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Trmun (north-eastern Italy): Multi-scale remote and ground-based sensing of a Bronze Age and post-Roman fortification

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A R T I C L E I N F O

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A B S T R A C T

We have used multi-scale remote sensing to investigate a little known archaeological site in northern Istria (north-eastern Italy). Airborne Laser Scanning (ALS) and archaeological field surveys have allowed us to identify the position and extension of a large Protohistoric hillfort. Its highest and best-preserved sector, corresponding to a modest elevation at the eastern margin of the settlement, has been further investigated through thermal imaging, high-resolution ALS, drone Structure from Motion (SfM) photogrammetry and 3D Ground Penetrating Radar (GPR), leading to a detailed identification of unexpected buried features. An excavation campaign conducted in 2022 has confirmed the remote and ground-based sensing results. This excavation has led to the discovery of a Bronze Age fortification, partially reused and modified with the construction of 2 or 3 square towers during the post-Roman period. Our results demonstrate that the combined analysis of multi-scale remote and ground-based sensing is crucial to planning archaeological exploration in the field. Digital methods provide high-resolution topography and detect buried features that assist in monitoring and managing cultural heritage.

1. Introduction

The combined analysis of multiple remote and ground-based sensing data, such as those provided by Airborne Laser Scanning (ALS), 3D Ground Penetrating Radar (GPR), Structure from Motion (SfM) photogrammetry and other non-destructive techniques, has dramatically changed the detection, documentation and understanding of archaeological features and sites. The integration of such techniques can provide high-resolution topography and associated buried anomalies related to archaeological features, including their spatial relationship with natural and anthropogenic land forms (Campana and Piro, 2009; Bernardini et al., 2013; Piro and Goodman, 2013; Opitz and Cowley, 2013; Bernardini et al., 2015; Forte and Campana, 2017; Campana, 2018; Leucci, 2019; Luo et al., 2019; Gaffney et al., 2020; Hadjimitsis et al., 2020; Bernardini et al., 2021a).

In this paper, we discuss the investigation of a poorly known archaeological site in north-eastern Italy through the integration of airborne and ground-based high resolution remote sensing techniques. ALS-derived images, combined with archaeological field surveys, carried out in the framework of the *Karstscape* project, have allowed for reconstructing the original plan of a large Protohistoric hillfort. Its highest and best-preserved sector, corresponding to a moderate elevation at the eastern margin of the settlement (hereafter defined as Trmun hilltop), has been further investigated through ALS, SfM and GPR, leading to the detailed identification of unexpected archaeological features. Moreover, the quality of the obtained data has been evaluated by comparing them with the results of an archaeological campaign carried out in summer 2022.

1.1. Geographical, geological and archaeological background

The Trmun site is located in north-eastern Italy on the Monte d'Oro marly-arenaceous ridge, which is part of the Eocene Flysch formation (Jurkovšek et al., 2016). This ridge gradually slopes from its highest

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point, the Socerb village in Slovenia, towards the Stramare landing place in Italy (Fig. 1). Running approximately in an east–west direction, the ridge, corresponding to the northernmost part of the Istrian peninsula, faces the Gulf of Trieste and divides the Rosandra Valley to the north from the Ospo Valley to the south. It is crossed by important routes from the coast to the interior (with east–west direction) and from the Trieste area to Istria (with north–south direction). Its strategic geographic position partially explains why the area is rich in fortified archaeological sites spanning from Protohistory (from the Early Bronze Age, approximately between 1800 and 1650 BCE, to the late Iron Age; Mihovilić, 2013; Borgna et al., 2018) and the early Roman period (from the beginning of the 2nd century BCE to the mid-1st century BCE; Bernardini et al., 2013, 2015, 2021b) to late Medieval and Modern times (Colombo, 1999).

Trmun is a 40 m-large sub-circular hilltop, elevated a few meters from the surrounding area, and marks the highest point of the ridge from the coast to the Caresana village (Fig. 2). Interestingly enough, Trmun is a Slovenian dialectal term that derives from an ancient Romance influence and it is likely connected to the concept of a border (Crevatin, 2020).

The topography of the hilltop that is characterized by a flat central area with raised edges, along with the presence of few surface-level Protohistoric pottery fragments, had suggested Trmun could be a Protohistoric hillfort (Flego and Župančič, 1991). However, the chronology, extension and plan of the original settlement had never been defined before this study. Such information is crucial to evaluate the function and archaeological significance of the settlement, especially considering that numerous Protohistoric hillforts are located within close proximity along the Monte d'Oro ridge (Fig. 1c). The Monte d'Oro hillfort, active from the Early Bronze Age to the Iron Age, is located just 1 km west of Trmun, while two other important hillforts, namely the Prebeneg and Socerb settlements, are located about 3 km east (Marchesetti, 1903; Flego and Župančič, 1991; Flego and Rupel, 1993), where the Monte d'Oro ridge joins the Mali Kras plateau. This plateau is located just east of the Socerb hillfort (Fig. 1). In the absence of stratigraphic excavations, the Socerb hillfort is attributed to the Bronze and Iron Ages primarily based on the surface pottery findings. A necropolis associated to this hillfort (about 0.5 ha wide), has been dated to a time spanning between the 6th century BCE and the 1st century CE (Dugulin et al., 2002). No chronological data are available for Prebeneg, but, considering its proximity to the Socerb fortification, it is likely that they were connected.

2. Materials and methods

2.1. Airborne Laser Scanning

ALS data, originally collected by the Helica Company for the Regione Friuli Venezia Giulia, were acquired using a Laser Terrain Mapper Optech 3100 and other instruments mounted onto a helicopter. The data of the studied area, featuring no less than 16.5 points per square meter, were processed using the free open-source software System for Automated Scientific Analyses (SAGA). The LAS files were imported into SAGA as point clouds, from which the points belonging to the ground were extracted and then interpolated to produce 0.5 m-resolution Digital Terrain Models (DTMs). Similar DTMs can be directly downloaded from https://eaglefvg.regione.fvg.it.

All DTMs were then processed using the open-source QGIS software and Relief Visualization Toolbox (Zakšek et al., 2011; Kokalj and Somrak, 2019), to produce a number of different visualizations (multiple and combined shaded reliefs at different light conditions, slope and contour maps). The resulting maps, as well as the available historical cartography – in particular, a version of the 19th century Franciscan Cadastral Maps – were imported and analysed in QGIS. The Franciscan Cadastral maps encompassed all lands under the Habsburg Monarchy in the 19th century, which at the time included the area of Friuli Venezia Giulia.

All of the main features identified in QGIS were checked on the ground through field walking to verify, when possible, their building technique and degradation, and to pinpoint potential stratigraphic relations with other structures and possible associated archaeological materials following the methodology developed in other areas of north-eastern Italy, Slovenia and Croatia and described in previous studies (Bernardini et al., 2013, 2015, 2018, 2020, 2021a; Bernardini and Vinci, 2020).

2.2. Drone structure from Motion photogrammetry

A drone (i.e. Unmanned Aerial Vehicle - UAV) survey of the Trmun hilltop was performed in order to produce a high resolution DTM and orthophoto (Eltner et al., 2016). Two separate flights, with the camera aligned perpendicular to the flight path and with a tilt angle of 45°, respectively, were planned with a flight planner software by Aeroscientific (Blackwood, Australia) to ensure a constant Ground Sample Resolution and to optimize the coverage area. Drone pictures were taken via DJI Mavic droneTM (DJI, Nanchan District, Shenzen, China) that is capable of providing 12Mp files with a zoom lens of 24–48 mm. Working with a medium-long focal lens instead of a wide angle permitted a higher flight above vegetation and maintained a high ground resolution (2040 mm/pixel) on a 2973 m^2 area. In order to reduce flight time, 300 orthogonal images and another series of 98 images with the same focal length but different angulations and ground resolutions were taken and processed using Agisoft Metashape (Agisoft LLC, St. Petersburg, Russia, 2019). The images were aligned and a sparse point cloud was generated using high quality settings.

2.3. 3D ground Penetrating Radar

The implementation of efficient and portable multi-antenna (or multi-array) GPR instruments, coupled with accurately synchronized positioning systems (RTK GPS and topographic total stations) correlated with the demand for 3D subsurface imaging are pushing towards a rapidly growing application of 3D GPR techniques to near-surface studies (e.g., Grasmueck et al., 2005; Novo et al., 2008; Böniger and Tronicke, 2010a, 2010b) and in particular to archaeological applications (e.g. Leckebusch, 2005; Trinks et al., 2010; Forte et al., 2021).

The 3D GPR datasets were acquired on a large sector (more than 1.000 m^2) of the Trmun hilltop using the MiniMIRA array GPR (Malå Geoscience, Sweden) equipped with 5 transmitting and 4 receiving 400 MHz shielded antennas, allowing for the collection of 304 parallel profiles with a constant distance equal to 8 cm, corresponding to 38 swaths 56 cm wide. To optimize the spatial resolution, we set a trace spacing also equal to 8 cm, thus obtaining a constant in-line and cross-line coverage.

The system was connected with both an electromechanical odometer for triggering and an RTK GPS for absolute positioning with centimetric accuracy. This permitted an extremely precise topographic correction to the entire GPR volume, and properly reconstructed the real geometry, depth and slope of the buried surfaces.

We applied a standard processing sequence (zero drift removal, background removal, bandpass filtering, amplitude recovery encompassing spherical divergence exponential corrections) to enhance the signal-to-noise ratio. GPR datasets were processed using rSlicers software (DECO Geophysical, Moscow, Russia), as well as an in-house module implemented in Matlab. Swaths were then interpolated. This process allowed us to apply the FK time migration on the whole dataset by means of the Stolt algorithm (Stolt, 1978) after velocity estimation through a dedicated diffraction hyperbola analysis.

A comparison of the standard 2D data and the results obtained with the 3D system at controlled test sites showed that complex near-surface conditions can be hardly, if at all, imaged by the 2D techniques due to the large amount of cross-line information (i.e., out-of-plane reflections and diffractions) recorded in the 2D profile, and are impossible to be

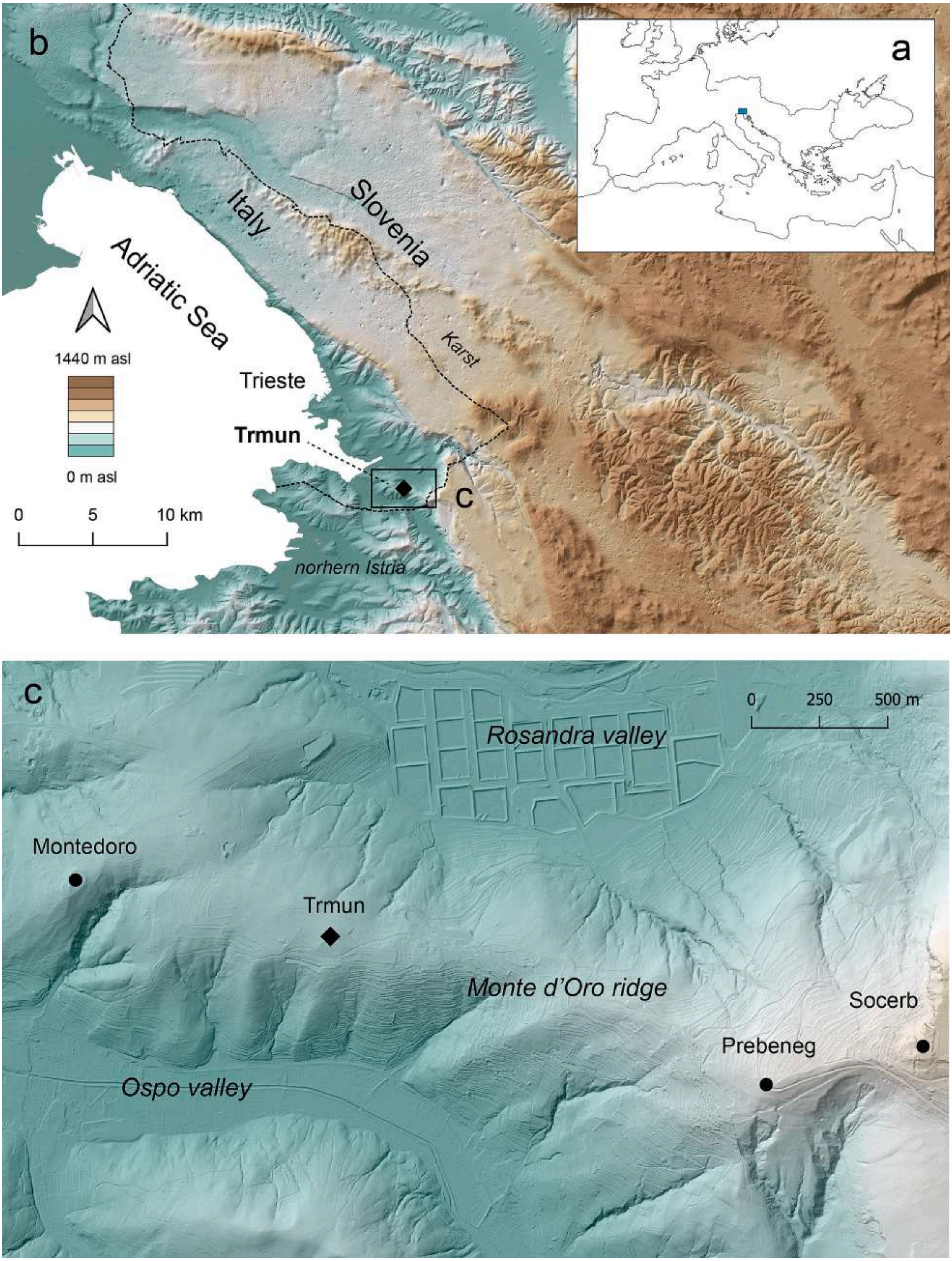

Fig. 1. Position of the Trmun site and other Protohistoric hillforts along the Monte d'Oro ridge.

Fig. 2. The Trmun hilltop, without vegetation and with the archaeological trench opened in summer 2022; view from east. The black arrow indicates the location of the close Monte d'Oro hillfort.

resolved by the imaging process if only in-line information is available. This was the case of the investigated area, which is characterized by very shallow and highly lateral changing structures lying just above a layered rocky bedrock.

2.4. Thermal imaging

A thermal survey of the Trmun hilltop was carried out in order to recognize possible thermal anomalies ascribed to buried archaeological structures. A thermal camera was mounted on a DJI Phantom 3 drone and the camera was aligned perpendicular to the flight path. A FLIR Vue Pro 336 thermal camera, 25° FOV, 13 mm, 9 Hz was used. The thermal images have a resolution of 640 × 480 and were processed with FLIR Thermal Studio software and manually geo-referenced.

3. Results

3.1. Size and plan of the Protohistoric settlement

Archaeological surface surveys enabled the collection of fragments of Protohistoric pottery not only from the Trmun hilltop, but also over several spots in a large area to the west (Fig. 3c). Even though the ancient landscape has suffered severe changes due to agricultural activities through time, the processing of ALS data, combined with observations on the ground, allowed for the identification of several sectors of the original defensive ramparts (Fig. 3).

From the Trmun hilltop, where the remains of a circular rampart were already recognised, a large collapsed wall progresses towards the south-west for about 50 m. This feature is approximately 10 m wide and roughly 1 m high.

Moreover, about 230 m west of the Trmun hilltop, the remains of another sub-circular fortification of similar size, associated with Protohistoric pottery, was identified. The still preserved semi-circular part is about 40 m long, less than 1 m high and 10 m wide.

Approximately 20 m north of the western circular fortification, part of another rampart was discovered. This rampart measures less than 1 m in height and approximately 5 m in width. It is approximately 100 m long and presumably developed towards the east following the direction of a modern land division wall, which was likely built on top the rampart remains.

According to these new data and the hypothetical reconstruction of the original settlement plan (Fig. 3c), the hillfort was approximately 350 m large and covered a relatively flat area of roughly 5 ha. The Trmun hilltop is therefore only a small portion of the settlement, even the highest and probably most strategic one in terms of visibility and territorial control.

3.2. The Trmun hilltop

The best-preserved sector of the Trmun hillfort corresponds to the

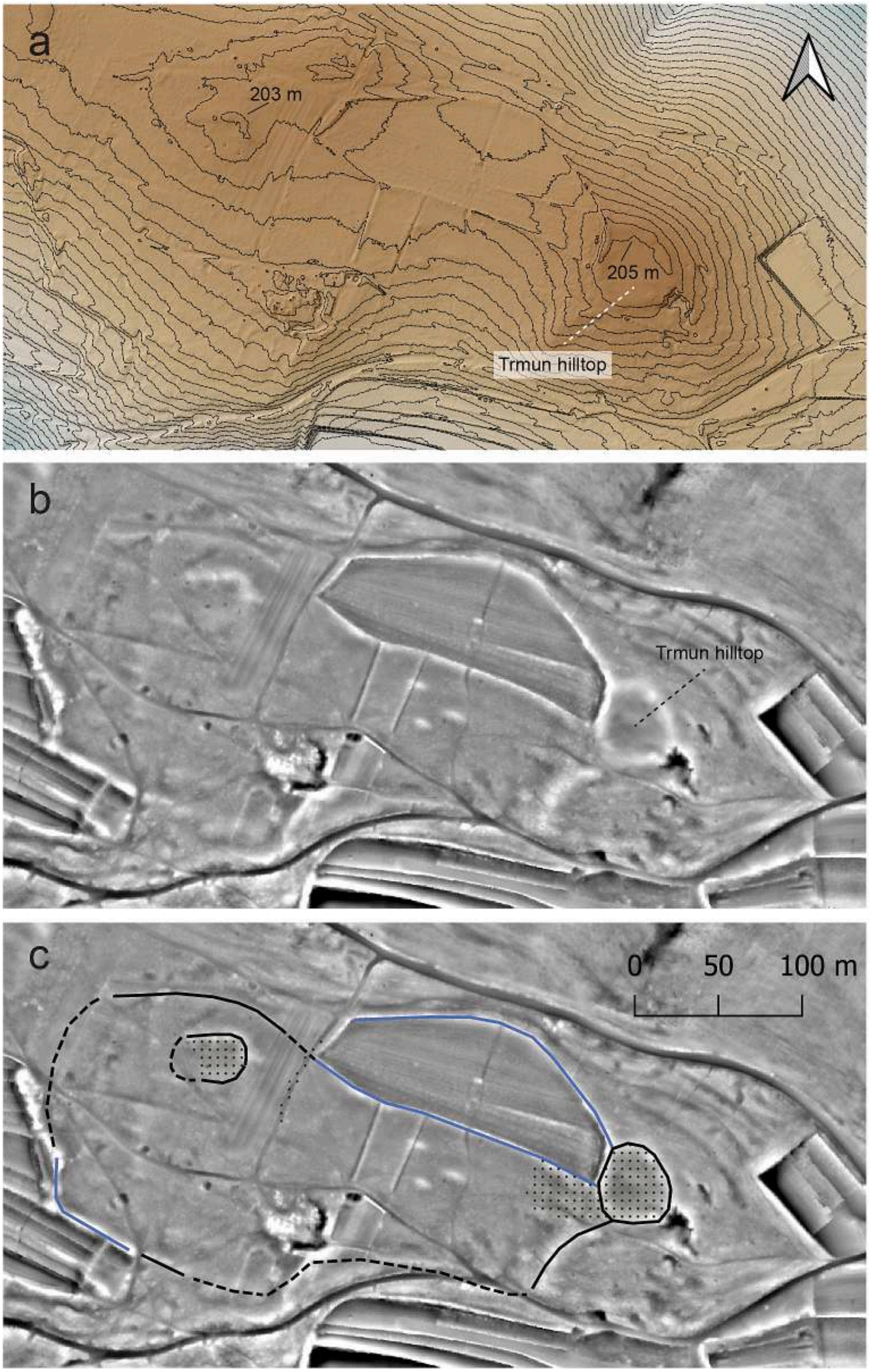

Fig. 3. The Protohistoric site of Trmun: ALS-derived hill shaded image combined with DTM and 1 m contour lines (a), local relief model without (b) and with the interpretation of archaeological features (c). Black lines: preserved ramparts; blue lines: probable ramparts covered by modern walls; dashed black lines: hypothetical position of ramparts; dotted areas: areas where Protohistoric shards have been found on the surface. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

moderate elevation located at the eastern margin of the settlement (Fig. 3). For this reason, we have focused our attention to this area and applied different integrated technologies, more precisely thermal imaging, SfM photogrammetry, ALS and 3D GPR.

Thermal images have shown the highest values on the top of the hill, but unfortunately, no anomalies related to archaeological structures are clearly visible (Fig. 4).

The most significant output of the photogrammetric acquisition is a 0.02 m-resolution DTM. Where areas of interest are free of vegetation, drone SfM photogrammetry can provide, at a low cost, 3D spatial data comparable to those available through much more expensive methods such as ALS (e.g. Historic England, 2017; Cucchiaro et al., 2020; Fig. 5).

An accurate observation of the high-resolution DTMs (Figs. 5-6a) has shown that the hilltop is not simply encircled by a low raised edge, hypothetically related to the buried remains of a Protohistoric rampart, but by 3 sub-circular bumps (Figs. 5-6a-b, nn. I-III), about 6x6 m wide.

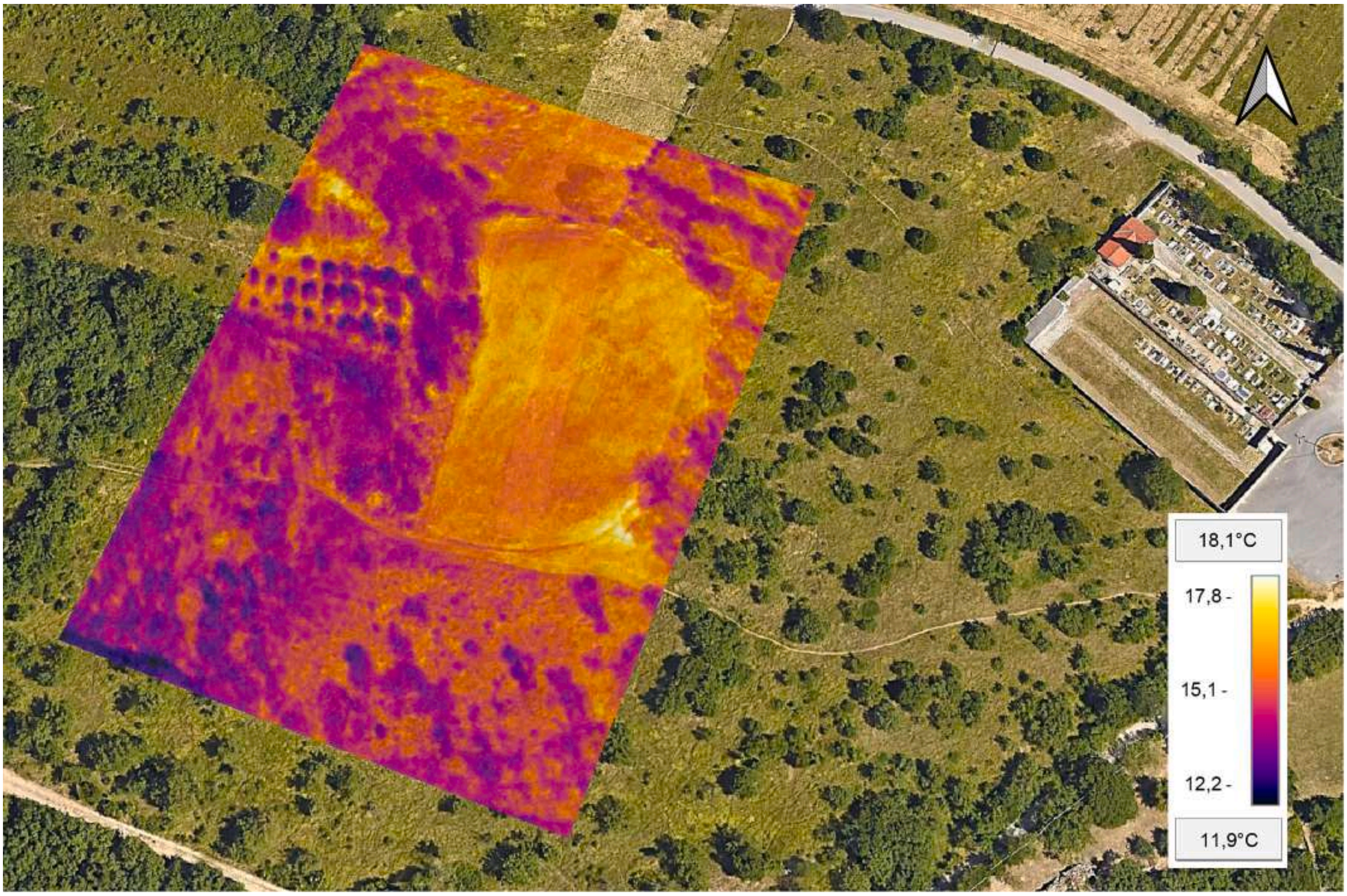

Fig. 4. Thermal image of the Trmun hilltop: thermal anomalies only seem related to vegetation and not to buried archaeological structures.

Interestingly, these features are contiguous to lowered passages through the edge of the hilltop (marked by green circles in Fig. 6a), probably entrances.

A large sector of the hilltop, including Features I and III, has been imaged through 3D GPR (Fig. 6c). A number of interesting anomalies have been detected in the northern sector of the investigated area, where Feature I emerges approximately 30 cm from the surrounding ground. Precisely at this spot, a very regular square anomaly (Anomaly 1), approximately 4x4 m, is visible from a few cm to about 50 cm from the present ground level (Fig. 6d, n.1). The intensity of reflected signals is compatible with a stone structure that, considering its size and position, could belong to a tower.

Just west of Anomaly 1, another large rectangular anomaly (Anomaly 2; Fig. 6d, n.2) has been detected; it is visible from a few cm to about 30 cm from the ground level. Based on GPR data, it could be a structure or a stone accumulation related to the collapse of Anomaly 1.

A third and smaller anomaly (Anomaly 3; Fig. 6d, n.3), detected between Anomalies 1 and 2, is visible from a few cm to about 1 m from the ground level. It is difficult in this case to interpret its meaning.

GPR data provided other important information, such as the very low bedrock depth, detectable as sub-parallel anomalies with north-west/south-east direction starting, in some areas, from merely 20 cm or so from the ground level (Anomaly 4; Fig. 6d, n.4). At less than 1 m of depth, only the layered (maximum dip equal to 40°-45°) flysch bedrock is visible (Supp Figs. 1-4), indicating the archaeological stratigraphy is not too deep.

At the north-eastern corner of the area investigated by GPR, an additional anomaly (Fig. 6d, n.5) has been recognised. Its presence could be related to the collapse of the Protohistoric rampart. Another similar anomaly is visible in the southernmost part of the investigated area, where the presence of the Protohistoric rampart has likewise been postulated (Fig. 7, n.6).

Finally, it is worth mentioning that where the topographic Feature III has been identified, no clear GPR anomalies have been detected (Fig. 6a, 7, Supp Figs. 1-4). This could be due to its closeness to the south-western limit of the GPR survey.

3.3. Remote sensing and ground-borne data vs excavation evidence: An almost perfect match

The Trmun hilltop was partially excavated during summer 2022: the area and limits of the trench had been planned based on the data presented in the previous chapters. A relatively large area, approximately 20x15 m, was opened because GPR data showed that the archaeological stratification was very compressed with no large volume of soil to be investigated and removed.

Fig. 8 shows that the GPR anomalies fit surprisingly well with the archaeological features brought to light during the excavation.

Anomaly 1 (Fig. 8) corresponds to an almost square stone base of a probable watchtower built with sandstone blocks and no mortar. The structure's height is preserved for about 50 cm, as the geophysical data suggests. The stone base is surrounded by an earth bank, about 1.5 m large, that was built at the same time. The presence of such intentional earth accumulation explains why the topographic Feature I, corresponding to the tower and visible in the DTMs (Fig. 6a), is quite larger than the GPR Anomaly 1 (Fig. 6d). No collapse of the structure, buried only a few cm below the ground surface, has been identified. This still has to be fully understood but there are 2 possible explanations: (i) stones and building material were removed from the site after its abandonment; (ii) the vertical parts of the structure were built with

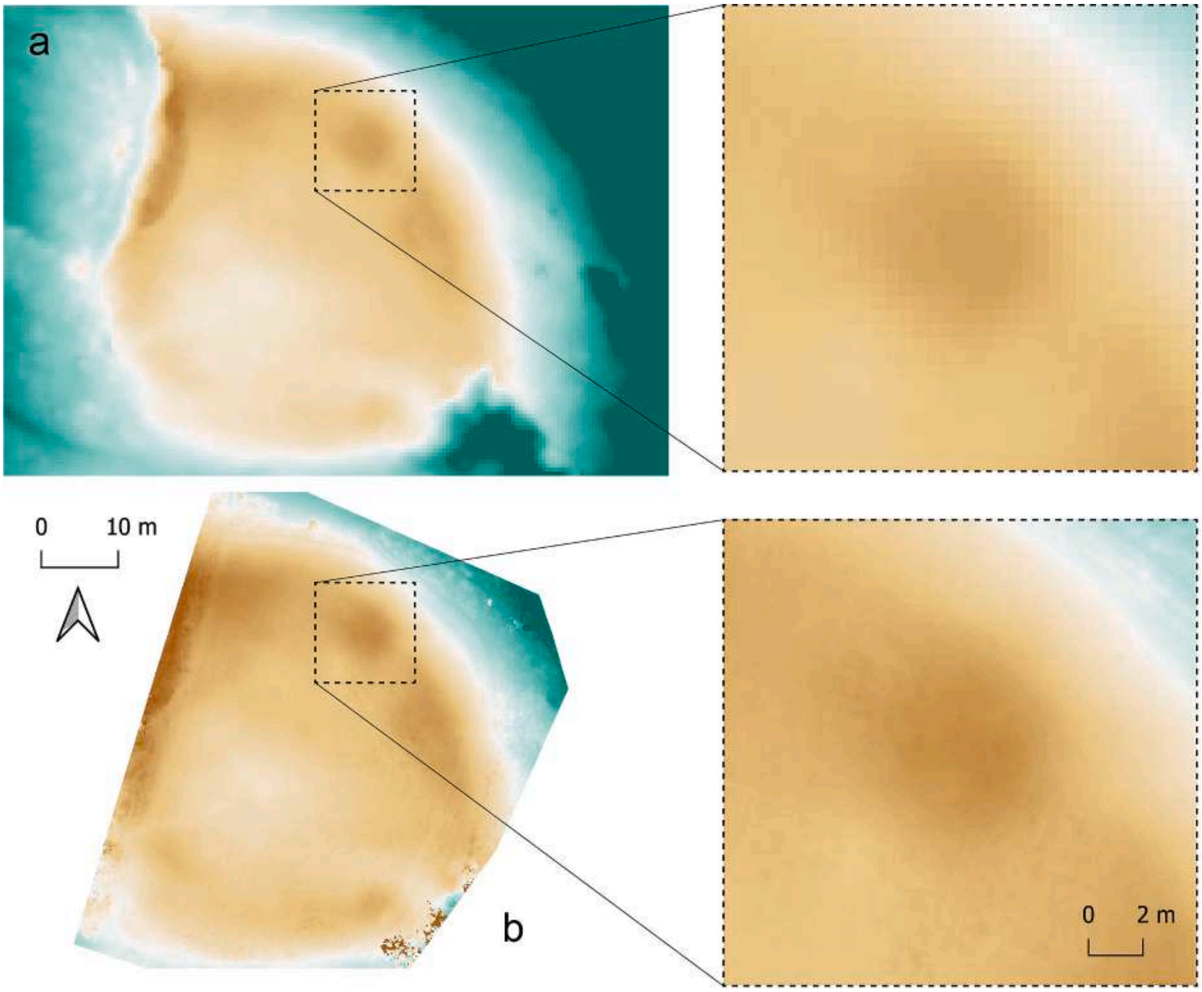

Fig. 5. Comparison between an ALS-derived 0.5 m-resolution DTM (a) and a 0.02 m-resolution DTM obtained through SfM photogrammetry (b). A zoomed view of a sub-circular topographic anomaly (Feature I), whose position is indicated by the dotted square, is shown in the right images.

wood and/or other perishable materials.

A few rims of very similar fire pots made with the wheel were found within and around the structure. The fire pots, together with an iron knife found at the bottom of the square stone base, suggest a post-Roman chronology. Such materials are briefly presented and discussed in a following, chronological, chapter.

The tower, whose remains have been excavated, was probably not isolated. The bumps, labelled as Features II and III (Fig. 6a), could hide the remains of similar structures. This is very likely for Feature II, where some aligned sandstone blocks are visible on the upper part of the mound-like structure detected in the high-resolution DTMs. For Feature III, the absence of clear GPR anomalies and the more flattened morphology suggest caution in its interpretation. However, it seems clear that in post-Roman time the strategic Trmun hilltop, characterised by a flat surface with raised edges due to the remains of the Protohistoric rampart, was exploited to create a sort of fortlet protected by 2 or 3 towers associated with the same number of entrances.

GPR Anomaly 2 (Fig. 8) has proved to be an external area arranged with sandstone slabs, most likely a rough pavement connected to the close tower. The pavement partially covers the earth bank around the square stone structure and seems to lead to its probable entrance located along the northern part of the south-west side. Furthermore, small pottery fragments resembling those associated with the tower have been found among the slabs of Anomaly 2.

GPR Anomaly 3 (Fig. 8) was created by a modern military foxhole, built in the second half of the last century based on its modern filling.

The bedrock (Anomaly 4 in Fig. 8) has been precisely identified where GPR data detected its presence. Sub-parallel layers of sandstones and marls outcrop from about 20 to 80 cm below ground level. Since marls are more prone to weathering than sandstones, the area is characterised by lowered stripes, corresponding to the marls, interspersed with raised sandstone strata.

The excavation has revealed the remains of a Bronze Age rampart - for chronology, see the following dedicated chapter - and associated archaeological layers that have given very abundant pottery, a few flaked artefacts and fauna remains (Fig. 8b). The rampart was about 1.6 m large and built with two external lines of large stones (only a few rows survived) and the space between them filled with soil and smaller stones. The belt between the rampart and the central part of the hilltop was levelled with an intentional accumulation of soil and archaeological material, mainly pottery.

The rampart collapsed almost exclusively towards the exterior, which leads to relevant implications for the interpretation of Anomaly 6 (Fig. 7). Unfortunately, the areas where GPR Anomaly 5 is visible fell outside of the excavation (Fig. 8) but their position at the very limit of the hilltop edges can be explained considering that, in the excavated sector, most of the rampart building material collapsed just outside the original line of the fortification. Here the collapse of the rampart, composed of large slabs and blocks of sandstones, reaches a maximum thickness of about 0.8 m.

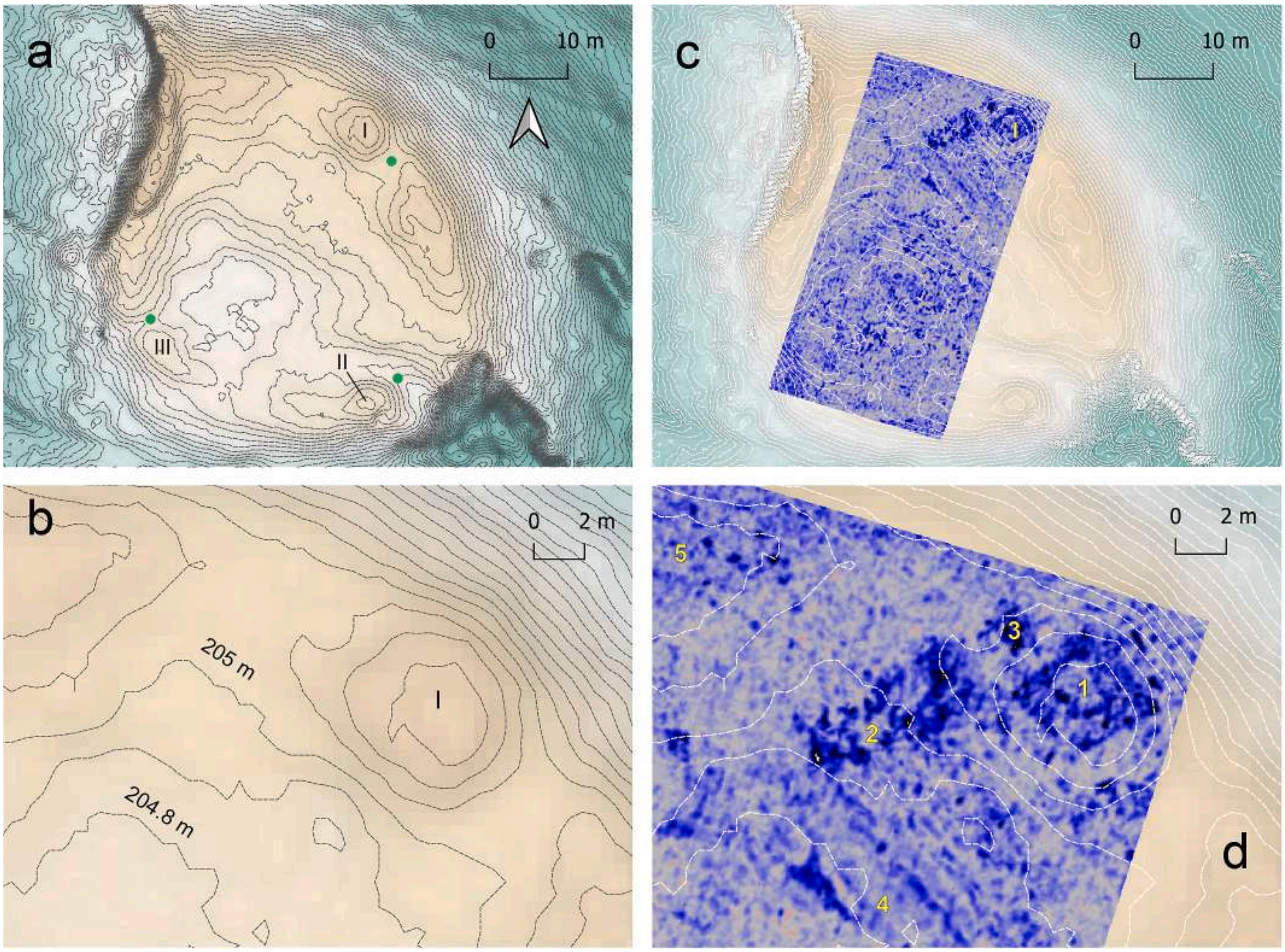

Fig. 6. ALS-derived topography compared to a GPR slice at 30 cm below the ground level: ALS 50 cm-resolution DTM with 10 cm contour lines where Features I-III and possible entrances (green dots) are shown (a); zoomed view of Feature I (b); GPR slice at 30 cm below the ground level superimposed to the ALS-derived DTM with 10 cm contour lines (c); zoomed view of the north-east sector of panel c where the main detected GPR anomalies are shown (d). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.4. Preliminary chronology of the Protohistoric and post-Roman phases

3.4.1. Protohistoric pottery

Among the artefacts unearthed during the excavation at Trmun, fragments of Protohistoric ceramic vessels are predominant (refer to Figs. 9-10). The majority of these fragments were discovered within a strip several meters wide, located adjacent to the inner edge of the fortification wall. The pottery finds exhibit remarkable consistency in terms of firing method, texture, surface treatment, and vessel type. Most of the vessels were fired in an oxidized atmosphere, displaying coarse- or medium-grained pastes, with only a few pieces exhibiting a fine-grained texture. The clay fabrics are characterised by abundant angular inclusions of variable sized marl, up to some mm large.

Among the vessel types, the bulk includes large and medium-sized pots (e.g., Fig. 9: 1, 6, 7; Fig. 10: 4, 6), although bowls (e.g., Fig. 9: 2, 3) and cups (e.g., Fig. 10: 1) are also found.

The ceramic finds from Trmun can be compared mainly to the contexts of the Early and Middle Bronze Age *Castellieri* culture, which was widespread in the area of present-day Istria, Karst and north-eastern Italy (cf. Marchesetti, 1903; Cardarelli, 1983; Mihovilić, 2013; Borgna et al., 2018). Ceramic vessels with a funnel rim (Fig. 9: 6, 7; Fig. 10: 4) are comparable to vessels from the site of Monkodonija in Istria, dated to the Early and Middle Bronze Age (see, e.g., Hellmuth Kramberger, 2017b, T. 4: 1, 3–4; 5: 2). Vessels with similarly shaped rims ("a tesa", everted or funnel rims) are typical Castellieri type. They were also found in the Karst, at the Elleri site (e.g., Lonza, 1981, Tav. 7: 4–6, 18; 13: 5; 14: 5; 15: 5; Maselli Scotti, 1997, Tav. 1: 9; 4: 4–8) and other Bronze Age sites (e.g., Lonza, 1977, Tav. III: 2; IV: 13; Borgna et al., 2018, fig. 5: 2). Similar vessels have also been found in Karst caves, but their precise chronological determination is not possible (see, e.g., Gilli and Montagnari Kokelj, 1993; Turk et al., 1993, Tav. 17: 2). A small vessel with a funnel rim (Fig. 10: 1) is comparable to a small jar from Zemono near Vipava, discovered in a pit and dated between the 19th and 17th centuries BC based on C14 analyses (Bratina, 2014a, 565, 567, fig. 35.4.: 1). Similar small vessels with everted rims and a globular shape, frequently with angular handles, remain in use even in later periods of the Bronze Age in the area of *Caput Adriae* (see, e.g., Lonza, 1981, Tav. 5: 1–15; Forenbaher et al., 2006, 43, Sl. 10: 4, 6).

The finds from Trmun include numerous fragments of vessels with handles and lugs. Among the tongue-shaped lugs there are many decorated with a finger impression (e.g., Fig. 10: 6, 12). Such lugs fall within the typical forms of lugs of the Bronze Age *Castellieri* culture and indicate the early development phases of this culture (see Borgna et al., 2018, fig. 5 and also e.g., Lonza, 1981, Taf. 11: 2–4, 7; 17: 3; Maselli Scotti, 1997, Taf. 1: 10; Flego and Rupel, 1993, 76; Hellmuth Kramberger, 2017a, 259, Sl. 226, 2017b, Taf. 33: 1; 76: 2, 3; 102: 3; etc.). They are also present among the material found in Bronze Age layers of Karst and Istrian caves and other sites (see, e.g., Gilli and Montagnari Kokelj, 1993,

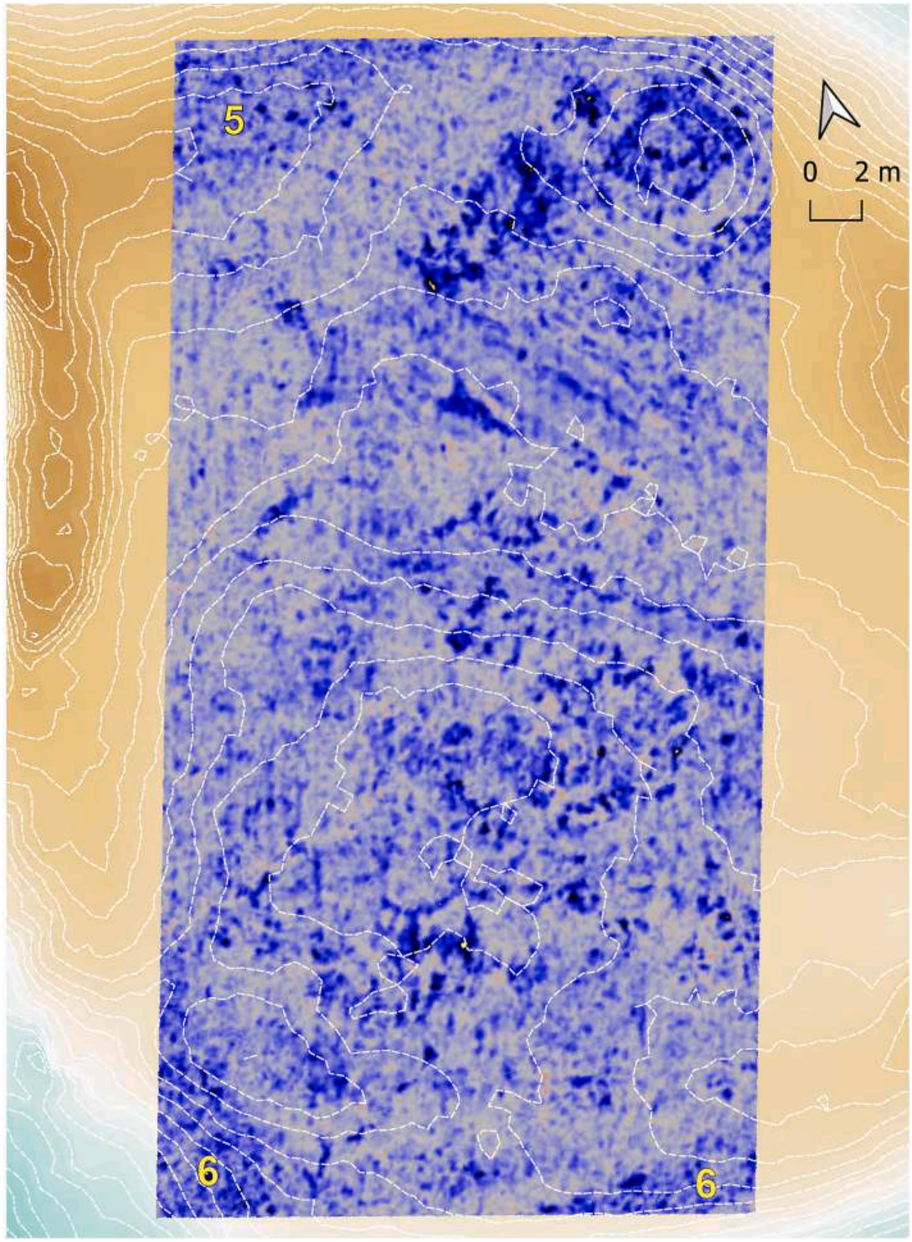

Fig. 7. GPR Anomalies 5–6 visible in a slice at 30 cm below the ground level superimposed to the ALS-derived DTM with 10 cm contour lines. They encircle the Trmun hilltop and most likely correspond to the collapse of the Protohistoric rampart.

figs. 59: 615; 60: 620; 62: 640–641; 64: 666; Čuka, 2009, Tab. IV: 23; V: 24, 25; Bratina, 2014b, fig. 36.6.: 16, 17).

A bowl with a carinated rim-to-wall transition from Trmun has an interesting X- handle located below the rim of the vessel (Fig. 9: 3). Such handles are known from Early and Middle Bronze Age sites in Istria and Karst (Hellmutt Kramberger, 2017a, 240–242, Sl. 211 and 212; see also e.g., Cardarelli, 1983, 91; Čuka, 2009, T. V: 26; Hellmuth Kramberger, 2017b, pl. 20: 1, 2; 74: 7, 8, 101: 3; Zendron, 2017, 215, fig. 108).

One of the more interesting pieces is a handle fragment with a triangular cross-section that tapers towards the top (Fig. 9: 5). Such handles are typical for the *Castellieri* culture in Istria and in the Trieste Karst, where they already appear in the Early Bronze Age and become widespread in the Middle and Late Bronze Ages (Hellmutt Kramberger, 2017a, 244–248, Sl. 215; see also Čović, 1983, 127, T. XIV: 4, 6–7; Lonza, 1977, T. XIV: 4, 6–7; T. II: 3–7, 8–11; 5: 1, 3, 5; Cardarelli, 1983, Tav. 18: 111; Zendron, 2017, fig. 114). A fragment of a semicircular handle with a trapezoidal overhand plate (Fig. 10: 5) can also be compared with assemblages from the *Castellieri* culture. This specific shape is, in all likelihood, the precursor of handles with an overhand plate, which appears in the area of Istria already at the end of the Early Bronze Age and experiences a wide distribution in the Middle Bronze Age, when several variants appear (e.g., Čović, 1983, 238, T. XIV: 1a; XXXV: 10; Borgna et al., 2018, 83-84). These handles represent one of the most characteristic elements of the *Castellieri* culture. According to the chrono-typological development of the handles with an overhand plate, the handle from Trmun belongs to the earliest forms and is dated to the Early Bronze Age (Borgna et al., 2018, 83-84, fig. 6: I).

Few fragments of conical-shaped bowls have a smoothed inner surface, while the outer surface is roughly abraded or irregularly roughened (e.g., Fig. 10: 7, 8). Most likely, these vessels belong to the so-called repertoire of 'briquetage' vessels, which refers to vessels used to harden salt during the last phase of salt extraction (Càssola Guida and Montagnari Kokelj, 2006; Montagnari Kokelj, 2007; Zendron, 2017, 224, fig. 121).

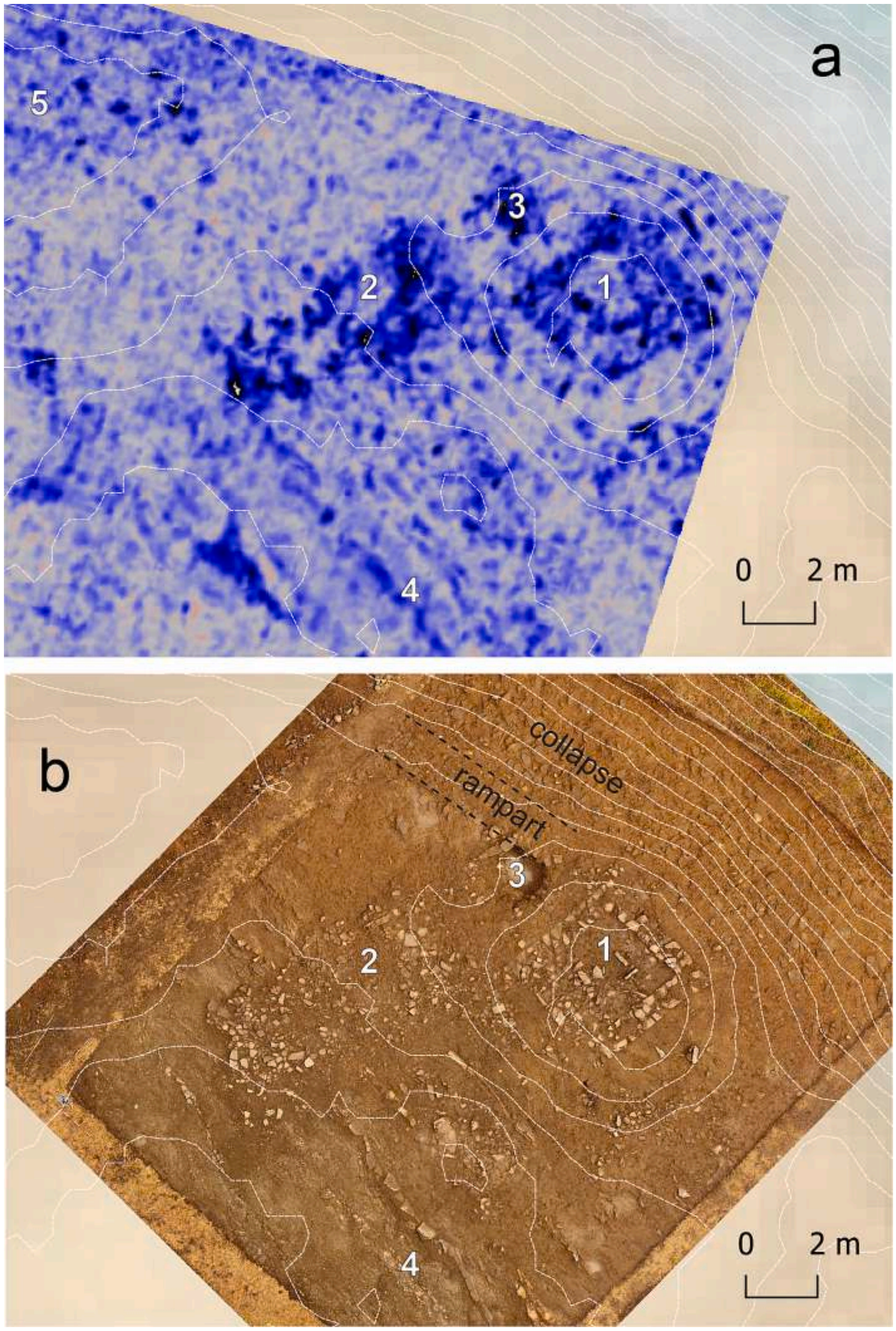

Fig. 8. Comparison between a GPR slice at 30 cm below the ground and a SfM photogrammetric orthophoto of an initial stage of the excavation with 10 cm contour lines.

Other fragments are interpreted as parts of tripods, more specifically legs (e.g., Fig. 9: 9; Fig. 10: 9), which were used as hearth wares. They have been found in large numbers in the Trieste Karst and Istria (Lonza, 1981, Tav. 41: 1–6; 42: 1; Maselli Scotti, 1997, Tav. 3: 4, Hellmuth Kramberger, 2017b, Tav. 11: 2–4; 23: 5; 58: 3; 71: 5).

3.4.2. *Post-Roman materials*

Only a few fragments of similar wheel-made fire pots have been found associated with the square stone structure (Fig. 10: 13–15). Their chronological attribution is not easy considering that vessels with a similar shape had been in use for a very long time span (e.g. Štular, 2006; Maccadanza and Mancassola, 2019, 311-351; Cirelli, 2021). Part of an iron scale-tang knife, found associated with the tower, is probably later than the XIII century (Goodall, 2011; Carrera and Ceppatelli, 2018, 269). C14 dating of charcoals will hopefully help to clarify the chronology of the square structure that could date back to the late Medieval or more likely, Modern periods.

4. Discussion and conclusions

The remote sensing results of the Trmun site shows how the application of combined and multi-scale non-invasive methods today is crucial, not only to detect archaeological features, but also to obtain high-resolution topography, geometry and size of buried contexts, which are comparable to those provided by invasive methods, such as archaeological trenching.

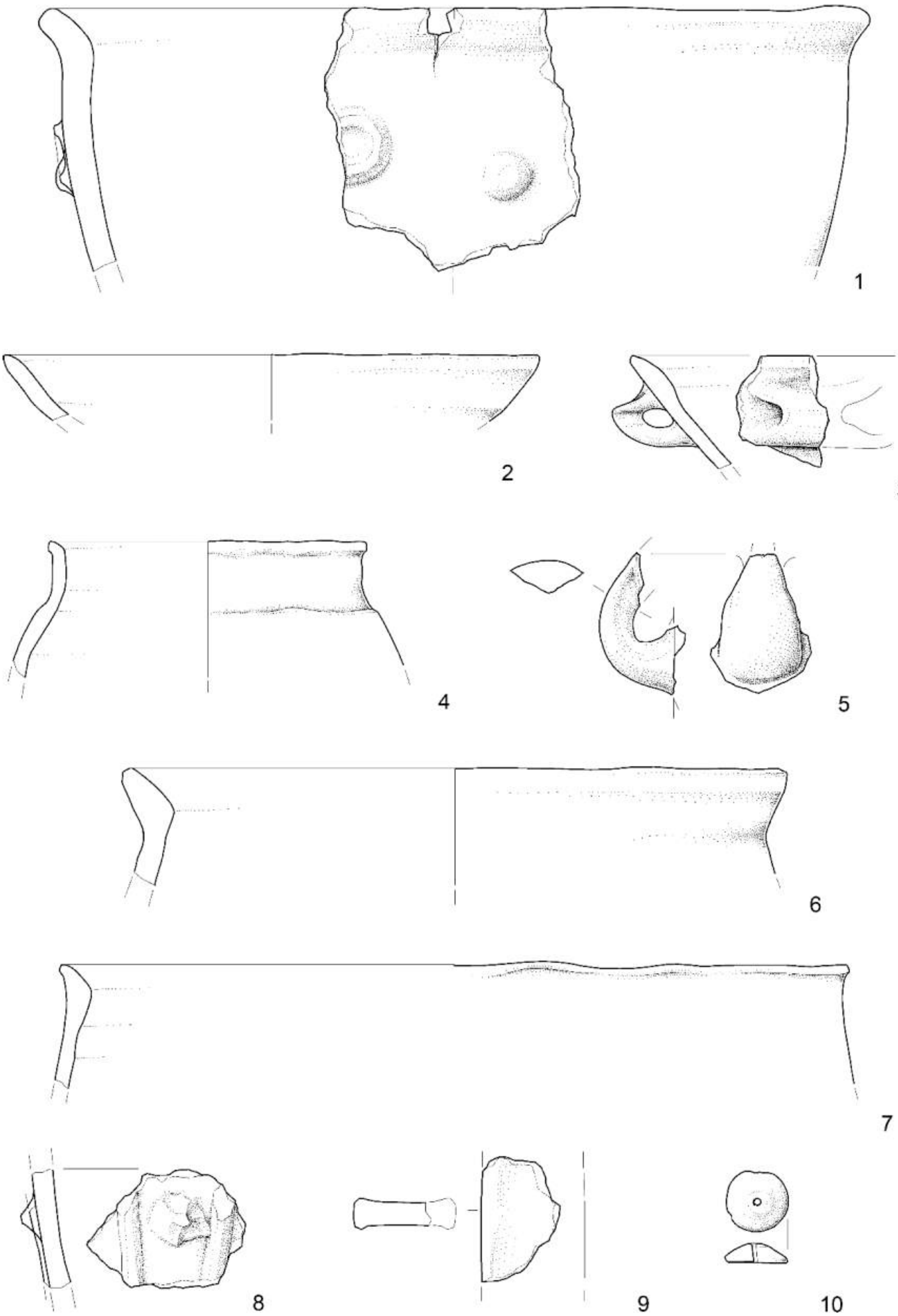

Fig. 9. Selection of ceramic vessels and material from the Trmun site. 1–10: SU 12. Scale 1:3. Drawings: T. Korošec.

The increasing development of ground, aerial and space remote sensing, including low-cost techniques such as SfM photogrammetry, are crucial for the planning of archaeological excavations, along with the monitoring and management of cultural heritage.

The combined application of ALS, SfM photogrammetry and 3D GPR have revealed the real dimensions of the Trmun site, providing detailed geometrical 3D data about the archaeological landforms and the related buried structures, whose accuracy has been confirmed by the recent archaeological investigations.

According to our results, the Trmun hillfort, probably built during

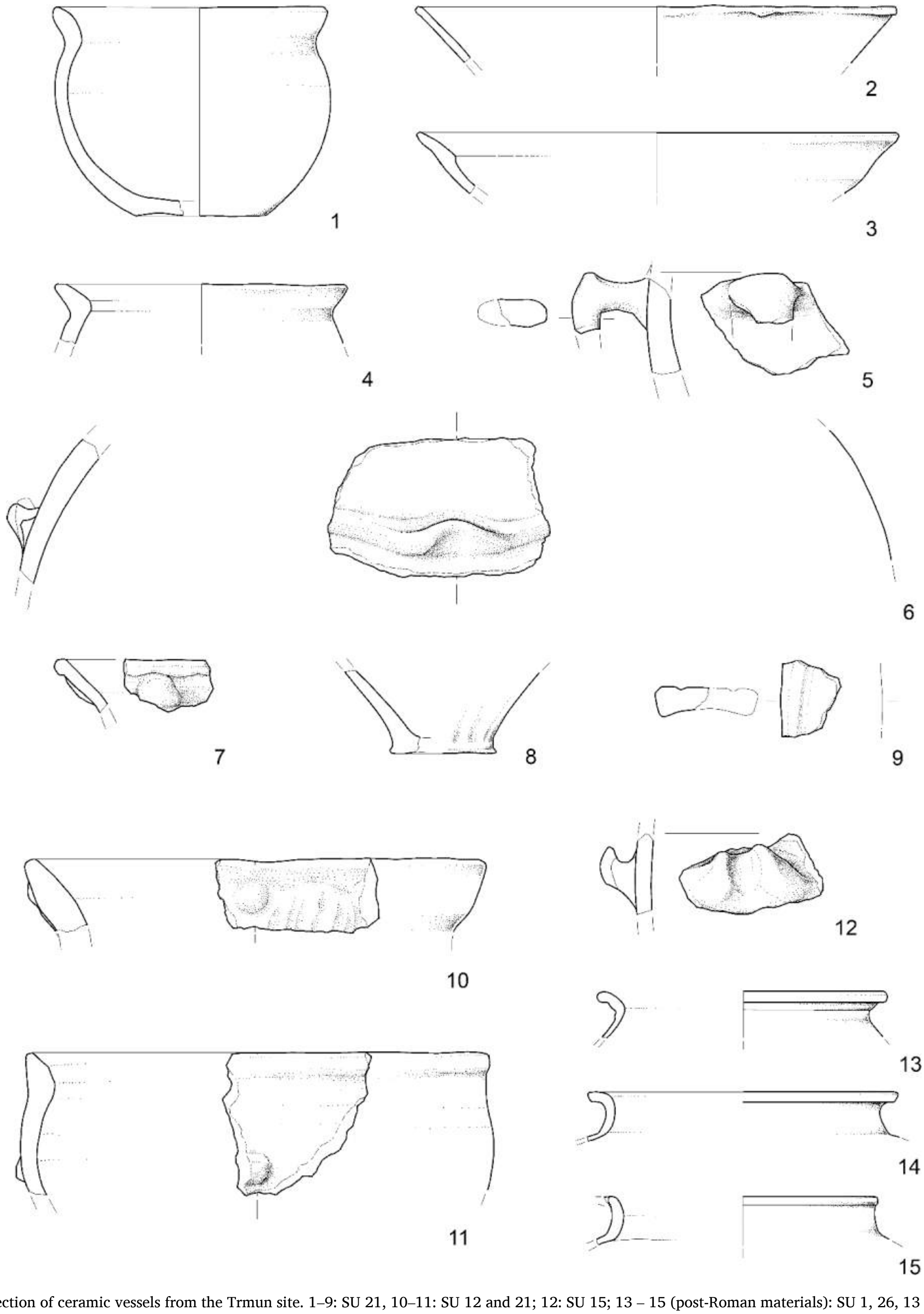

Fig. 10. Selection of ceramic vessels from the Trmun site. 1–9: SU 21, 10–11: SU 12 and 21; 12: SU 15; 13 – 15 (post-Roman materials): SU 1, 26, 13 and 23. Scale 1:3. Drawings: T. Korošec.

the early phase of the *Castellieri* culture, covered a large (about 5 ha), relatively flat, area. The presumed area occupied by the settlement is quite extensive. However, it is worth noting that several other settlements, including the nearby hillforts of Monte d'Oro (7 ha considering the ALS-derived DTM) and Monte Carso (20 ha), occupy even larger areas.

The Karst plateau and the Istrian peninsula at the north-eastern shore of the Adriatic Sea are marked by the presence of hundreds of

Protohistoric settlements, generally located on hilltops. These sites, protected by dry-stone walls, locally called *castellieri*, *gradine* or *gradišča*, were settled on for a prolonged period of time spanning from the late Early Bronze Age, approximately between 1800 and 1650 BCE, to the late Iron Age (Mihovilić, 2013; Borgna et al., 2018). The preliminary study of a representative selection of pottery from the Trmun hilltop shows that the site was used for a relatively short time period, probably between the late Early Bronze Age and the Middle Bronze Age. Its study is therefore important for improving our understanding of the early phase of the *Castellieri* culture. During this period the Monte d'Oro hillfort, located just 1 km west of Trmun, was in use too (Fig. 1c; Marchesetti, 1903; Flego and Župančič, 1991; Flego and Rupel, 1993), suggesting they were part of the same territorial system. They probably exercised control over an important route passing between the two settlements through the Monte d'Oro ridge and connecting the Trieste and Karst areas with northern Istria.

This seems to confirm that, during the Bronze Age, these regions were characterised by a cultural landscape divided into small-scale territorial systems, that later disappeared with the formation of new, larger territorial divisions controlled by a few dominant settlements (Novaković, 2005; Vinci and Bernardini, 2017).

The obtained results additionally show that the Trmun hilltop was reused in the post-Roman time, most likely during the late Medieval or Modern periods, to create a fortlet with 2 or 3 towers and the same number of entrances. The space between the towers along the perimeter of the small elevation, where the ruined Protohistoric rampart still stands, was likely protected by a wooden defence structure which has not left any archaeological traces. In absence of well datable archaeological artefacts, the now in process C14 dating will help to clarify the chronology of such a historical fortification, that seems to have been used for a very short period of time.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2023.104108.

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