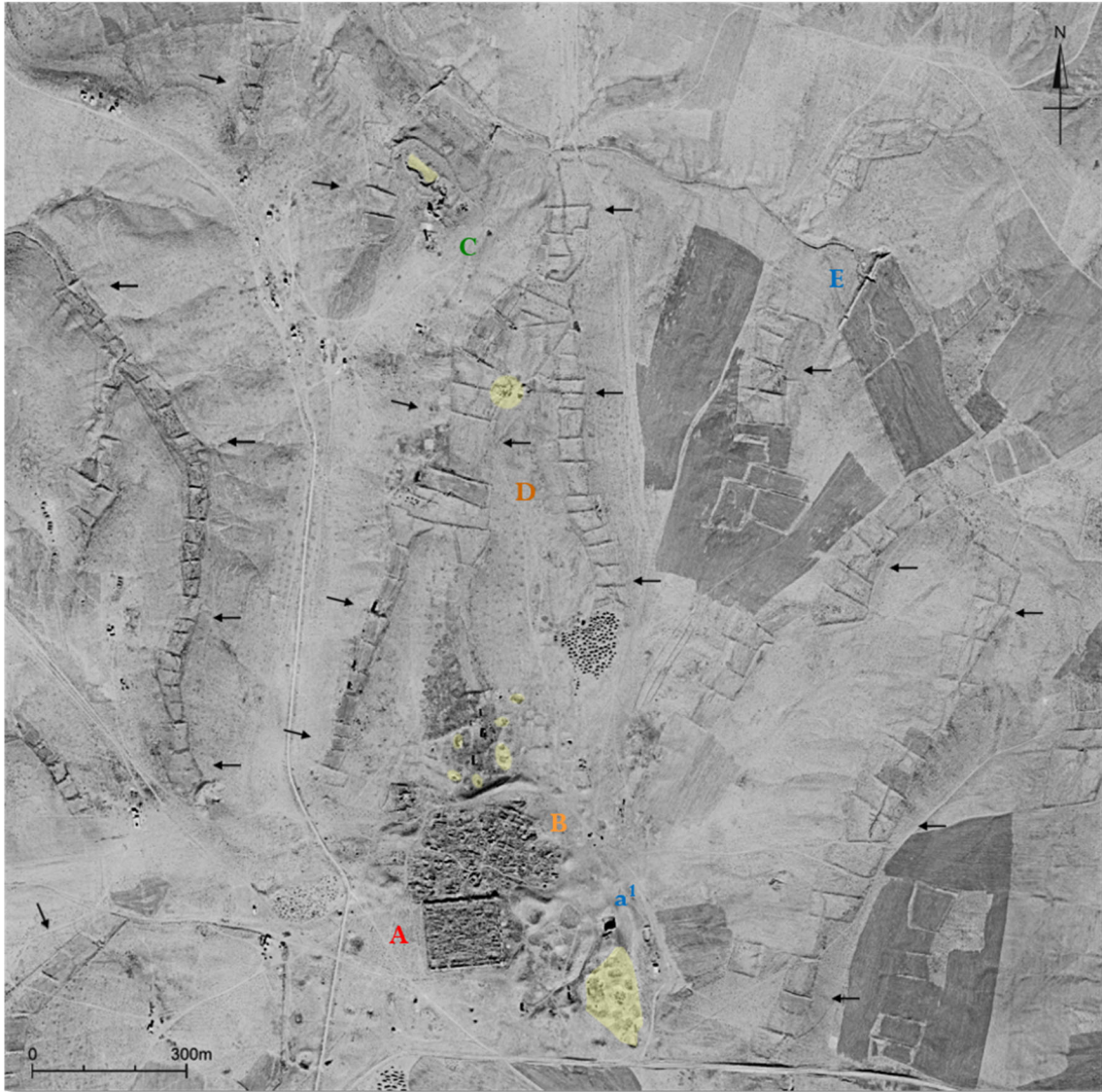
156 These photographs enable us to recreate the topography and landscape of the archaeological site.  
157 ~~These photographs~~ capture a desert landscape marked by the pure presence of ruins. A desert landscape  
158 is crossed by roads and wadis but without modern overlays, such as urbanisation or new agricultural uses  
159 of the soil.

160  
161 Historical satellite photographs, in particular a Hexagon KH-9 from 1974, suggest a landscape very  
162 similar to that photographed by Stein. Hexagons are well-known panoramic satellite images taken by  
163 American spy satellites between 1971 and 1984. Their accuracy on the ground ranges from 1.20 to 0.60  
164 metres.

165 In addition to the three settlement units (A - the Tetrarchic Castrum, with its water reservoir, in the  
166 south; B - the Byzantine-Umayyad settlement, immediately to the north of castrum; C - the stylite complex  
167 tower, about two kilometres to the north), the 1974 Hexagon allowed us to better contextualise all of the  
168 archaeological evidence. From the north to the south, these comprised quarries and material extraction



169 sites (marked in yellow on the plan); irrigation and hydraulic systems (dams and canals -D), which describe  
170 the surrounding zone; and a large dam to the NE (about a kilometre and a half from the castrum -E) (Fig.  
171 3). More specifically, we can make out a series of roadways that lead to, cross, or border the Byzantine  
172 hamlet, as well as a network of canals and water storage facilities southeast and east of the castrum. The  
173 northernmost component, the stylite tower complex, clearly displays canal-dam systems.

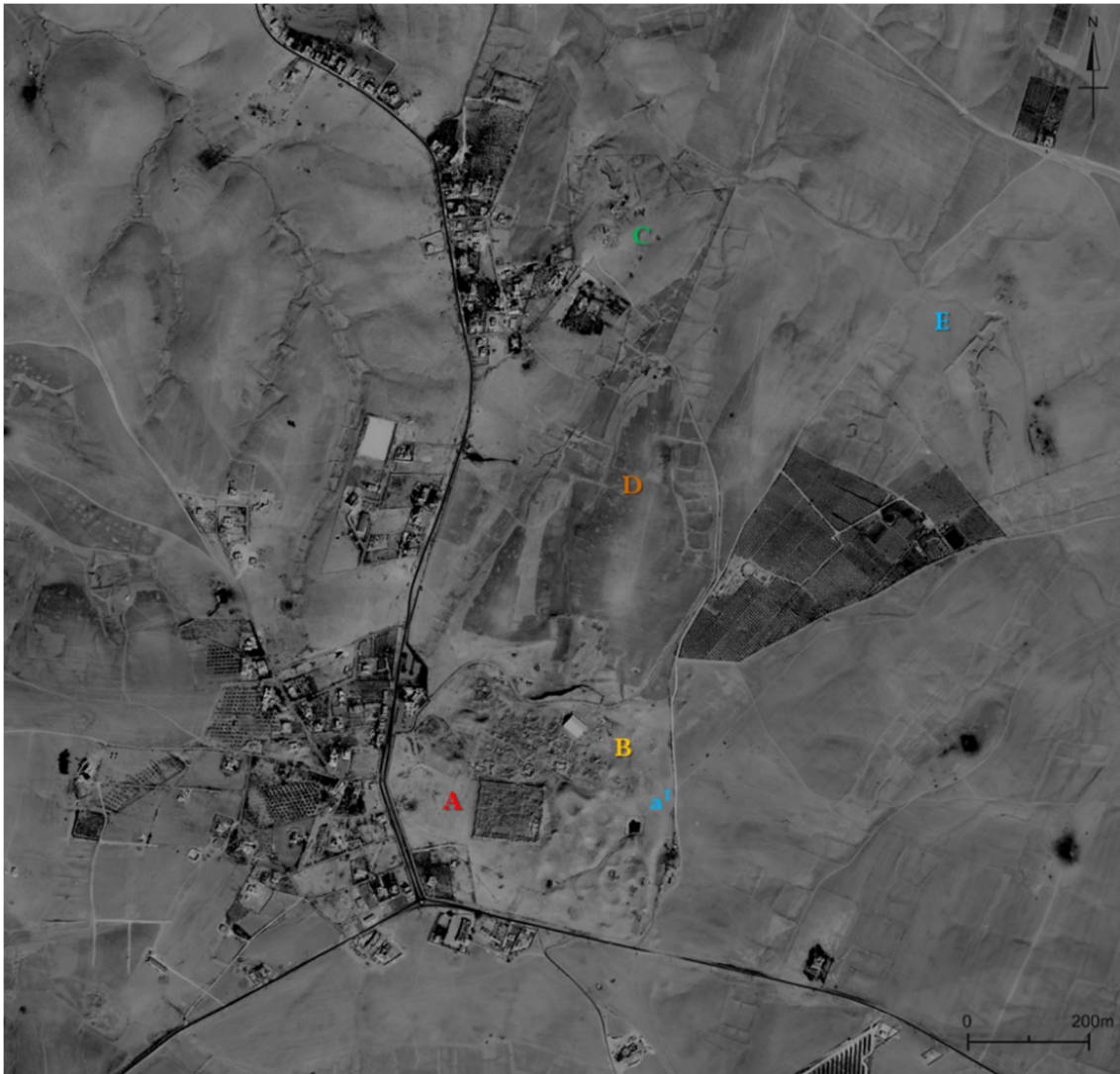


174 **Figure 3** - Umm ar-Rasas. Hexagon KH9 images 1974/12/01, ground resolution: 1.20-0.60 m.  
175 Featured: **A** Roman castrum; **a<sup>1</sup>** hydraulic reserve; **B** Byzantine and Umayyad settlement; **C** Stylite  
176 tower complex; **D** System of irrigated plots (channels and dams); **E** the dam. Quarries and material  
177 extraction points are highlighted in yellow, whilst arrows indicate hydraulic channelling systems.

178 We can assess the conservation state of the traces of the fossilised agricultural ecosystem seen on the  
179 Hexagon by comparing them to a recent and high-resolution satellite image, Pleiades 1-A from 2020 (Fig.  
180 4). Additionally, archaeological features from published maps were georeferenced and vectorized using  
181 the 2020 Pleiades-1A. Furthermore, it was essential for validating, georeferencing, and vectorizing any data  
182 obtained through on-site remote sensing analysis.

183 In order to make archaeological and paleoenvironmental traces and remains more legible, the Pleiades-  
184 1A satellite image was lastly processed utilising data fusion and different enhancing techniques.

185  
186 The image processing of optical satellite data, carried out using specific software in order to facilitate  
187 the identification and examination of archaeological marks and anomalies, represents one of the  
188 possibilities offered by the remote sensing application for archaeology.



**Figure 4** - Umm ar-Rasas. The Pléiades 1A satellite's image acquired on October 30, 2020, ground resolution 0.50m. Featured: **A** Roman castrum; **a**<sup>1</sup> hydraulic reserve; **B** Byzantine and Umayyad settlement; **C** Stylite tower complex; **D** System of irrigated plots (channels and dams); **E** the dam. The hydraulic channelling systems remain visible, albeit less prominent than depicted in the Hexagon image.

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194 A satellite image is a matrix of numerous pixels, and the value of each is related to the solar energy  
195 reflected by the corresponding portion of the earth's surface. This energy is divided into various bands of  
196 the electromagnetic spectrum: a small portion of this radiation, divided into the blue, green, and red bands,  
197 gives an image similar to that of an aerial photo; another portion, wider and particularly important,  
198 especially for archaeological studies, is occupied by the Red Edge (720nm) and Near Infrared (840nm)  
199 channels, which allow the investigation of elements and phenomena of the earth's surface otherwise not  
200 visible to the human eye. These two bands are very important for archaeological applications because they  
201 are particularly sensitive to stress factors in vegetation growth, which, as is known, is one of the main  
202 mediating elements of the archaeological features (crop marks). The presence of positive buried ancient  
203 structures (wall structures, floors, ruins) affects the vegetation growth, while the negative archaeological  
204 structures or even paleo-elements of the ancient landscape (ditches, canals, excavated trenches, but also  
205 depressions and paleo-riverbeds) favour full vegetation growth thanks to ideal conditions in the humus soil  
206 layer that is very drained of humidity.

207 Over the years, numerous methodologies and techniques have been developed to improve these  
208 images, i.e., processing classes that operate on the particular radiometric, spectral, and geometric  
209 properties of satellite data (Lasaponara, Masini 2012). These elaborations are necessary to increase the  
210 readability of the images and to better discriminate small differences in tone and colour, which, as is well



211 known, are useful indicators in the identification of marks related to buried or semi-surfaced ancient  
212 structures.

213 Therefore, the availability of two very high-resolution satellite images that capture the Umm er-Rasas  
214 area - the first image acquired on October 30, 2020, by the Pléiades 1A satellite and the other acquired on  
215 November 11, 2022 by the Pléiades Neo-4 satellite - has allowed us to test the potential of remote sensing  
216 applications through specific data processing chains for the investigation of the ancient topography of the  
217 site and its territory. Compared to its predecessors Pléiades constellation, which provides four  
218 multispectral bands (Blue, Green, Red and Near Infrared) (Pléiades satellites provide images with a  
219 resolution of 0.5 m in panchromatic mode and a resolution of 2 m in multispectral mode,  
220 <https://earth.esa.int/eogateway/catalog/pleiades-esa-archive>), Pléiades Neo images have a better spatial  
221 resolution and have two additional bands, the Deep Blue and the Red Edge, thus adding important  
222 information on the earth's surface characteristics (Pléiades Neo satellites provide images with a resolution  
223 of 0.3 m in panchromatic mode and a resolution of 1.2 m in multispectral mode,  
224 <https://earth.esa.int/eogateway/missions/pleiades-neo>).

225 Pléiades Neo data products are characterised by two images: the RGB image, with Red, Green and Blue  
226 channels, and NED image, with and Near-infrared, Red Edge and Deep Blue channels. As anticipated, Red  
227 Edge is very important for archaeological applications because it is used for analysis of vegetation status  
228 through detailed photosynthesis characterization. Thanks to the ready availability of the images in  
229 Standard Ortho mode (the product is a georeferenced image in Earth geometry and is corrected from  
230 acquisition and terrain off-nadir effects), the pre-processing operations, which involve the geometric and  
231 radiometric correction of the image, have been skipped.

232 For the two images of Umm er-Rasas, the most performing processing chains were then applied for the  
233 identification of the archaeological traces and are already widely used in consolidated remote sensing  
234 studies applied to archaeology: the RGB Colour Composite, the Datafusion and the Principal Component  
235 Analysis. The software used was ENVI 4.7. A necessary and preparatory first step to the subsequent image  
236 processing phases was a qualitative examination based on the visual inspection of each band.



237 **Figure 5 - Umm er-Rasas area in the panchromatic band of Pléiades 1A image.**



238 This phase was necessary to verify the visibility of the different types of traces and their immediate  
239 surroundings and to evaluate which bands guarantee more effective discrimination of their spectral or  
240 radiometric separability. The evaluation showed that, to the detriment of the spectral information, the  
241 panchromatic band proved to be very useful in the identification of the micro-reliefs produced by buried  
242 or semi-buried ancient structures because its very high spatial resolution allows the detailed visualisation  
243 of the micro-reliefs (Fig. 5). On the other hand, the spectral bands, in particular the near infrared, the red  
244 edge, and the red, allow us to investigate characteristics of the soil surface, such as the surroundings of  
245 buried elements that appear more vegetated or humid. Once the properties of each band have been  
246 examined in depth, the effective processing chain has begun.

247 Among the most basic processing techniques, there is undoubtedly the RGB Colour Composite, which  
248 allows viewing the image with a different order of band overlapping, useful for perceiving some  
249 information better than others. So, the image is displayed with an appearance similar to what the human  
250 eye perceives in the "true colour combinations", while in other combinations, called "false colour  
251 combinations", the near infrared or red edge band, invisible to the human eye, appears in place of the red  
252 and green bands.

253 In the case of the Umm er-Rasas site, the simple composition of bands with false colours facilitated,  
254 making it more immediate, the preliminary visual analysis of the more humid and vegetated surfaces,  
255 normally difficult to identify in these geographical contexts characterised by very arid conditions but  
256 potentially indicative of disappearing elements of the ancient landscape. This result is particularly clear in  
257 the false-colour composition of the Pléiades 1A image, acquired in October, a period when the soil is not  
258 excessively dry. The infrared band (visible in red) and the red band (visible in green) show a consistent  
259 network of small wadis exploited through reclamation and regimentation works to obtain cultivable areas  
260 (Fig. 6A). While other interesting features are more evident in the false colour composition of the Pleiades  
261 Neo image, the small vegetated and rounded depressions that are highlighted within the remains of the  
262 buried village could correspond to disused cisterns (Fig. 6B).



263 **Figure 6** - Umm er-Rasas. RGB Colour Composite in false colour of the Pléiades 1A image showing the  
264 general view of the Umm er-Rasas area, and of the Pléiades Neo-04 image showing a detailed area  
265 of the late antique castrum and the Umayyad village.

266 Other image processing techniques, useful for obtaining the maximum information in qualitative and  
267 quantitative terms, were therefore employed. The datafusion technique of the panchromatic and  
268 multispectral data of the Pléiades Neo-04 of 2022, exploiting the high spatial resolution of the  
269 panchromatic image (0.30 m) and the high spectral resolution of the multispectral image (6 bands), was  
270 performed to obtain an optimal result. This operation, carried out using the "Gram-Schmidt" method of  
271 the ENVI routine, produced a "pansharpened image", a new image where the spectral resolution of the

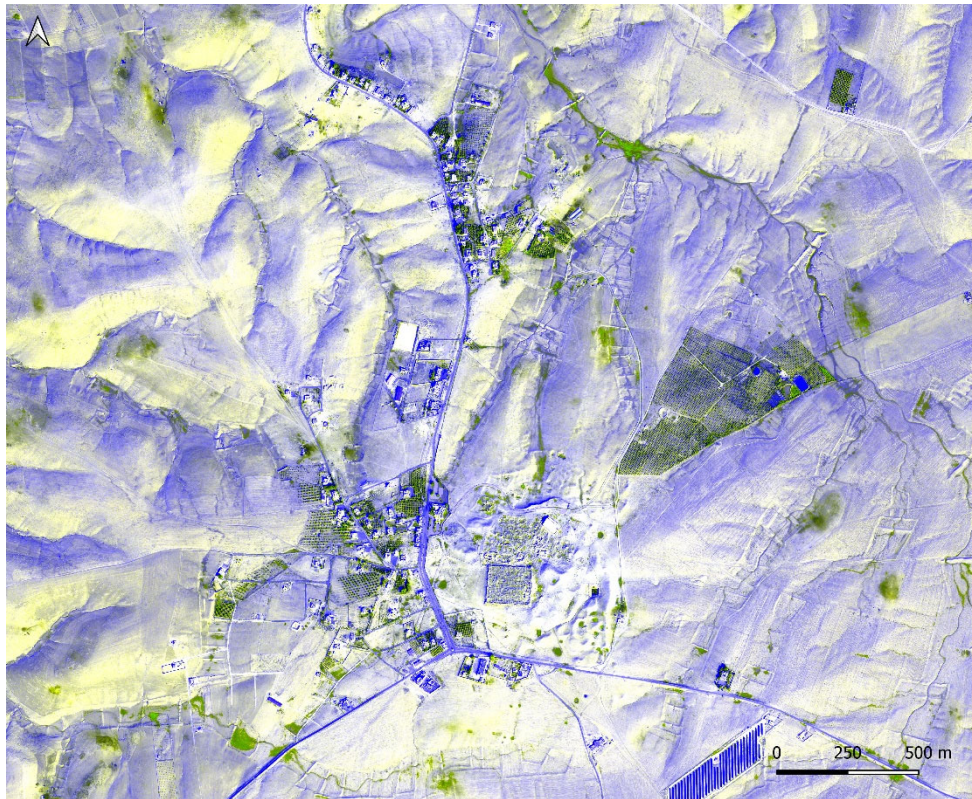


272 colour bands has been adapted to the resolution of the panchromatic data (Lasaponara, Masini and  
273 Scardozi 2007, pp. 213-217).

274 The result obtained was a good qualitative image for the discrimination of spatial details and a good  
275 quantitative image for the discrimination of a series of crop marks and dump marks highlighted, as  
276 mentioned before, by the responses in the infrared band, the red edge, and red (Fig. 7).



277 **Figure 7** - Pansharpened product of the datafusion technique by panchromatic and multispectral data  
278 of Pléiades Neo-04 image.



279 **Figure 8** - RGB colour composite in false colour of the Pléiades Neo-04 multispectral image processed  
280 by PCA technique. R: PC1 band of RGB data; G: PC1 band of the NED data; B: PC2 band the NED data.



281 The choice to apply Principal Component Analysis technique (PCA) using the pansharpned bands and  
282 to minimise the redundancy in information in some areas seemed quite effective (Lasaponara, Masini,  
283 Scardozi 2010, pp. 486-490). Among the six new bands obtained, the best were the first (PC1) and second  
284 (PC2) bands of the RGB image and of the NED image (Fig. 8).


285 At this point, some operations were tested to combine the products obtained from the individual  
286 enhancement techniques into a new false colour composition; this operation does not improve the analysis  
287 of the anomalies much, but overall it offers a more immediate perception of some feature traces.

288 Finally, since the outputs of the various processing products were exported in geotiff format, their  
289 loading into a GIS platform was sufficient to implement the information layers of the project. After a further  
290 visual examination and interpretation of the images on the basis of other contextual information, the traces  
291 and anomalies identified were vectorized.

## 292 Results

### 293 *From the air to the ground*

294

295 The remote sensing analysis was then followed by the verification of all the proof discovered from  
296 above. All quarries, irrigation systems, and water canalization have been mapped in detail. Forty reservoirs,  
297 dozens of quarries, and dozens of canal systems have been mapped in total. In addition, hypogean settings  
298 probably going back to the Bronze Age, such as those found in Amman's Citadel, have been identified . One  
299 thing to note about the water reservoirs: we recognised their primary role as a quarry in at least five or six  
300 of them.

301 Finally, a fantastic result was obtained with the discovery of a dam to the north-east of Umm ar-Rasas.  
302 It was made possible by Hexagon analysis and a later check survey on the ground. The dam has not been  
303 photographed by Stein and has never been studied before. The Jordanian Department of Antiquities itself  
304 didn't know about the existence of this dam. From the ground, we were able to determine that the dam's  
305 construction period for building materials, dimensions, and block fabrication can most likely be considered  
306 contemporaneous with the castrum or of the same period as the castrum.

307

### 308 *Laser scanner and photogrammetric surveys*

309 They were then carried out during the Kastrum Project 2021 and 2022 missions: preliminary  
310 architectural and stratigraphic analysis; study and documentation (photographic and graphic) of  
311 architectural components; photogrammetric surveys and processing of the walls (tests); laser scanner  
312 surveys and processing; archeological-architectural surveys inside the walls.

313 For the research and documentation of the castrum walls, a special form has been developed.

314 Despite significant obstacles, photogrammetric acquisition of the castrum's exterior walls began in  
315 2021. Difficulties brought on by the following factors: a large castrum (159 x 138 m approx.); numerous  
316 collapses; and (of course) the Mission's short duration.

317 Even so, a first photogrammetric test of the walls' full external circuit has been completed (Fig. 9).



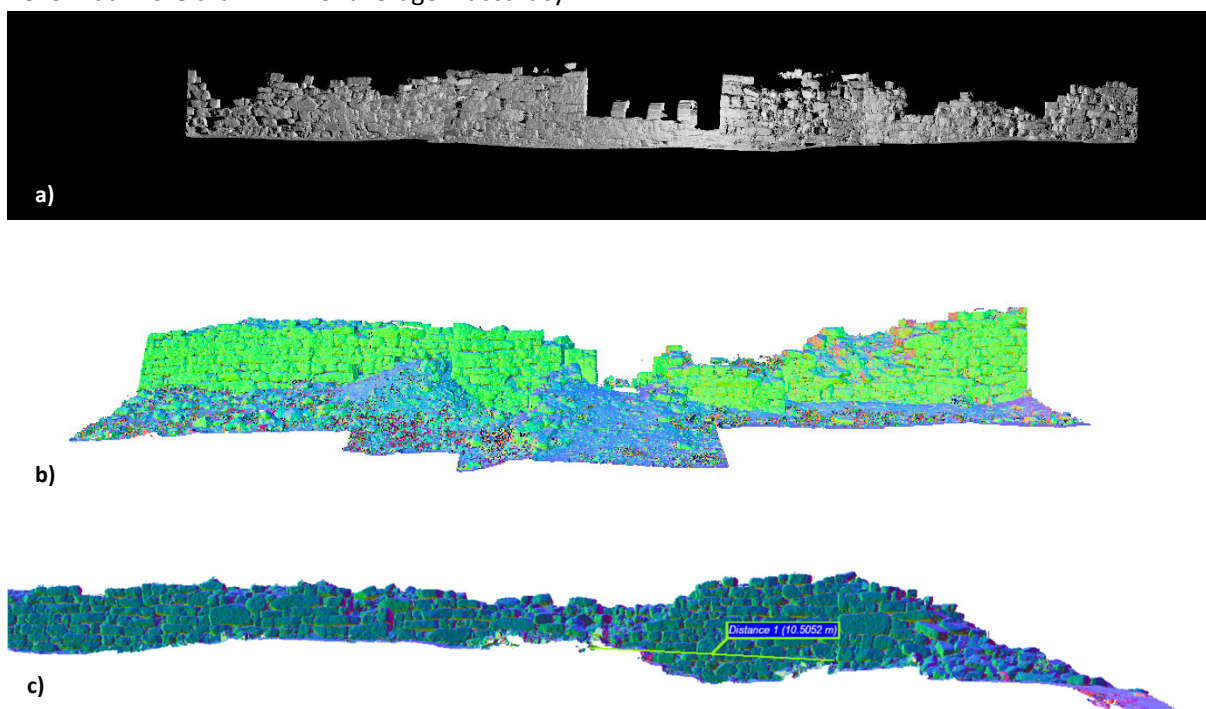
318 **Figure 9** – Kastrum Project 2022 **a)** Print screen processing of all wall reliefs completed; **b)** Detail of  
319 the west wall, print screen processing in progress

320 As a result, a first laser scanner acquisition campaign was run during the 2022 expedition, allowing  
321 accurate documentation of the masonry and the castrum's state of conservation. Two pieces of equipment,  
322 the FARO Focus 3D S120 (which can scan objects up to 120 metres away and measure at speeds of up to  
323 976,000 points per second, with an optimal distance of 50 to 60 metres) and the FARO Focus X 330 HDR  
324 (can scan objects up to 330 metres away and measure at speeds of up to 976,000 points per second, with  
325 an optimal distance between 208 and 290 metres), were used to conduct the laser scanner surveys. Two  
326 instruments were employed to expedite the measurements due to the limited amount of time available.  
327 One point every three millimetres at a distance of ten metres was the resolution that the two laser scanners  
328 had been calibrated to.

329 The two laser scanners were positioned less than 50 metres from the castrum walls and 10 metres  
330 apart from one another (they were spaced this way to provide sufficient scan overlap). This shows that the  
331 two instruments performed at their highest level.

332 The scans were processed using Reconstructor 4.4, a software created by a Brescia University spinoff.

333 Before being registered automatically, the scans were manually pre-registered. This procedure has  
334 never had more than 2mm of average inaccuracy.



335 **Figure 10 – a)** Results of the data processing phase: Ortho-image of East Gate; **b)** Noth Gate. Data  
336 processing phase. Colour mapping: inclinantion; **c)** a section of West wall. Colour mapping:  
337 inclinantion.

338 However, this is a comprehensive survey that enables us to create a 3D model that can be remotely  
339 measured and analysed (Fig. 10).

## 340 Discussion and upcoming perspectives

341 In summary, the material, construction, stratigraphic, and structural degradation characteristics of the  
342 masonry were identified. We also finished the photogrammetric and laser scanner surveys of the exterior  
343 walls in order to accurately record the structures, create a 3D model that can be remotely measured and  
344 analysed, plan future research and preservation efforts, and improve accessibility.

345 About the systematic analysis of (unpublished) remote sensing data, both historical and recent, in  
346 terms of a large-scale question: the remote sensing analysis allowed the identification of new  
347 archaeological sites (hypogeum environments/graves of the Bronze Age emptied and used as  
348 dwelling/shelter in Umayyad times until recent times, dams and the dam, etc.); the remote sensing analysis



349 allowed the identification and study of the historical landscape (specifically on water channels, dams,  
350 quarries, reservoirs, and systems of irrigated plots) and the connection with the Byzantine-Umayyad  
351 settlement. In terms of a smaller-scale question (about the castrum), the analysis of remote sensing data  
352 (particularly historical data) combined with a preliminary survey on the ground enabled the identification  
353 of ancient wall remains (Fig. 11).



354 **Figure 11** – Umm ar-Rasas. Highlighting the site where remains of ancient walls have been found,  
355 either from the earlier and smaller fortress of Umm ar-Rasas (Severan period) or from the same  
356 period as the castrum wall (Tetrarchic period).

357 These walls could be associated with the castrum or with a previous and smaller fortification (Severian  
358 ages?). In this regard, a fragmentary Latin inscription indicating a Roman presence in 306 and 307, as well  
359 as many pottery shards from the 2nd-3rd centuries AD, have been found (Scarpati 1991; Lewin 2001; Bujard  
360 2008, p. 22, 35). After all, there are several references in the bibliography to Severan fortresses that were  
361 later incorporated into much larger Tetrarchic fortifications (Arce 2010; 2015).

362  
363 ~~In closing~~, Umm ar-Rasas has recently been used as an experimental lab for interdisciplinary searches.  
364 Research aimed at understanding and ~~maximising a site with a lot of potential. There's still a lot to do.~~

365 Regarding the prospects for the future, aerial photogrammetric and laser scanner surveys will be used  
366 to finish the surveys (we would have preferred to present the results here, but it was not possible due to  
367 issues with permits from the Jordanian Department of Antiquities) and in order to improve the map of the  
368 military camp during the Tetrarchic period. We plan to use electrical resistivity tomography to investigate  
369 the area inside the castrum walls in order to find and confirm structures that were present at the time the  
370 castrum was built as well as to find and confirm the presence of earlier structures (previous fortification).

371 We intend to define the extent of the Byzantine and Umayyad settlement in the north, confirm the  
372 existence of walls surrounding the Byzantine settlement, and investigate the hydraulic systems of the

373 settlement using geophysical surveys, processing, and archaeological interpretation of new remote sensing  
374 data.

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