[Supplementary material]

New discoveries at Mokarta, a Bronze Age hilltop settlement in western Sicily

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Integrated prospection summary

For the survey at the Castello di Mokarta settlement core, a combination of remote sensing data evaluation, historic terrain modelling, geophysical prospection, and soil coring and geochemistry was used to obtain data for this evaluation, with the main goal being to identify new structures and human activity zones within the site. Integrated prospection survey blends a suite of non- or minimally invasive techniques designed to provide a range of information about extent and condition of archaeological remains on and below the modern ground surface, past and present environmental conditions, and human land use. These may vary based on environmental and archaeological conditions present at a given location, as well as on research questions asked. Together, these techniques provided a rapid overview of aspects of the site's subsurface extent in the vicinity of the archaeological park. Details of the approaches are provided below, with a corresponding summary and interpretation in the main text of the article. All figure numbers refer to figures in the main text.

Analysis of historic aerial imagery

Historic aerial imagery has played an important role in our understanding of developments that may have affected the preservation of the archaeological record at Mokarta. Prior to conducting the geophysical prospection and soil sampling surveys, vertical and oblique aerial images, satellite and land cover data collected over the last 40 years were consulted to gain an understanding of land use change and indications of potential additional archaeological features. Principal image sets used in this study consisted of vertical and oblique images covering a period of over 40 years and imagery and land cover data available through the Italian National Geoportal and Google Earth (Table S1) (Doneus 2007; Geoportale Nazionale 2019; Google Earth 2019). The older aerial photographs capture the transformation that the agricultural landscape was undergoing in the region, when the hilltop complex was being modified for the planting of vineyards. It appears that this change, which occurred just prior to the collection of the 1975 images, had a major impact on the topography of the settlement complex. Oblique images depict the area nearly 30 years later, after the establishment of the archaeological park, in the midst of archaeological excavations that began in the early 1990s (Figure 3). While the 1975 image set does not indicate the presence of any buried structures, additional potential buried structures manifesting as cropmarks in the vegetation to the north of the excavations at *Castello di Mokarta* were identified through visual inspection of the 2004 image set (Doneus 2007: 280) (Figure 4 top). Although outside the archaeological park, this area also falls within the initial boundary of the settlement core as established via surface survey (Mannino & Spatafora 1995: 12).

Table S1. Principal remote sensing image data used in this study.

Data set	**Date**	**Time of year**	**Type**	**Platform**	**No. of images**	**Overlap %**
0120040501	2 May 2004	Spring	Oblique colour digital images	DSLR camera	22	> 70
257-XII-670-672 257-XIII-664-666	9 May 1975	Spring	Vertical B/W photographs	Vertical mapping camera	6	60 (front)/30 (side)
National Geoportal WMS	1988, 1994, 2000, 2006, 2012	Various	Vertical colour; B/W photographs	Vertical mapping camera	Orthomosaic	n.a.
Google Earth Pro	2004, 2006,	Spring–Autumn	Vertical colour	Satellite (various)	Orthomosaic	n.a.

	2010, 2011, 2013, 2015, 2016, 2017		digital images			
Datas	**Altitude (m asl)**	**Focal length/resolution**	**Products**	**Use**	**Source**	
0120040501	600	35mm/12mp	hDEM; Orthomosaic	Terrain analysis; landscape change assessment	University of Vienna Aerial Archive	
257-XII-670-672 257-XIII-664-666	2600	152.55mm/1:15 000	hDEM; Orthomosaic	Terrain analysis; landscape change assessment	Istituto Geografico Militare	
National Geoportal WMS	Various	1m–0.50m spatial	Orthomosaic (via WMS)	Landscape change assessment	Geoportale Nazionale	
Google Earth Pro	Various	1m–0.50m spatial	Orthomosaic (via WMS)	Landscape change assessment	Google Earth	
B/W = Black & White; DSLR = digital single-lens reflex,; m asl = meters above sea level; m = metres, mm = millimetres; mp = megapixel; n.a. = not applicable; WMS = web map service						

To assess the quantity of recent natural and/or anthropogenic topographical change, historic imagery was used to extract 3D terrain information corresponding to the dates the images were taken. Following procedures established in Sevara *et al*. (2018), 0.50m spatial resolution historic digital elevation models (hDEMs) were calculated from the 1975 and 2004 image sets. Although vegetation in the 2004 imagery prohibits complete reconstruction of the ground surface, there is sufficient exposed ground to establish an initial estimate of terrain change in critical sections of the settlement. Of particular interest was the effect that repeated ploughing might have had on soil retention and, by proxy, the likelihood of subsurface preservation of archaeological remains. Our results indicate that while there appears to be less than 0.50m of change within the central (unexcavated) segment of the archaeological park, there is up to 0.80m of erosion at the north-western edge, and some potential accumulation of soils and debris among the vegetation on the south-western edge of the plateau. More significant loss appears to be happening outside the park boundaries in areas not covered by vegetation, evidenced by the estimated loss of over 1 m of soil in areas upslope, to the northeast of the archaeological park (Figure 4 bottom).

Geophysical prospection

Although there is evidence of settlement and mortuary activity at several locations across the hilltop complex, for permitting reasons our work focused on the accessible areas in the archaeological park near the excavations at the Castello di Mokarta. The geophysical prospection survey, conducted over seven days in October of 2017, consisted of combined handheld magnetometry (fluxgate gradiometry) and Ground Penetrating Radar (GPR; details in Table S2). Altogether, 2.4ha was surveyed within the archaeological park.

Table S2. Parameters for geophysical prospection equipment & survey.

System	Type	Area surveyed (ha)	Measuring Grid (m)	Resolution/ frequency	No. sensors/ antennas	Georeferencing
Förster Ferex	Fluxgate magnetometer	1.8	0.16 × 0.5	0.1 nT, 20 meas/sec.	4 sensors	Post-processed GNSS
Sensors & software PulseEkkoPro	Ground penetrating radar	0.6	0.05 × 0.25	500 MHz	3 antennas	RTK GNSS
ha= hectares; m= metres; nT= nanotesla; MHz = Megaherz; RTK = Real-time kinematic; GNSS = Global Navigation Satellite System.						

The magnetometry survey yielded a significant amount of data regarding potential archaeological features in the unexcavated portion of the archaeological park. The presence of a modern iron flagpole and the remains of a water tank unfortunately masked the magnetic signatures of any potential archaeological features in those areas. Despite this interference, the magnetometry results indicate at least 43 anomalies that could be burned clay or hearth features, with another 23 anomalies that could be clay floors or features that have not been severely burned. Further contrasting anomalies surrounding some of these could represent wall structures similar to the limestone walls exposed in the excavation areas. Additionally, several linear anomalies could be further walls or paths (Figure 5).

Due to the presence of numerous stones on the ground surface and the need for the GPR antenna to be in close contact with the earth, it was only possible to survey a portion of the area covered by the magnetometry survey. Nevertheless, faint traces of circular structures can be identified, particularly in the western section of the survey area. The results may be faint due to the relatively low difference in compaction between the features and the surrounding soil, or to topsoil characteristics that lead to absorption and dispersal of the radar signal. Although faint, many of the anomalies identified do correspond to structures identified in the magnetic data (Figure 6). Features and structure identified in the GPR data block appear to be between 0.50 and 1.4m below the modern ground surface.

In total, the combined results from the magnetic and GPR surveys indicate the remains of at least 37 additional circular huts with pincer-shaped antechambers, some with associated rectangular outbuildings. These huts appear to have interior diameters ranging between 2.9 and 7m. with most between 4.9 and 5.3m, similar to those already excavated (Nicoletti & Tusa 2012b: 906). Several linear features, possibly external walls, rectilinear outbuildings or paths comparable to those in the excavated areas can also be seen. Furthermore, there are magnetic anomalies that we have not yet been able to assign to a structure. Additionally, at least two larger rectangular structures that appear similar to the one exposed in the western excavation area can be seen amongst the other features (Figure 7).

Soil coring and geochemistry

Soil coring and sampling for archaeological soil chemistry was conducted in conjunction with the geophysical survey. Samples were taken from 21 locations (Figure 7) using a hand-operated Oakfield soil probe with a 20 mm diameter sample tube. Soils were described in the field based on soil colour, texture, boundaries and inclusions. Site sediments are relatively shallow, brown to reddish-brown, stony, friable silty-loam, sandy-silt and coarse-grained regosols. No well-defined soil horizons or evidence for soil formation was identified; some colluvial deposits were documented in low areas along the south side of the archaeological park and at the base of the slope at the eastern border of the archaeological park. Most cores contained cultural material in the form of badly degraded ceramics and charcoal.

Thirty-five samples of approximately 100g were taken from the 21 cores and analysed for available phosphates (Pav), pH and carbonates: 26 were taken to characterize unexcavated portions of the site, and 9 to aid in the interpretation of specific geophysical anomalies. Pav values were obtained using a ring-chromatography, or spot, test (Eidt 1973; Salisbury 2012), pH was measured with a calibrated pH meter using a 1:1 soil:water mix, and carbonate content was classified based on reaction with HCl at a 7:20 ratio of 6mol HCl and distilled water.

Available, or labile, phosphates (Pav) in soils are enriched primarily through the deposition of organic matter, especially bone, blood, and dung, and high levels of phosphorus therefore strongly correlate with human activity. Phosphates typically remain fixed in the soil and are not easily removed through daily processes of farming or natural chemical activity. Ring-chromatography tests involve fast, weak-acid digestion of sediments and the addition of molybdenum blue (ammonium molybdate) to produce blue spots with radiating lines. Relative size and darkness of the blue spot, length of radiating lines, and the time it takes the spot to develop all relate to the amount of Pav in the soil, and reveal phosphate levels relative to other samples in a specific location. Results are ranked 1–5 (method derived from Eidt 1973 with modification by Bjelajac *et al*. 1996), where 1 is no color at all = low and 5 very dark blue = high, providing a semi-quantitative result (Parnell *et al*. 2002; Holliday & Gartner 2007; Salisbury 2012) that can be statistically analysed, mapped, and interpolated.

Pav was consistently high across the site area, with very little horizontal or vertical variability. Soil pH averaged 6.65 with a range of 1.6. All samples were strongly effervescent on reaction with HCl. Stratigraphic descriptions and soil chemistry are presented in Table s3.

Samples in Cores 1–12 averaged 0.33m below the current ground surface. Soils were dry, brown (Munsell 10YR 4/3), stony, friable silty-loam. Fragments of pottery, burnt clay, and charcoal were found in most cores. Pav was moderately-high to high (4–5), and pH was very slightly acidic (pH 6.52).

Cores 13–16 were placed in an "open area" of some 80 m^2 in the geophysical results (Figure 7) to check the stratigraphy and Pav content. Pav from upper and lower samples was moderately-high to high (4-5), with pH of 6.43. Core 17 and 18 were placed on the south side of the saddle, at the most likely point of drainage. Soils here were brown to greyish-brown stony, friable silty-loam with high Pav content.

Cores 19 and 20 were placed over magnetic and GPR anomalies (respectively) that were interpreted as Bronze Age houses. These cores comprised an upper layer of approximately 0.55m of dry, friable, brown, stony silty-loam over cultural fill extending to a depth approaching 1m. Core 21 was placed 5m north-west of Core 20 to examine a dark band observed in the GPR data. A rock impasse was reached at 0.35m depth (Table S3). Elevated Pav across the site, in conjunction with difficulty in sampling Bronze Age surfaces, suggests that the enrichment of phosphates in the upper layers derives from one or more of several possible processes, including erosion of sediments with culturally enriched phosphate from the now stony slope east of the archaeological park, regular grazing and fertilization by sheep in recent decades, and the mixing of organically enriched deposits from the Bronze Age and Medieval occupations when the site was being ploughed. Samples from Bronze Age levels in cores 19 and 20 yielded evidence for Pav enrichment.

Table S3. Core information and soil sample analysis.

<table>
<tr><th>Core no.</th><th>Soil description</th><th>Depth (m)</th><th>No. samples</th><th>Pav values</th><th>pH</th><th>HCl reaction</th></tr>
<tr><td>1–12</td><td>Dry, brown (Munsell 10YR 4/3), stony, friable silty-loam</td><td>0.33 (avg.)</td><td>22</td><td>4/5</td><td>6.52</td><td>4</td></tr>
<tr><td>13–16</td><td>Brown (10YR 4/3) stony sandy-loam in upper part; dark greyish-brown (10YR 4/2) stony sandy-silt in the lower part; rock impasse</td><td>0.45 (avg.)</td><td>8</td><td>4/5</td><td>6.43</td><td>4</td></tr>
<tr><td>17</td><td>Brown (10YR 4/3) soft, stony silty loam</td><td>0.76</td><td>2</td><td>5/5</td><td>-</td><td>4</td></tr>
<tr><td>18</td><td>Greyish-brown (10YR 5/2) silty-loam, gravel; rock impasse</td><td>0.44</td><td>2</td><td>5/4</td><td>-</td><td>4</td></tr>
<tr><td rowspan="3">19</td><td>Brown (10YR 4/3) stony silty loam in the upper part;</td><td>0.56</td><td>3</td><td>5/5/5</td><td>6.90</td><td>4</td></tr>
<tr><td>Greyish-brown (10YR 5/2) compact silty-loam in the middle;</td><td>0.75</td><td>1</td><td>5</td><td>6.31</td><td>4</td></tr>
<tr><td>Brownish fill in the lower part</td><td>0.95+</td><td>1</td><td>5</td><td>7.20</td><td>4</td></tr>
</table>

20	Brown (10YR 4/3) soft silty loam in the upper part;	0.30	0	-	-	-
	Brown (10YR 4/3) granular, stony silty-sand in the middle part;	0.55	2	4/4	6.90	4
	Brownish fill in the lower part	0.82+	2	4/2	-	4
21	Brown (10YR 4/3) sandy-silt with rock fragments; rock impasse	0.35	0	-	-	-
Pav: 1=low; 2=moderately-low; 3=moderate; 4=moderately-high; 5=high Pav = available phosphates		HCl reaction: 4=strongly effervescent; bubbles form low foam HCl = 6mol Hydrochloric acid diluted 7:20 with distilled HCl				

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