06TH INTERNATIONAL SCIENTIFIC CONFERENCE

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PROCEEDINGS

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Content

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Preface

Ina Miloglav

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Methodology and Archaeometry (MetArh) is an annual scientific conference organized since 2013 by the Department of Archaeology of the Faculty of Humanities and Social Sciences of the University of Zagreb, and the Croatian Archaeological Society. The goal of the conference is to entice interdisciplinarity, critical thinking, new insights and approaches as well as new theoretical frameworks in contemporary archaeological science.

During the last 7 years, *MetArh* becomes a platform for discussion about theoretical and practical issues in two major topics of archaeological research: archaeological methodology and archaeometry. The first topic covers the development of the methodology for data acquiring, primarily through archaeological excavations and varieties of non-destructive techniques for data gathering. Second is focused on the application of scientific methods and techniques in data analysis. Both improve the overall archaeological methodology and ensures more reliable and valid data which leads to more comprehensive archaeological interpretation of the distant past. What makes *MetArh* different from other similar conferences, which are usually focused on specific methodological themes, is the wider perspective in observing methodology and methodological practices, also challenging traditional approaches in archaeological research, and following the creative adaptation of methods from other disciplines into archaeology. It offers an opportunity for scholars to present their work, engage in discussion and motivate young scholars and archaeology students to pursue contemporary topics and present their research.

With the intent to publish contributions from the conference in fool text publicly and freely available last year we started with the digital edition of the Proceedings from the conference (https://openbooks.ffzg.unizg.hr/index.php/FFpress/catalog/book/33). This, second edition of the conference Proceedings contains eight scientific papers from the 6th *MetArh* conference which was held at the Faculty of Humanities and Social Sciences of the University of Zagreb, from 6th - 7th of December 2018. Papers are focused on different aspects of archaeological methodology and archaeometry, including case studies from Croatia, Slovenia, Serbia, Greece and Russia. In order to create a volume of high scientific quality, each of the conference paper was reviewed in the peer review process in which the identity of both reviewers and authors, as well as their institutions, are respectfully concealed from both parties. I would like to thank the reviewers and Editorial board for their comments, opinions, and remarks as well as all the authors who contributed to this volume.

Archaeological remains in soil context

Luka Gruškovnjak

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Department of Archaeology
University of Ljubljana
Aškerčeva 2
SI – 1000 Ljubljana, Slovenia
luka.gruskovnjak@ff.uni-lj.si

The majority of archaeological contexts are located within the soil, therefore processes of soil formation and soil geomorphology play an important role in their formation history. These processes have important implications for the ways of observing and recording as well as understanding and interpreting these contexts. In order to demonstrate their implications a theoretical overview of only a few of those processes which seem most important for archaeology is given in this paper. This is accompanied by hypothetical profile depictions based on the presented theory in order to illustrate in a simplified manner some possible outcomes of the discussed processes reworking the archaeological record. The overview focusses on the difference between sediments and soil horizons and on processes of horizonation, bioturbation and additions or removals of material to or from the soil surface. It demonstrates that the principles of archaeological stratigraphy cannot be universally applied to sites altered by these processes. There the observed layers and contexts may not be the result of depositional events, be it anthropogenic or natural, to which these principles apply. Instead, they may be the result of in situ transformations of original contexts by long-term soil processes. In such cases, the principles of archaeological stratigraphy cannot be applied and the concept of stratigraphic contexts must be replaced with the concept of archaeological remains in soil context. The discussions of processes and accompanying hypothetical depictions in this paper should prove useful to archaeologists in the evaluation of such contexts and in thinking about how they may have been formed. However, the actual formation processes which resulted in the observed archaeological soil context can only be deciphered through interdisciplinary scientific research.

Keywords*: archaeological record, soil, horizons, bioturbation, soil geomorphology, stratigraphy, formation processes.*

Introduction

The archaeological record represents a complex intertwinement of past human activities and natural processes involved in its formation history. Post-depositional processes involved in this history are responsible for the fact that the archaeological record almost never corresponds to the original state of deposition by human action but is reworked and transformed through various natural processes and subsequent human activities which are affecting and changing it up until the moment of its observation as archaeological context (sensu Schiffer 1972: 157; Ib. 1973: 55; Ib. 1983: 676-678). Among the post-depositional processes which almost invariably affect and rework the archaeological record in open-air sites are processes of soil formation and soil geomorphology. The majority of past human activities had taken place on the soil surface thus the material remains reflecting these activities were first affected by processes working on the soil surface, then by processes which buried them and consequently by processes working under the surface or within the soil. In all of these three stages processes of soil formation and/or soil geomorphology are involved. They can work to blur or even destroy original stratigraphy, move and displace artefacts, as well as burry, expose or destroy the archaeological record. Because of these effects processes of soil formation and soil geomorphology are crucial for the understanding of the archaeological record and bear strong implications for the methodology of both its research and recording as well as its final interpretation.

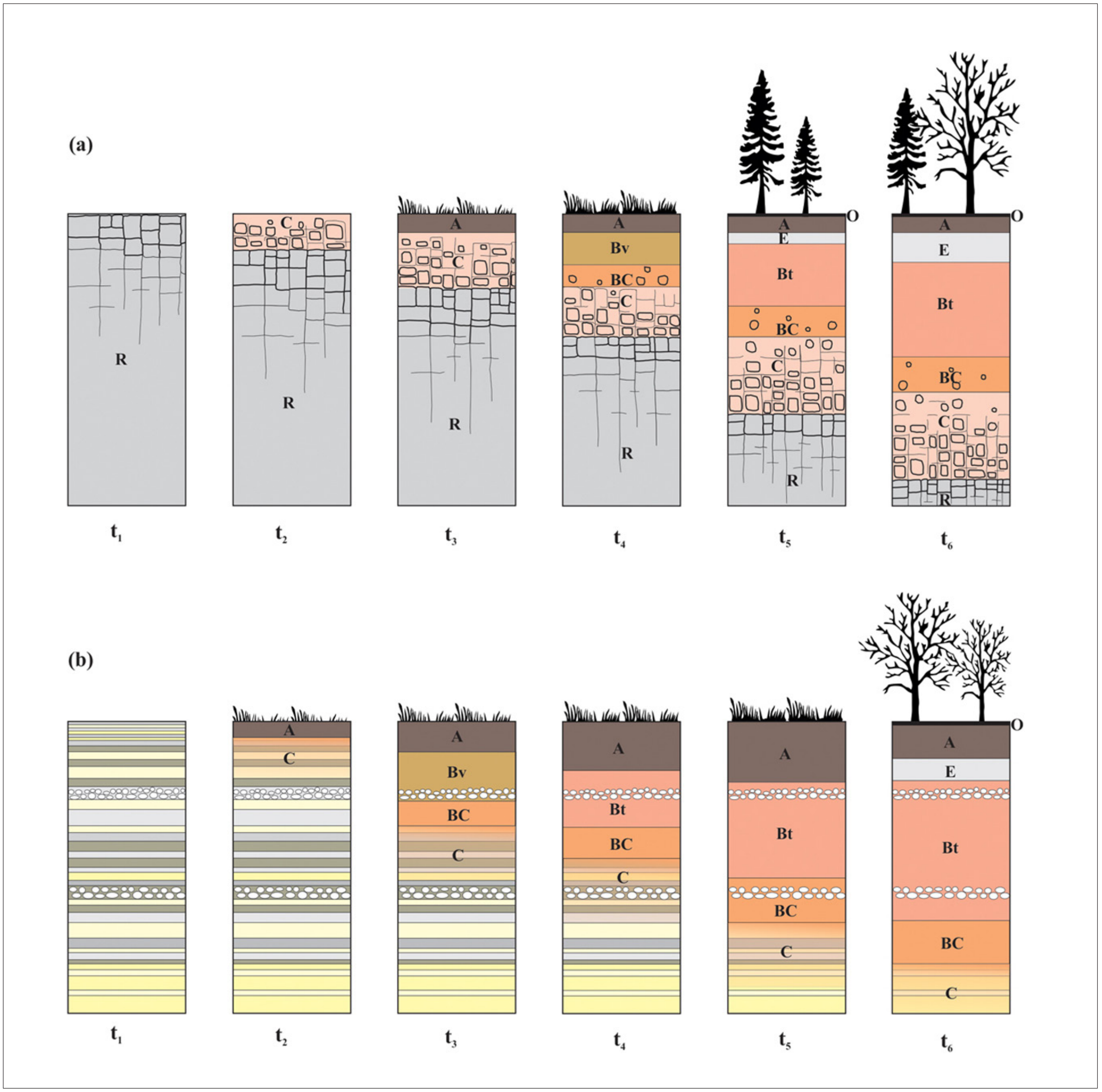

FIGURE 1. Hypothetical profile of soil development by top-down pedogenesis. (a) Soil forming on a rock parent material weathering in situ. The weathered rock or saprolite and the soil forming on it constitute the regolith (drawn after models in Schaetzl and Anderson 2005: Fig. 3.2-3; Weil and Brady 2017: Fig. 2.26, 2.36). (b) Soil forming on a stratified alluvial sedimentary parent material (drawn after models in Straffin et al. 1999: Fig. 2; Mandel and Bettis 2001: Fig. 7.1; Holliday 2004: Fig. 5.5; Weil and Brady 2017: Fig. 2.26). Legend: t = time of observation.

Layers, sediments, soil horizons and the law of superposition

Archaeological contexts are located within the mantle of unconsolidated material lying above the bedrock and consisting of different types of layers (sensu Phillips and Lorz 2008) (Fig. 1), recognition of which is crucial for geological, geomorphological, pedological and archaeological research. Because the origin of layers varies greatly it is important to ascertain how they formed in order to interpret them correctly. The archaeological interpretation of layering relies on principles of archaeological stratigraphy (see Harris 1979; Ib. 1989: 29-53; Davies 2015: 3), which can only be applied to layers formed through depositional events. That is why it is crucial to differentiate between layers resulting from deposition and layers developing in situ such as soil horizons to which the stratigraphic law of superposition does not apply (Goldberg and Macphail 2006: 46; Phillips and Lorz 2008: 144-146). The mantle of weathered rock material formed in situ, i.e. the regolith, can be divided into several layers which are gradually and simultaneously forming in place (Gregorich et al. 2001: 297; Huggett 2007: 89; Anderson and Anderson 2010: 162-163), therefore the law of stratigraphic superposition does not apply to them. As the constituents of the regolith are removed, transported and then deposited at another location by natural forces and processes or through human action we are dealing with the transported regolith or clastic sediments (Stein 1987: 339; Harris 1989: 47-48; Schaetzl and Anderson 2005: 32, 171; Huggett 2007: 89; Howard 2017: 3, 43). To all layers of natural or anthropogenic sediments deposited in this manner, the principle of stratigraphic superposition does apply.

Both rock weathered in situ and natural or anthropogenic clastic sediments located on the surface or near the surface represent parent materials in which soils form (Fig. 1). All soils are composed of a different number of horizons which are all genetically linked because they interdependently form through the pedogenic alteration of parent materials into layers with distinct physical, chemical and biotic properties (Holliday 1990: 527; Tandarich et al. 2002: 338; Schaetzl and Anderson 2005: 36; Phillips and Lorz 2008: 145; Vrščaj 2013: 318, 321; Vidic et al. 2015: 19, 41). Because soil horizons are genetically linked they do not reflect a sequence of deposition, therefore the law of stratigraphic superposition does not apply to them (Finkl 1980: 171; Cremeens and Harth 1995: 26; Holliday 2004: 83).

Because soils represent a continuum in the landscape and a background to any human activity the majority of archaeological contexts we observe are located within the soil or on the soil surface (Goldberg and Macphail 2006: 42). Consequently, pedogenic and geomorphic processes involved in soil formation are also crucial in the formation of archaeological record itself. Therefore, some degree of their understanding and recognition in the field is needed in archaeological research.

Soil formation and soil geomorphology

Processes of soil formation and soil geomorphology are important for the understanding of the archaeological record because they can blur or even destroy sediment stratigraphy, cause artefact movement, as well as contribute to the burial, exposure or destruction of the archaeological record.

Processes involved in soil formation or pedogenesis may be divided into two main groups. The first group is represented by processes causing horizonation, while the second group is represented by processes countering it and causing haploidization or homogenization. Horizonation refers to pro-anisotropic conditions, factors and processes causing anisotropy (order, sorting, non-randomness) by altering parent material into a soil profile with genetic horizons. Haploidization or homogenization refers to pro-isotropic conditions, factors and processes causing isotropy (disorder, chaos, randomness) by countering horizonation, causing profile simplification, and destruction of soil horizons. In the latter, especially pedoturbation or soil mixing processes, as well as geomorphic processes of erosion and deposition are involved (Johnson and Watson-Stegner 1987: 356-357, tab. 1-2; Blume et al. 2016: 294). However, from an archaeological point of view, both horizonation and pedoturbation can be seen as mixing processes, because archaeology is interested in the original state of deposition and both processes, no matter whether they are working towards order or disorder, cause mixing of the original state and thus blurring or destruction of primary depositional contexts (Holliday 2004: 263). In the case of horizonation, only the fine fraction is affected, while pedoturbation also affects the coarse fraction.

Horizonation

Horizonation works from the top down and is time progressive in terms of depth it reaches and the strength of differentiation of the profile (Johnson and Watson-Stegner 1987: 349; Almond and Tonkin 1999: 2; Weil and Brady 2017: 88, Figs. 2.36, 2.39). It effectively causes pedogenic layering recognition of which is crucial during archaeological observations because soil horizons which are not recognized as such may erroneously be interpreted as a stratigraphic sequence of depositional layers (Fig. 9c: I). This will cause a misunderstanding of site's formation processes and lead to errors in the interpretation of depositional events at the site (e.g. Phillips and Lorz 2008: 152). Additionally, in the case of stratified parent materials, horizonation causes progressive destratification of the original depositional layers. At an archaeological site (Fig. 2), artefacts which were once part of depositional layers will lose their original stratigraphic context and become part of soil context. Some data about the original relative stratigraphy may, in this case, be preserved only in the positions of artefacts within the soil[1]. The original stratigraphy of a site will only be preserved under the lower boundary of the pedon, where it has not yet been subjected to intensive changes through pedogenic processes (e.g. Wilkinson 1990: 91-92, Fig. 2).

Pedoturbation: bioturbation

Pedoturbation is usually described as a mixing of materials through different processes[2]. However, these may not only cause mixing (pro-isotropic processes) but also sorting (pro-anisotropic processes) of materials. Whether pedoturbation works towards mixing or sorting is often dependent on the size fraction observed, as many forms of pedoturbation mix the fine fraction while sorting and causing order within the large fraction. When coarse fragments, such as stones and artefacts, are not included in the mixing process this may cause the formation of subsurface layers, as in the case of bioturbation (Fig. 3), or surface covers, as in the case of cryoturbation and argilliturbation, consisting of coarse fragments (Wood and Johnson 1978; Johnson et al. 1987: 278-279; Schaetzl and Anderson 2005: 240; Blume et al. 2016: 308; Fey and Schaetzl 2017: 10). Pedoturbation processes have very strong implications for archaeology. On one hand, the mixing of the fine fraction can cause blurring or even total obliteration of original sediment stratigraphy and its transformation into a single massive layer. On the other hand, it implies that coarse fragments[3] such as stones and artefacts are not static elements of the sedimentary or soil matrix but may be translocated, mixed or sorted within it.

Bioturbation is perhaps the most important group of pedoturbation processes to be considered in archaeology as it is the most ubiquitous. It involves biomechanical action of living organisms, animals (faunalturbation) and plants (floralturbation), which can produce and destroy soil horizons as well as other types of layers by causing the movement of fine soil fractions as well as coarse fragments upward, downward or laterally (Wood and Johnson 1978: 318-333; Johnson 2002: 7; Schaetzl and Anderson 2005: 247-262). The main product of bioturbation is the formation of the so-called biomantle, which is the topsoil layer or A horizon formed primarily through processes of bioturbation. Because biomantles are essentially ubiquitous over Earth's subaerial substrates the concept of the biomantle and processes involved in its formation holds huge implications for archaeology (Johnson 1993: 71-76; Johnson 2002; Johnson et al. 2005a: 38, tab. 1; Johnson et al. 2005b, 16, 19, 21-22, tab. 1; Goldberg and Macphail 2006: 59). Namely, most past human activities took place on the surface of this highly energetic and dynamic topsoil layer and were in different ways also involved in its formation. Thus, most open-air archaeological sites had originally formed on the surface of the biomantle and/or were subsequently subjected to the processes of its formation and strongly affected by them throughout their formation history.

From an archaeological perspective, some of the most important possible effects of faunalturbation are the burial of surface materials, the downward sinking of coarse fragments, the obliteration of features within the biomantle and the translocation of coarse fragments through burrows (Figs 3-4). Burial is achieved primarily through surface mounding, caused by different types of fauna, as well as the gradual downward sinking of coarse fragments through the biomantle. Gravitational sinking results from a combination of burrowing around the coarse fragments, collapsing of the burrows and constant transfer of fine fraction to the surface. Earthworm activity is one of the main reasons for this process in temperate zones and when achieved primarily through earthworm activity the effect is pro-anisotropic. At the maximal depth of faunalturbation, coarse fragments

[1] Contrary to the view that archaeological stratification may exist without artefacts (Harris 1979: 112).

[2] For a list and description of different forms of pedoturbation processes see Schaetzl and Anderson 2005: 245-294, Tab. 10.1 and for some of their effects on archaeological sites see Wood and Johnson 1978.

[3] For a list of pedoturbation processes which can move coarse fragments see Schaetzl and Anderson 2005: Tab. 10.2.

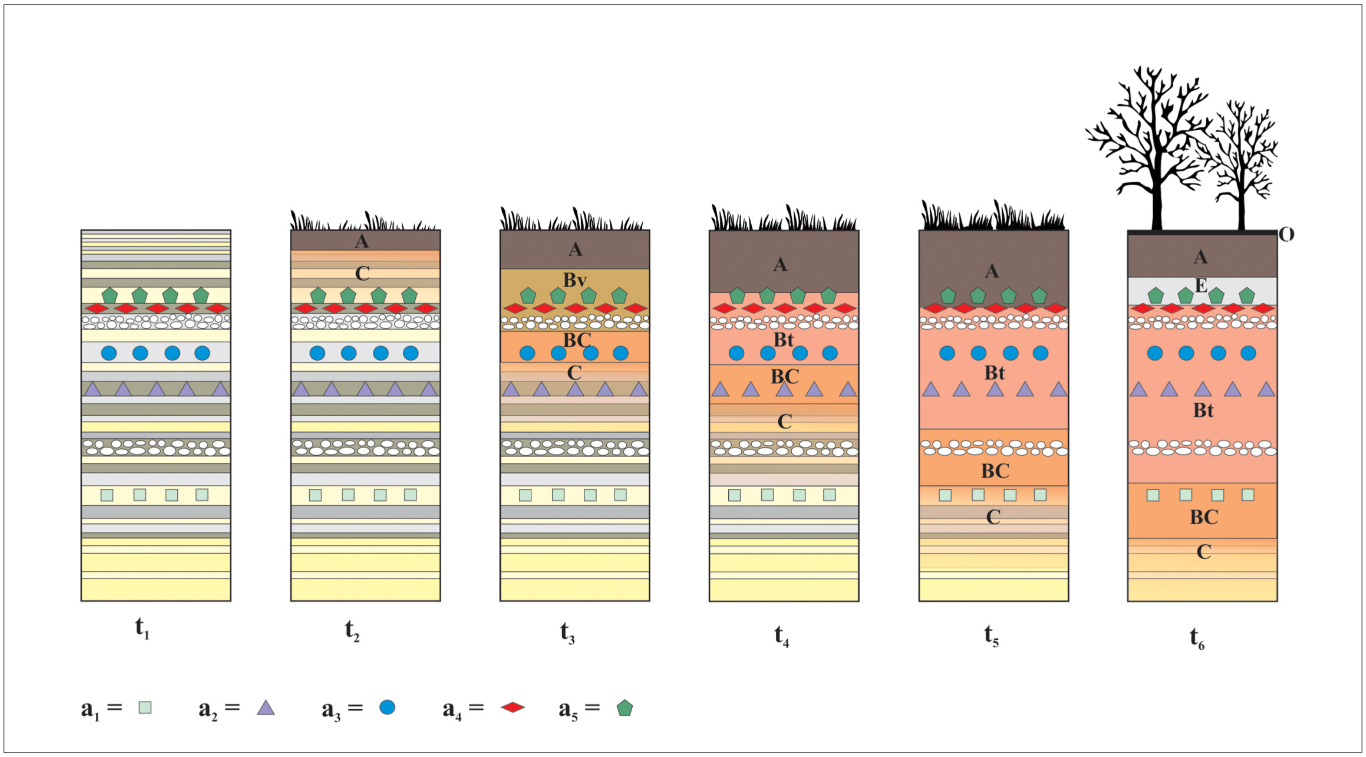

FIGURE 2. Hypothetical profile of stratified parent material from Fig. 1a, with added archaeological artefacts. This case represents a visualization of a stratified multiperiod archaeological site, which is being progressively destratified through pedogenesis. With the formation of soil horizons, artefacts lose their initial stratigraphic context and are becoming part of soil context, with horizons which are genetically linked and contemporaneous. The only relative stratigraphic data preserved are represented in artefact positions within the soil. Legend: t = time of observation; a = artefacts of different periods.

become concentrated within the so-called stone- and/ or artefact-lines or layers, which give a false impression of a depositional event, paleosurface and/or cultural layer (Fig. 3). Therefore, artefacts of different time periods which had been exposed to the process of sinking for long enough to reach the terminal depth can be mixed within such layers, while artefacts which have not yet reached the terminal depth may retain their relative superposition (Atkinson 1957: 221-225; Wood and Johnson 1978: 321-328; Rolfsen 1980: 119; Stein 1983: 280; Johnson 1989; McBrearty 1990; Johnson and Balek 1991; Vermeersch and Bubel 1997: 126; Leigh 1998; Balek 2002: 43; Johnson 2002: 8, 24, figs. 5A, 6-9; Peacock and Fant 2002; Van Nest 2002, 62-63, 77, 79; Canti 2003: 139-142; Johnson et al. 2005a: 40, tab. 1; Johnson et al. 2005b, 21-22, tab 1). Simultaneously, earthworm activity causes thorough mixing of the fine fraction resulting in blurring or obliteration of different types of layers and features. At an archaeological site earthworm activity may for example completely destroy original living surfaces and associated anthropogenic layers, upper parts of cut features (pits, ditches etc.) (Fig. 3: t_3–t_6) and buried soils under smaller mounds and embankments (Atkinson 1957: 225-227; Langmaid 1963; Rolfsen 1980: 117; Stein 1983: 280; Canti 2003: 142; Tryon 2006: 199). Abandoned occupational sites with their abundance of organic materials on which earthworms feed may even be preferred locations of their activity, while trampled and compacted ground at such sites may also result in the intensification of burial through earthworm casting. It is important to note, that burial and sinking effects, while very variable, can be achieved quite rapidly, as terminal depth of sinking can already be reached within only two decades[4] (Stein 1983: 280; Vermeersch and Bubel 1997: 126-127; Canti 2003: 141-142; Hanson et al. 2009: 243-245).

The activities of larger burrowing animals can also contribute to the downward sinking of coarse fragments, while they also oppose it and their influence on the movement of coarse fragments within the soil is much more pro-isotropic (Fig. 4). The activities of animals such

[4] The speed of sinking is fast enough that its influence must already be considered in criminal investigations of 6-12 months old events (Hanson et al. 2009: 245).

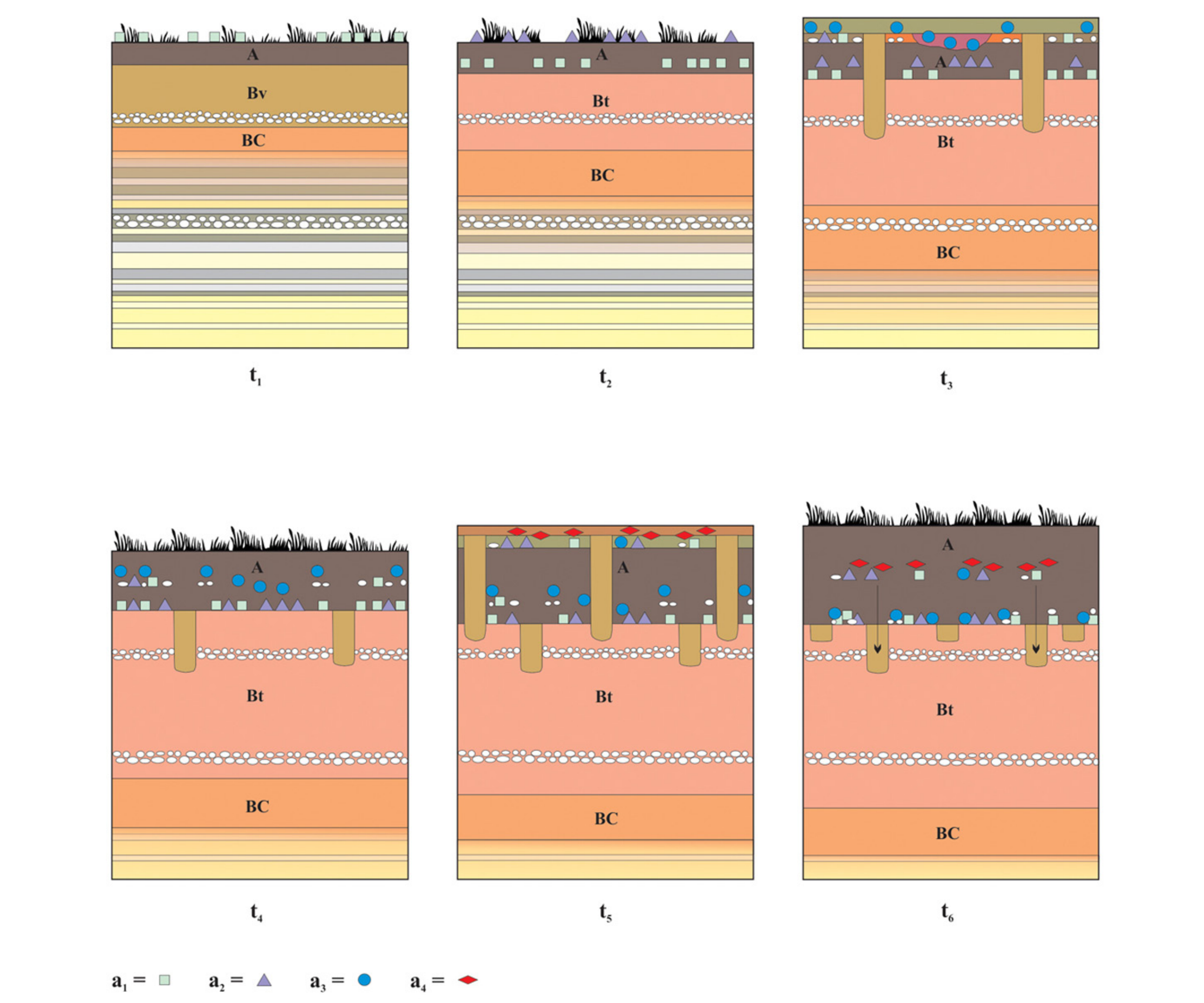

FIGURE 3. Hypothetical profile of a multiperiod archaeological site subjected to the process of biomantle formation. At the first time of observation (t1), artefacts of the first period (a1) are deposited on the natural soil surface. By the t2, these have sunk down into the A horizon but have not yet reached terminal depth, while a2 artefacts are deposited on the surface. At the t3, some settlement remains are visible, consisting of post hole pits, earthen floor and a fireplace in the house interior, an anthropogenic layer on the house exterior and a destruction layer covering and burying the remains. By this time, a1 artefacts have already sunk to the terminal depth, while a2 artefacts have not and thus still preserve some relative stratigraphic relation with a1 artefacts. Because the construction of the house involved digging into the soil, some of the a1 and a2 artefacts have been translocated to the surface and mixed into cultural layers of the third period (anthroturbation). By the t4, the layers and features of the third period which were present on the surface or within the A horizon have been thoroughly mixed and obliterated by bioturbation. The artefacts connected with the occupation of the house (a3) have sunk into the A horizon and their position in the profile no longer corresponds to the original occupation surface. Beneath them, a1 and a2 artefacts are mixed within the artefact line or layer. Because of anthroturbation some of them are also located higher within the profile. At t5, some settlement remains of the fourth period (a4) are visible on the surface. These are represented with artefacts, post holes, anthropogenic layer and a destruction layer covering and burying the remains. The a3 artefacts have sunk deeper but have not yet reached terminal depth, thus still preserving some relative stratigraphic relations to the older artefacts which are already mixed at the bottom of the A horizon. Due to anthroturbation some older artefacts were translocated and mixed into the anthropogenic layer of this period. At t6, the layers and features of the fourth period (a4) have again been thoroughly mixed and obliterated within the A horizon. Artefacts of the fourth period (a4) have sunk into the A horizon and no longer correspond to the original occupation surface. At the bottom of the A horizon a1–3 artefacts are mixed within the artefact line or layer, while due to anthroturbation some of them are also located higher within the profile, near to a4 artefacts. With time some of these artefacts may sink into cut features and become incorporated into their fill, thus complicating the original context of the site even further. The only remains preserved of the houses in the third and fourth period are parts of post holes which reach into the B horizon and have thus not been subjected to intense bioturbation. A typical site subjected to this kind of formation processes will thus consist of shallow pit remains preserved only within the B horizon, of a naturally formed layer of translocated and mixed artefacts belonging to different occupation periods located just above the B horizon or at the bottom of the A horizon, and some possible levels of artefacts within the A horizon which have not jet sunk to the terminal depth. All anthropogenic layers, occupation surfaces and shallow features such as fireplaces will be absent. Legend: t = time of observation; a = artefacts of different periods.

as rodents, moles, rabbits, badgers, foxes, wild boars etc., who burrow, make dens, excavate, scratch or in other ways impact the soil, as well as the activities of humans, all cause different types of disturbances including coarse fragment movements and rearrangements (Dunwell and Trout 1999; Johnson et al. 2005b: 20-22, tab. 1). The type of movement and the size fraction of fragments affected depends on the species, size and type of burrowing or excavating behaviour of the animal in question. Because of their activity, coarse fragments are subjected to movement in the upward and downward direction as well as laterally (Rolfsen 1980: 116; Bocek 1986; Johnson et al. 1987: 283-284; Balek 2002: 42, 46; Araujo and Marcellino 2003).

Coarse fragments, including archaeological artefacts, can also be mixed within the soil and brought to the surface through tree-uprooting or treethrow (Fig. 5) which

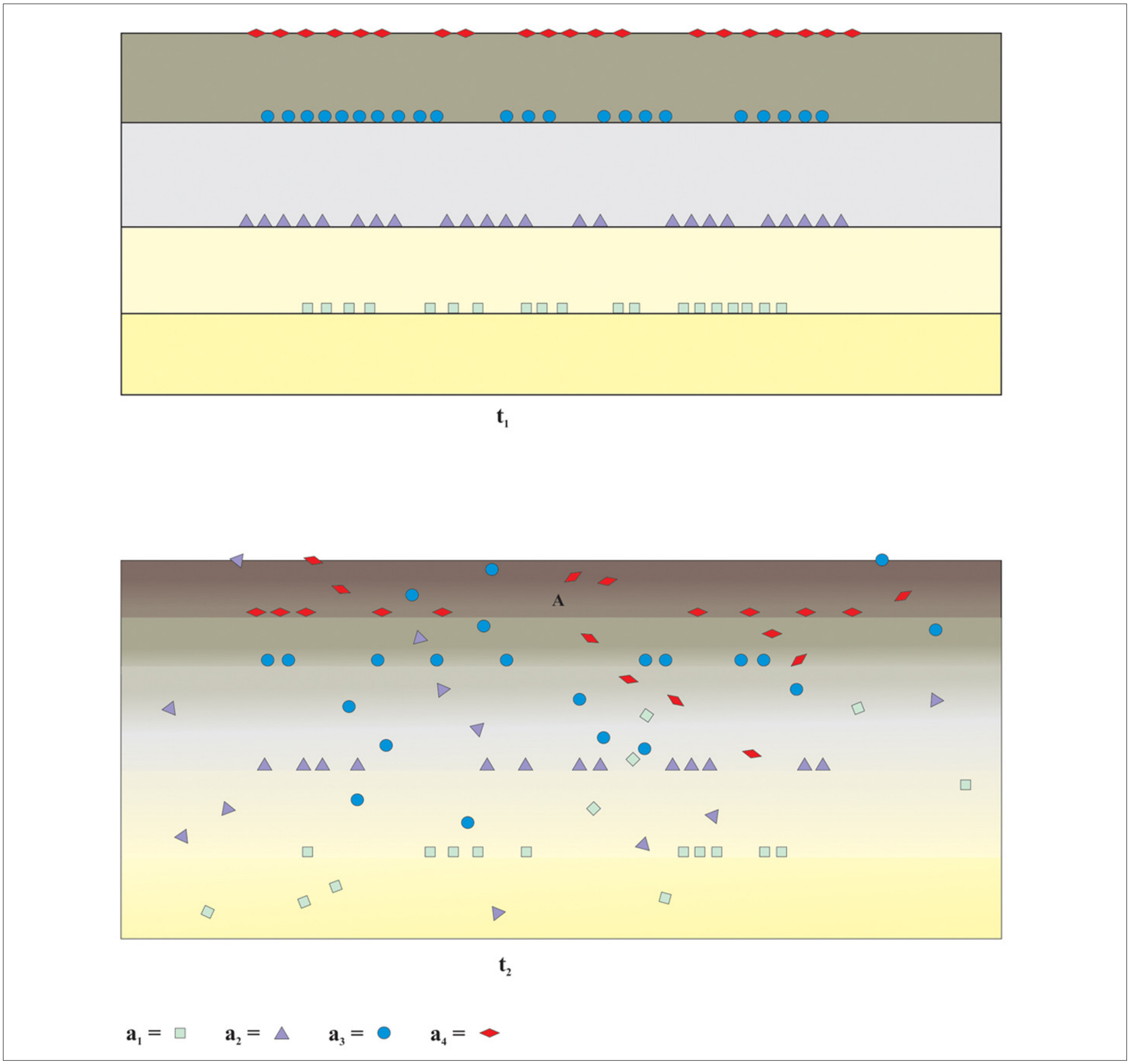

FIGURE 4: Hypothetical example of archaeological stratigraphy affected by faunalturbation by small burrowing mammals. Artefacts which were located on the surface (t1, a4) have sunk to the bottom of the newly formed A horizon. All levels have been disturbed and artefacts translocated in all directions. The artefact densities of original distributions have decreased and parts of original associations have been lost. However, the depth distribution of artefacts still indicates the original deposition levels of each period. Due to mixing the boundaries between layers have started to blur (created after the models in Johnson et al. 1987: Figs. 12-13; Araujo and Marcelino 2003: Figs. 2, 8-11; Schaetzl and Anderson 2005: Fig. 13.59).

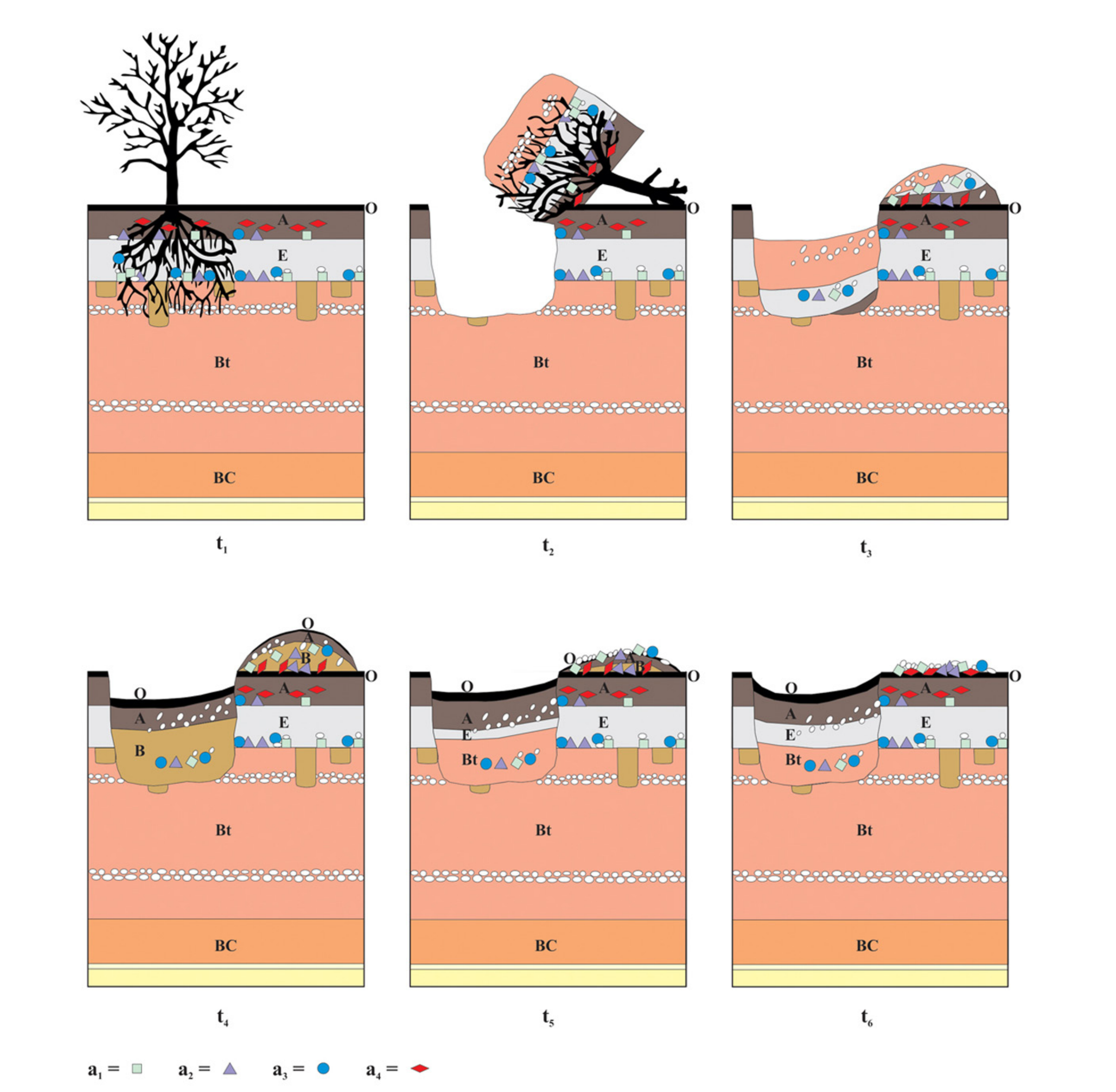

FIGURE 5. Hypothetical example of treethrow effects on the archaeological record. A tree growing on an archaeological site (t1) is uprooted, displacing a larger volume of the soil (t2) and thus damaging and reworking a part of the archaeological record. Part of the volume falls into the pit and part on the ground surface next to it, forming a characteristic pit and mound microtopography (t3). In this simplified hypothetical example, soil horizons are inverted while the artefacts are translocated and mixed. New soil formation begins both in the pit fill and mound material (t4–t6) (shown in a simplified manner, for concrete examples see Schaetzl 1986, fig. 2-3; Schaetzl and Follmer 1990: 3; Šamonil et al. 2013, fig. 5; Šamonil et al. 2016, fig. 2. Note that the scenario also has implications for anthropogenic mounds, pits and similar features.). With time the mound is eroding while the pit is filling with materials from its surroundings (t5–t6). The erosion of the mound leads to the formation of a concentration of artefacts and other coarse fragments on the surface in form of a lag concentrate (t6) (created after models in Schaetzl et al. 1989: Fig. 1-2; Norman et al. 1995: Fig. 2; Schaetzl and Follmer 1990: Figs. 1, 4).

represents the most studied process of floralturbation also referred to as arboturbation. This is a process in which the tree falls together with most of its larger roots intact. This can disrupt and move a considerable volume of soil or sediment material, causing bending, mixing or even complete inversion of soil horizons or stratified layers. Furthermore, treethrow is also an important cause for bringing coarse fragments including very large rocks

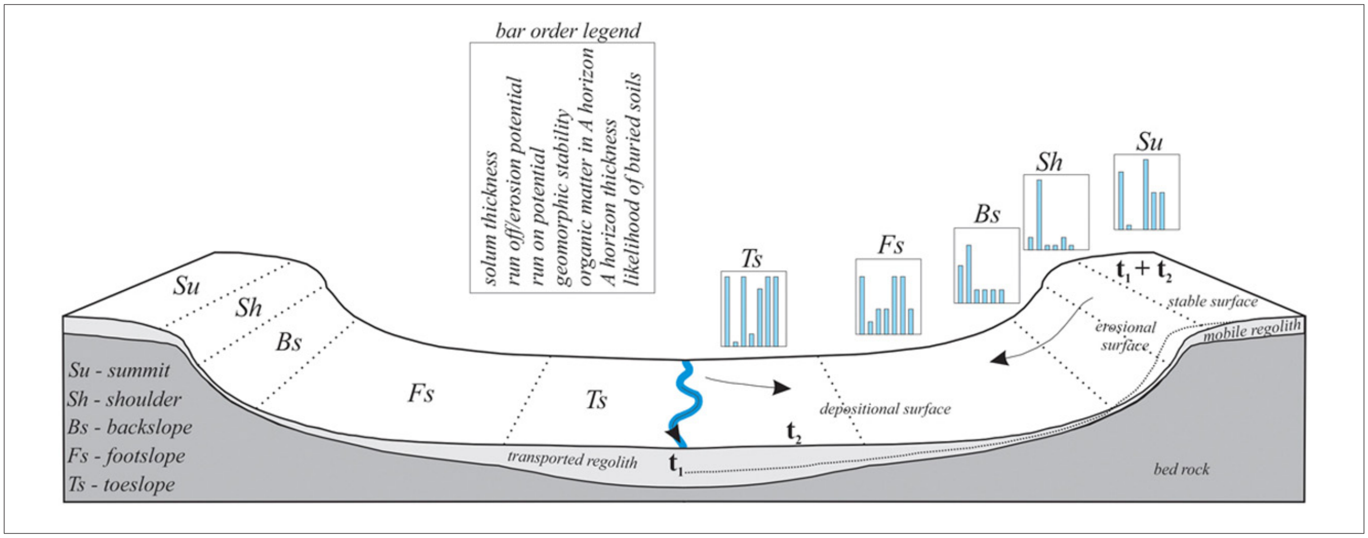

FIGURE 6. Model of five slope elements in an open drainage catena. The bars indicate relationships between soil characteristics and geomorphic processes along the slope. Arrows indicate general directions of sediment transport by water and gravity (colluviation downslope, bedload and suspended load downstream, and overbank deposition of suspended load or alluviation). The time transgressive nature of geomorphic surfaces (stable, erosional and depositional) is indicated on the left by the dotted and full-line and the position of each surface at time1 (t1) and time2 (t2) (created after the models in Schaetzl and Anderson 2005: Figs. 13.2, 13.4, 13.10; Schaetzl 2013: Fig. 3).

and stones to the surface. In all forests uprooting is a very common and widespread process due to either catastrophic events influencing the whole forest or ubiquitous and constant uprooting of individual trees. Thus, through a longer time span this temporally and spatially discontinuous process may encompass a very large part of the landscape (Schaetzl 1986: 181; Schaetzl et al. 1989: 5-7, tab. 2; Schaetzl et al. 1988: 166-167; Schaetzl and Anderson 2005: 243-244). For central European beech forests it is generally estimated that a third of all trees die due to uprooting, that the whole forest area is submitted to this process within the time span of 900-1400 years and that at the same location it is repeated every 500-3000 years (Šamonil et al. 2013: 127; Šamonil et al. 2015: 589; Šamonil et al. 2016: 55-56). This has some strong implications for archaeology. Namely, it seems that many archaeologists presume that archaeological sites in forested areas are well preserved because they were not subjected to cultivation[5]. However, whole forested areas may be naturally "ploughed" and disturbed within the span of approximately two millennia. Among other consequences, this also leads to increased concentrations of coarse fragments on the surface, allowing detection with the surface survey.

[5] At the same time, it is also often presumed that areas not subjected to modern cultivation somehow escaped anthropogenic reworking and disturbance despite, among other things, the fact that much land has been taken out of agricultural production in the recent past (Padgett 1994: 37).

Geomorphic processes

Geomorphic processes strongly influence both soil and archaeological record formation. Therefore the ability to identify areas of erosion, transport and deposition of material (alluvial or colluvial) as well as the areas of no erosion and deposition is a prerequisite for the study of any landscape as well as of soils and archaeological record within it. The interplay between geomorphic and pedogenic processes, which is in large part determined by topography (Fig. 6), will determine the nature, completeness and variability of the archaeological record both on the scale of the landscape as well as individual sites (Ferring 1986; Waters and Kuehn 1996: 485; Mandel and Bettis 2001: 181-183; Barton et al. 2002: 186-187; Stafford and Creasman 2002; Goldberg and Macphail 2006: 59-60, 73).

On stable surfaces (Fig. 6), the archaeological record will be most strongly subjected to pedogenic processes causing horizonation (Fig. 2) since soils in such locations are deep and well developed. In the absence of anthropogenic sediment depositions, the burial of the archaeological record on such surfaces will be shallow and primarily caused by bioturbation. Because of the low rate or even absence of sedimentation, the remains of different phases of past human activities such as occupation will be mixed in the form of a palimpsest and concentrated within the A horizon or in the stone-line at its bottom (Fig. 3). In these circumstances, higher artefact

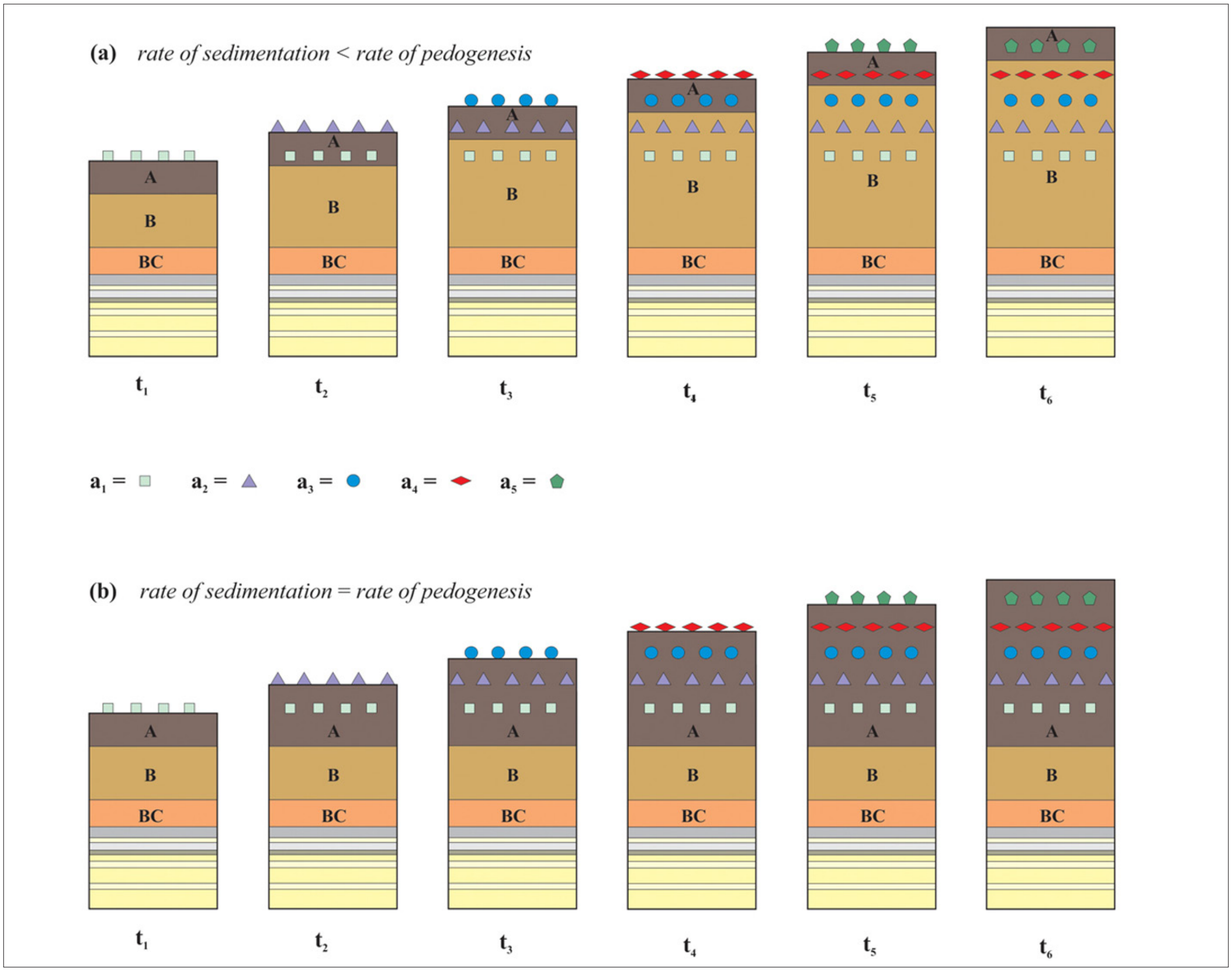

FIGURE 7. Hypothetical profiles of upbuilding soil with archaeological remains of different periods. (a) Developmental upbuilding. Artefacts deposited in different periods as well as sediment additions (natural or anthropogenic) first become incorporated into the A horizon and later into the B horizon. All levels of deposition will with time become part of the upbuilding B horizon and will be discernible only through the relative stratigraphic relations preserved in artefact positions within the overthickened B horizon. (b) Cumulisation. Artefacts deposited in different periods, as well as sediment additions (natural or anthropogenic) are becoming part of the upbuilding A horizon. The levels of deposition will be discernible only through positions of the artefacts within the overthickened A horizon. Legend: t = time of observation; a = artefacts of different periods (created after the model in Holliday 2004: Fig. 2-4; Schaetzl and Anderson 2005: Fig. 12.78; Lowe and Tonkin 2014: Fig. 1-2).

densities and unclear spatial patterns can be expected (Ferring 1986: 264-265; Leigh 1998; Mandel and Bettis 2001: 175, 185; Balek 2002; Van Nest 2002; Holliday 2004: 142-143).

On erosional surfaces (Fig. 6), the influence of removals on the archaeological record will be mainly conditioned by the strength of erosional processes. Erosion caused by surface runoff and wind action gradually lowers the surface and soils are consequently shallow and weekly developed. Because of soil erosion, the borders of soil horizons constantly migrate downward as the A horizon gradually develops in the previous B horizon and the B horizon in the unmodified parent material below (Fig. 8b). Such soil erosion may gradually destroy buried archaeological layers while constant removal of fine soil particles causes the surface to become enriched with coarse fragments in the form of surface lag concentrate or carpetolith (Fig. 8b: t_2–t_3, t_5–t_6). In such circumstances, the archaeological artefacts from different phases of past human activities will be concentrated and mixed in the form of a palimpsest on the surface. Thus high densities of surface artefacts and unclear spatial patterns can be expected. On the other hand, strong erosion phenomena such as many mass movements can remove large bodies of soil and archaeological record if present and transport their material over a long distance in only a single catastrophic event (Fig. 8b: t_3–t_4). Archaeological material transported in this way will not contain any patterns related to its primary deposition (Birkeland 1984: 184; Ferring 1986: 264-265; Bintliff and Snodgrass 1988: 508-512; Schaetzl and Anderson 2005: 169, 456).

On depositional surfaces (Fig. 6) sedimentation causes the surface to gradually grow upward (Figs. 7–8a). On such surfaces, the main pathway of soil formation is through upbuilding in contrast to top-down pedogenesis through horizonation. Soil upbuilding relates to natural or anthropogenic additions of mineral or organic material to the soil surface causing upward thickening or growth of the soil profile. Depending on the relationship between the rate and amount of additions and the rate of pedogenesis there can be three main scenarios of soil upbuilding resulting in different types of cumulative soil profiles: developmental upbuilding, cumulisation and soil burial (Birkeland 1984: 184-185; Johnson 1985: 30; Cremeens and Harth 1995: 24; Holliday 2004: 90-96, Fig. 5.9; Schaetzl and Anderson 2005: 456-460, Fig. 12.78).

All three scenarios of cumulative soils are very important from the archaeological point of view. First two scenarios of developmental upbuilding and cumulisation are characteristic for low energy depositional surfaces and result in overthickening of the B and A horizon respectively. In both cases, slow accretion contributes to the burial of archaeological record, which generally positively affects its preservation and stratification. However, because burial is slow the archaeological record will still be quite heavily reworked by surface and pedogenic processes. In the case of cumulisation (Fig. 7b) (see Birkeland 1984: 185; Schaetzl and Anderson 2005: 458-459; Jacobs and Mason 2005: 97-100; Schaetzl 2013: 149), the archaeological record once deposited on the surface will be located within the overthickened A horizon and subjected to dynamic processes characteristic for this topsoil layer. In the case of developmental upbuilding (Fig. 7a) (see Birkeland 1984: 184; Almond and Tonkin 1999: 3; Schaetzl and Anderson 2005: 458; Eger et al. 2012: 499, fig. 4; Lowe and Tonkin 2014: 34-35, Fig. 1), the archaeological remains will at first be subjected to processes characteristic for A horizon formation and later to the processes of the overthickening subsurface B horizon into which they will gradually become incorporated. Homogenization and eventual loss of original sediment structure are characteristic for both A and B horizons (Goldberg and Macphail 2006: Tab. 3.4; Buol et al. 2011: 46; Weil and Brady 2017: 90). Therefore in both scenarios, the relative superposition may be discernible only on the basis of preserved levels of artefacts or/and other durable remains. The levels of different phases of occupation will thus be located within a uniform overthickened B or A horizon. In such circumstances relying on texture and colour differences of the matrix in order to discern stratigraphy of the site will not be effective.

In the case of more rapid gradual additions or sudden additions of a large volume of sediment the soil gradually or rapidly becomes buried and new soil starts to form in the fresh sediment (Fig. 8a) (Schaetzl and Anderson 2005: 459). The presence of buried soils within the stratigraphic sequence of the site is very important because buried soils represent a longer period of past surface stability which is needed for their formation. Generally, the degree of development reflects the relative duration of soil formation[6], thus weakly developed soils indicate short intervals of surface stability while strongly developed soils indicate longer periods of stability[7]. Burial with new sediment, on the other hand, reflects the instability of the surface, a change in the environmental conditions, and in comparison with soil formation a much shorter period of time. In certain conditions, especially in the case of catastrophic events, large volumes of material can be deposited very suddenly. Even though burial generally aids to the preservation of archaeological record and to its stratification a long period of stability before burial means that archaeological remains have been exposed to reworking by surface and near-surface processes for a longer period of time. Buried soils, especially well-developed ones, may thus contain a palimpsest of remains of subsequent phases of past human activities which will be concentrated in the area of the A horizon (Figs 3; 8a: t_1) and heavily reworked. However, in the case of a sudden burial, a simultaneous erosion of the upper part of the soil may occur and is expressed by the absence of the A (and E) horizon (Fig. 8a: t_3–t_4). Identification of this is important as it may have caused the destruction and removal of the archaeological record formed before the deposition of the new sediment. Erosion before burial may also result in welding of the

[6] For estimates of the time needed for the development of some of the soil types see for e.g Alexandrovskiy (2007).

[7] Though this rule is complicated in the case of polygenetic soils and processes causing rejuvenation of soil profiles (Johnson and Watson-Stegner 1987), such as bioturbation (e.g. Langmaid 1964). All soils at archaeological sites may be considered polygenetic, because there have been at least three stages of development with differences in soil -forming factors (Jenny 1994): (1) initial natural conditions before occupation, (2) conditions durring occupation (addition of the anthropogenic factor; see Schaetzl and Anderson 2005, 317-320; Howard 2017: 58-60), and (3) conditions after occupation.

buried B horizon and the B horizon of the soil developing in the new parent material (Fig. 8a: t_3–t_5). Identification of this is important for the stratigraphic sequence as the welded B horizons are not genetically linked and contemporaneous but subject to the law of superposition. Such welding, on the other hand, can also be caused by the blurring of the buried A horizon through formation processes of the new soil (Fig. 8a: t_5–t_6) (Holliday 1988: 530; Ib. 1990: 530; Ib. 2004: 90-91, 140-143, 285, Figs. 5.10, 7.1; Cremeens and Harth 1995: 20-21; Mandel and Bettis 2001: 187; Goldberg and Macphail 2006: 62).

Archaeological remains in soil context and archaeological stratigraphy

By touching upon only a few types of soil formation and soil geomorphology processes it has been demonstrated that these essentially result in archaeological remains becoming part of soil context. The concept of archaeological remains in soil context (see Anderton 2000) differs from that of archaeological stratigraphic context and represents a problem for the application of archaeological stratigraphic excavations, principles of archaeological stratigraphy and Harris matrix (see Harris 1979; Ibid. 1989). This is because the archaeological stratigraphy is conceptualised as composed especially of events such as deposition, construction, destruction, digging, erosion, etc., and by longer periods of duration which may be represented by interfaces, e.g. living surfaces, as some of the most important units of archaeological stratigraphy (see Harris 1989; Davies 2015). However, the concept does not involve in situ transformations of these types of remains by long-term processes of soil formation.

The excavation of stratigraphic units in the reverse order of their formation is based especially on the observation of differences in texture, colour and composition of layers and the observation of their tridimensional forms and boundaries while artefacts themselves are supposedly not that important in these observations (Harris 1979; Brown and Harris 1993: 10). Stratigraphic units of layers and interfaces represented by their upper boundaries give stratigraphic context to related artefacts and superposition of the units determines their relative temporal relations. Soil horizons differentiated according to colour, texture, etc., also appear as layers in superposition, however, they are not related to deposition, boundaries between them do not represent interfaces known in archaeological stratigraphy and the principle of superposition does not apply to them. Soil horizons reflect long-term pedogenic processes and when belonging to the same soil they are contemporaneous, while artefacts within them are not related to the time reflected by the soil or soil horizons in which they are encountered. In the presence of soils, the observation of artefacts (as well as other types of coarse fragments and durable archaeological features) in the soil context thus becomes crucial for the process of excavation. At a site altered by pedogenesis, these may be the only remains still reflecting the original stratigraphy which is no longer recognizable through the observation of the matrix in which they are encountered (Fig. 2). On the other hand, some post-depositional pedogenic (e.g. bioturbation, Fig. 3) and geomorphic (e.g. erosion; Fig. 8b) processes may produce levels of artefacts and visible remains of cut features which no longer correspond to surfaces or interfaces on which they were originally deposited or from which they were originally dug. Recognition of these types of post-depositional processes is thus crucial from the point of view of the excavation methodology itself as well as types of observations and recordings used which also condition the final interpretation of the site.

Differentiation between features and properties resulting from geogenic, pedogenic and anthropogenic processes and events is needed because all of these cannot be interpreted with the use of the same sets of stratigraphic principles. Therefore, sites formed by a mix of these processes require recognition of at least three different types of stratigraphies which represent different sets of information about them. These are lithostratigraphy, pedostratigraphy, and archaeological stratigraphy (Courty et al. 1989: 31-32, Fig. 2.2; Goldberg and Macphail 2006: 28, Fig. 2.1) (Fig.9; Tab. 1).

On one hand, it is important to recognize lithologic or lithostratigraphic units (see Gasche and Tunca 1983: 327-329; Stein and Holliday 2017: 34-35) which reflect the sedimentation at the site and possible changes in sedimentation environments or processes of sedimentation through time. The processes of sediment deposition[8] may be natural or anthropogenic and the principle of superposition applies to these depositional units (Fig. 9a). However, in a natural open-air environment, these units will inescapably be more or less reworked by processes of soil formation (Fig. 9b).

A soil with its horizons represents a single pedostratigraphic unit because soil horizons are contemporaneous. The upper boundary of the pedostratigraphic unit corresponds to the top of the topmost soil horizon while

[8] For descriptions of various natural and anthropogenic deposition processes relevant at archaeological sites and resulting sediment properties see Karkanas and Goldberg 2019: 21-148.

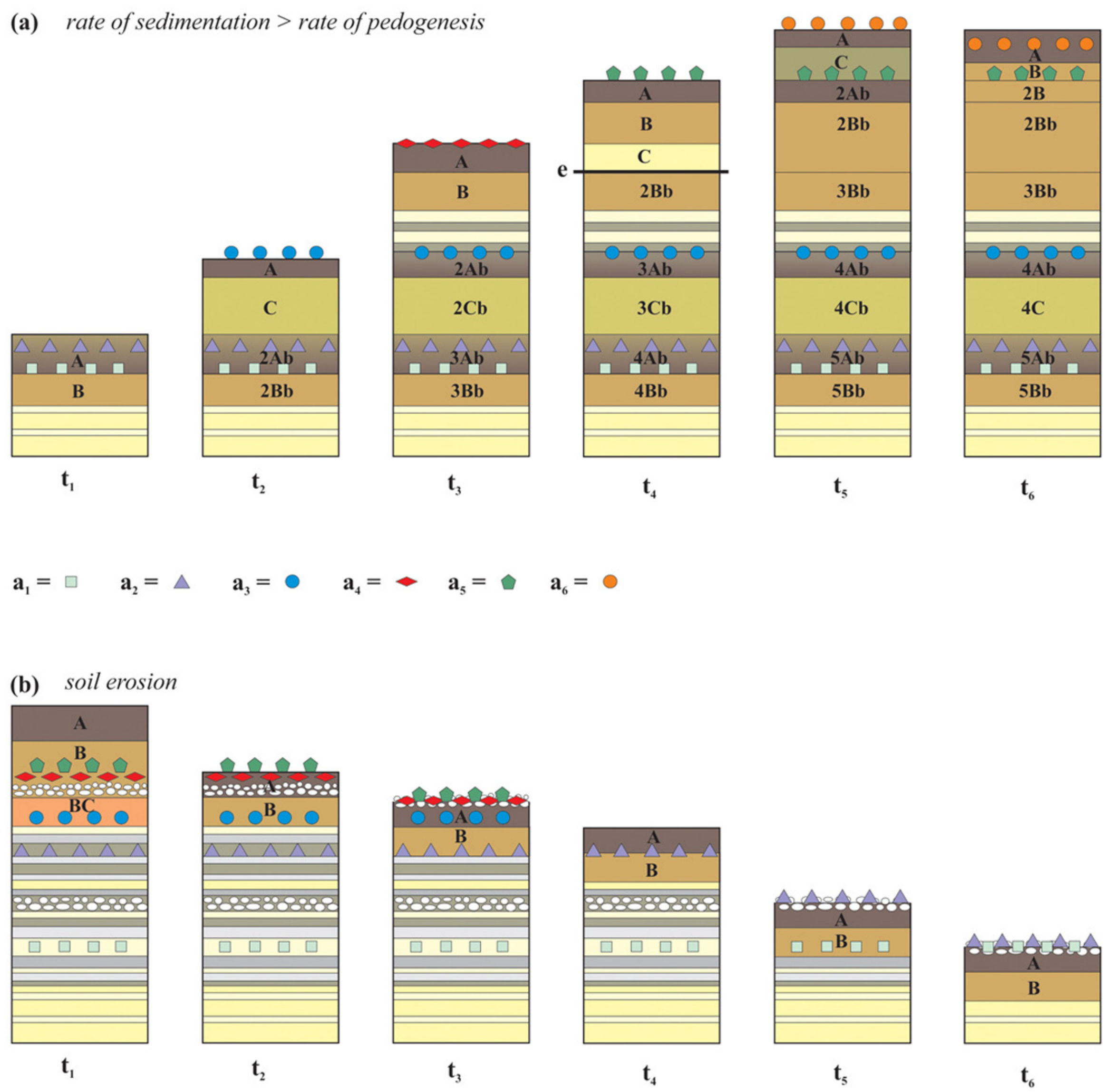

FIGURE 8. (a) Hypothetical sequence of buried soils at an archaeological site. Before t1 there were two phases of deposition of archaeological material. The first has sunk into the A horizon due to bioturbation and the second was incorporated into a cumulic A horizon through slow sediment additions. In between t1 and t2 deposition of a thick layer of sediment occurs and during a short period of stability only a weak A horizon forms and some archaeological material is deposited on its surface. This is followed by a sequence of thin sediment depositions in between t2 and t3. Initially, the material is incorporated into the soil profile and the A horizon appears cumulic but becomes buried later on. New soil develops in the stratified sediment and archaeological material is deposited on its surface. In between t3 and t4 the soil is buried by a thick layer of sediment, before the deposition of which erosion occurs and removes the A horizon together with the archaeological material. With further soil development in between t4 and t5, the new and the buried B horizons become welded together. This is followed by a deposition of a layer of sediment burying the soil. In the initial stage of soil formation, an A horizon develops on the new parent material and some archaeological material is deposited on its surface. In between t5 and t6 further soil development on a stable surface transforms the buried A horizon into the B horizon of the new soil while the archaeological material is buried by bioturbation. (b) Hypothetical profiles of soil erosion at an archaeological site with weakly developed soil migrating downward into the stratified material. In between t1 and t3 gradual soil erosion causes archaeological artefacts of different phases to be exposed on the surface in the form of a lag concentrate. In between t3 and t4, a stronger erosional event removes part of the soil together with archaeological artefacts. In between t4 and t6 gradual soil erosion again causes artefacts of different phases to be exposed in the form of a lag concentrate. Legend: t = time of observation; a = artefacts of different periods; e = eroded surface (created after the model in Johnson and Balek 1991: Figs. 1-4; Holliday 2004: Fig. 2-4; Schaetzl and Anderson 2005: Fig. 12.78; Lowe and Tonkin 2014: Fig. 1-2).

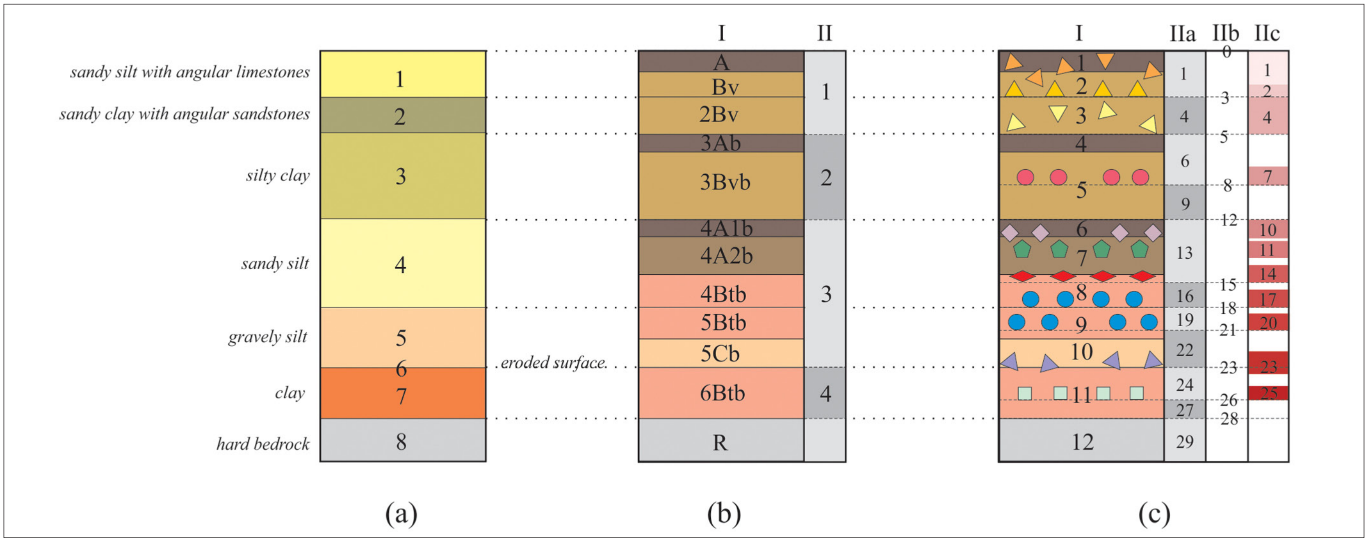

FIGURE 9. A hypothetical example of the same profile in terms of (a) lithostratigraphy, (b) pedostratigraphy, and (c) archaeological stratigraphy in soil context. (a) The profile is differentiated into lithostratigraphic units, determined on the basis of sediment composition, texture and bedding. Each of them represents differences in past sedimentation environments at the observed location in the landscape. The profile is composed of seven lithostratigraphic units and an eroded surface, to which the stratigraphic law of superposition applies. (b) The profile is differentiated on the basis of different soil forming periods at the observed location, which occurred during periods of surface stability in the past landscape. The soils formed in parent materials, which are represented by lithostratigraphic units of the first example. The profile is composed of four pedostratigraphic units (II), which represent four soil forming periods and to which the law of superposition applies, while it does not apply to soil horizons within a particular pedostratigraphic unit. Soil formation, expressed by the development of soil horizons, thus represents post-depositional processes, which reworked the original state of deposition of lithostratigraphic units. Boundaries between these lithostratigraphic units represent lithologic discontinuities reflecting the original geologic stratigraphy of the location. (c) The third example depicts the stratigraphy of the profile from the standpoint of archaeological remains it contains. The differentiation of the profile, marked as I, shows the differentiation based on texture and colour differences of layers in the profile. This differentiation corresponds to the pedological differentiation of the profile and reflects post-depositional processes of soil formation. Interpreting this as a stratigraphic sequence would lead to misunderstanding of the geological, pedological and archaeological record at the location. In the case of an appropriate archaeological differentiation of the profile (II), different phases of sedimentation (IIa), discerned past surfaces or interfaces (IIb) and archaeological remains (IIc) are documented. The last reflects the past human activities, which represent archaeologic discontinuities in the profile. These allow additional past surfaces and phases of sedimentation to be discerned in comparison to those reflected in lithostratigraphic and pedostratigraphic characteristics of the profile. In the interpretation (Table 1) of the archaeological record, past landscape in which it was deposited as well as its post-depositional modifications, all three presented ways of observation must be taken into account (modified after the model in Courty et al. 1989, Fig. 3.3; Goldberg and Macphail 2006, fig. 2.1).

its lower boundary corresponds to the bottom of the lowermost soil horizon, usually, the B horizon, while the C horizon is excluded (Finkl 1980; Cremeens and Harth 1995: 18). If several pedostratigraphic units are present in the profile the law of superposition applies to them and reflects the sequence of periods of landscape stability separated by periods of instability, during which sedimentation occurred (Fig. 9b: II). If the soil has formed in more than one lithologic units their previous stratigraphy might be recognised in the form of lithologic discontinuities. These are thus parts of the soil developed in more than one kind of parent material such as stratified sediments. However, if not reflected by differences in coarse fragments (e.g. gravels and artefacts in Figs: 1b–2) the boundaries between these may be very hard to recognise during macroscopic observations. In soil profile description the presence of lithologic discontinuities is expressed by Arabic numerals added as prefixes to the main horizons, e.g. B, 2B, 3B etc., where the B horizon has developed in the uppermost parent material, the 2B in the underlying parent material etc. (Scahetzl and Anderson 2005: 37; Ahr et al. 2017). Thus each horizon labelled in this way represents the presence of lithostratigraphy which has been blurred by pedogenic processes (Fig. 9b: I).

The remains of human activities or the anthropogenic deposition of materials may correspond to lithologic discontinuities (Fig. 9c; Tab. 1: SU 4). This will happen especially in cases of distinctly anthropogenic layers of different composition (e.g. sequences of urban sites, sequences of tell settlements etc.). However, there may also be several levels of archaeological remains present within a single natural lithostratigraphic[9] or pedostrati-

[9] In the sense of units belonging to the same natural sedimentation environment, while they can be composed from a hierarchy of layers corresponding to individual depositional events (e.g. individual floods) (Gasche and Tunca 1983: 328-329; Stein 1990: 514-516).

SU	INTERPRETATION
0	Modern soil surface.
1	Roman period landfill with material belonging to the end of the 1st century and beginning of 2nd century AD.
2	Remains of a Roman period building with material belonging to the middle and 2./2 of the 1st century AD.
3	The surface of landfill SU 3, on which human activity SU 2 takes place.
4	Roman period landfill with material belonging 1./2 of the 1st century AD.
5	Soil surface on which human activity SU 4 takes place.
6	Period of sedimentation.
7	Remains of a wooden Iron Age house.
8	The surface on which human activity SU 7 takes place.
9	Period of sedimentation.
10	Late Bronze Age settlement pottery remains, which have sunk into the A horizon due to bioturbation. The reworked state of the assemblage is actually contemporaneous with the soil surface SU 12. However, because it retains its relative stratigraphic relation with SU 11, it is interpreted as younger than the soil surface SU 12 as well as settlement remains SU 11.
11	Early Bronze Age settlement pottery remains, which have sunk into the A horizon due to bioturbation. The reworked state of the assemblage is actually contemporaneous with the soil surface SU 12. However, because it retains its relative stratigraphic relation with SU 10, it is interpreted as younger than the soil surface SU 12 and older than settlement remains SU 11.
12	Soil surface on which two phases of human activities SU 11 and 10 took place.
13	Period of sedimentation.
14	Mesolithic hunting camp.
15	The surface on which human activity SU 14 takes place.
16	Period of sedimentation.
17	Upper Palaeolithic station.
18	The surface on which human activity SU 17 takes place.
19	Period of sedimentation.
20	Middle Palaeolithic butchering site.
21	The surface on which human activity SU 20 takes place.
22	Period of sedimentation.
23	The absence of the A horizon indicates an erosional surface, on which a surface lag deposit of Middle Palaeolithic stone tools is located. The tools indicate human activities which are older than the erosional surface. However, the reworked state of the tool assemblage is contemporaneous with the erosional surface and thus documented with the same SU number.
24	Period of sedimentation.
25	Lower Palaeolithic butchering site.
26	The surface on which human activity SU 25 takes place.
27	Period of sedimentation.
28	The surface of SU 29 or interface between SU 29 and 27.
29	Solid bedrock.

TABLE 1. Interpretation of the archaeological record of the hypothetical profile in Fig. 9c: IIa–c. It can be seen that the complexities introduced into the record by geomorphic and pedogenic processes may defy the law of superposition (see SU 23, 12, 11, 10). The sequence of stratigraphic unit (SU) numbers relates to the temporal interpretation of the record. Some stratigraphic units reflecting human activities (figure 10c: IIc) no longer correspond to the surfaces or levels on which these activities actually took place. Each phase of human activities is in a simplified manner labelled with only one SU number, while most of them would actually be composed of several different units, related to different types of remains of each phase.

graphic unit (Fig. 9c; Tab. 1). When these represent the remains of primary deposition they correspond to past surfaces on which human activities had been played out. In such cases, they can also be referred to as archaeologic discontinuities (Fig. 9c; Tab. 1: SU 26&25, 21&20, 18&17, 15&14, 8&7) (see for e.g. Fedele 1984: 12). These may be levels with any kind of archaeological remains or consequences of past human activities in situ (e.g. artefacts, anthropogenic layers, hearths, pits etc.).

Archaeological remains represent discontinuities which are present only at archaeological sites or areas with traces of past human activities in the landscape. During the observation of lithostratigraphic or pedostratigraphic profiles away from such areas these types of data about past landscapes which are of relatively fine spatial and temporal scale are not present. Also, during lithostratigraphic and pedostratigraphic profile observations at archaeological sites, many of the archaeologic discontinuities present at the site will not also be present or discernable in the observed profile. This may be because of their small spatial extent (e.g. small features which do not extend into the observed profile) or some other characteristics which make them invisible or hard to spot in the profile (e.g. a level with low artefact density). That is why many types of archaeologic discontinuities may be detected only during meticulous archaeological excavations and ground plan observations.

However, because of post-depositional reworking by geomorphic and pedogenic processes, some levels with anthropogenic remains and features may no longer correspond to original surfaces of past human activities and cannot be treated as archaeologic discontinuities. For example, a level with preserved parts of cut features, upper boundaries of which have been obliterated by bioturbation or erosion (Figs 3 and 8b) does not correspond to the level from which they had been dug and cannot be treated as an archaeologic discontinuity (Fig. 9c; Tab. 1: SU 10, 11). Similarly, a stone/artefact line/layer caused by soil erosion no longer corresponds to the original surface of artefact deposition and cannot be considered as an archaeologic discontinuity, though it could be considered as a lithologic discontinuity (Fig. 9c; Tab. 1: SU 23). On the other hand, a stone/artefact line/layer caused by bioturbation (Fig. 3) cannot be treated either as an archaeologic nor as a lithologic discontinuity but can be treated as a pedologic discontinuity (Ahr et al. 2017: 2, 4) to which the law of superposition does not apply.

The interpretation of the archaeological record thus requires the recognition of postdepositional processes which demands an interdisciplinary approach including the observation and recording of geogenic, pedogenic and anthropogenic processes and phenomena. On one hand, such an approach is crucial for the correct interpretation of data about past human activities and the understanding of their environmental context which represent some of the main goals of archaeological science. On the other hand, archaeological data can significantly contribute to the research of processes and phenomena studied by natural sciences such as geology and pedology. In this regard, the archaeological record in the landscape can be seen as a “natural laboratory” which without an interdisciplinary approach remains unthoroughly exploited while each such intervention into it causes a loss of data relevant to several disciplines.

Examples of archaeological remains in soil context

In the following text, three archaeological sites from Slovenia are briefly presented as potential examples of some of the discussed scenarios of the archaeological remains in soil context. The sites were chosen on the basis of data from their publications and/or field reports. Based on these it seems that the situations observed at these sites could be explained by some of the presented processes resulting in archaeological remains in soil context. However, the presented explanations are not certain as detailed interdisciplinary analyses would be needed to reconstruct their formation history. In this sense, the presented examples, on one hand, point to the potential explanatory power of theoretical models presented and on the other hand serve as a reminder that without an interdisciplinary approach, the excavated remains may never be properly understood and interpreted.

Cogetinci near Lenart

The site Cogetinci near Lenart (Fig. 10a) is located on a footslope and has the following recorded layer sequence (Fig. 10b). The surface brown layer SU 1 (0,14–0,40 m thick) was the ploughzone with only rare recent finds. In the lower part of the footslope, the ploughzone was underlied by a light yellowish brown loamy layer SU 2 which did not contain any finds and was interpreted as the parent material on which the modern cultivation took place. Under it lay a yellowish-brown silty loam layer SU 7 interpreted as a cultural layer which contained only Late Roman Period finds. This was underlied by a culturally sterile yellow silty loam layer SU 231, interpreted as a geological basis the upper boundary of which represent-

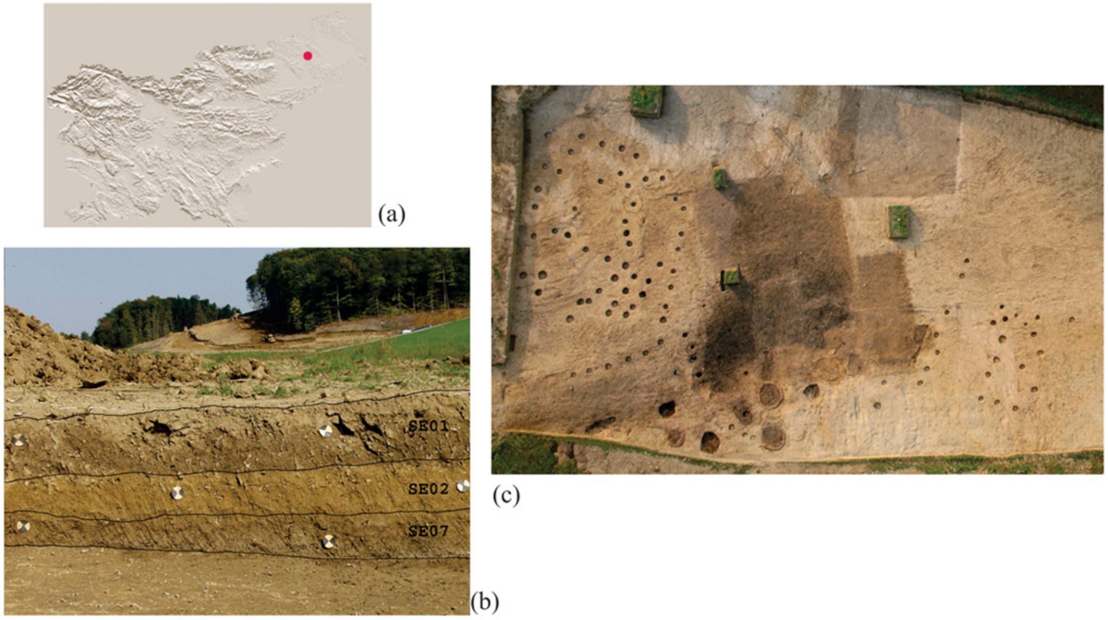

FIGURE 10. (a) Geographic position of site Cogetinci near Lenart (Horvat 2013: sl. 1). (b) Profile of layers at the footslope (Horvat 2007: sl. 3). Plough zone or Ap horizon (SU 1), formed on colluvium (SU 2 + 1), which buried the soil (SU 7 or Ab horizon and SU 231 or B horizon under it) dating to antiquity. (c) Remains of postholes for timber structures and pottery kilns preserved within the zone of the B horizon and belonging to a potter's workshop from the end of the 4th and 1st half of the 5th century AD (Horvat 2013: sl. 17).

ed the Late Roman living surface. Postholes, dumping pits and pits for pottery kilns were cut into this layer (Fig. 10c), together representing the remains of a countryside pottery workshop dating to the end of the 4th and first half of the 5th century (Horvat 2013: 11-12, 88).

The described layer sequence should, in fact, be interpreted as soil horizons representing two pedostratigraphic units (e.g. Fig. 8a: t_2). The "cultural layer" SU 7 represents the A horizon and layer SU 231 the B horizon of a buried soil. This pedostratigraphic unit was buried with material on which new soil began to form, with Ap (SU 1) and B, BC or C (SU 2) horizons together representing one pedostratigraphic unit. Soil burial[10] in the lower part of the site which isolated and protected the level with Late Roman remains is probably connected with soil erosion and damage of Late Roman remains in the upper part of the site. There the buried A horizon containing Late Roman artefacts was not preserved and modern ploughing reached directly into the SU 231 (Horvat 2013: 12). Thus, the present soil is temporarily transgressive as is typical for soils along a slope (Fig. 6).

However, the interpretation of the upper boundary of the buried B horizon (SU 231) as a living surface of the Late Roman pottery workshop poses a problem regarding the formation of the observed archaeological context at the site. Namely, the B horizon is a subsurface soil horizon, therefore it could not have been the living surface. The question is, whether the level interpreted as the living surface truly corresponds to the surface of the Late Roman activity and thus represents an archaeologic discontinuity or not? In the case it does, a scenario of developmental upbuilding (Fig. 7a) after the abandonment of the Late Roman pottery workshop should probably be supposed, because the upper boundary of the B horizon in the time of its operation must have been located below the living surface or top of the soil in Late Roman times. On the other hand, a post-depositional reworking of the site by processes in the biomantle (Fig. 3) could also explain the observed soil context of archaeological remains at this site. The fact that all Late Roman artefacts were located at the bottom of the buried A horizon (SU 7)[11] could correspond well with this scenario. In this

[10] The sedimentation process is not established in the report or the final publication.

[11] Personal communication with the excavator M. Horvat.

case, the upper boundary of the buried B horizon where dug features were preserved and directly above which the artefacts were discovered would not correspond to the actual living surface and thus would not represent an archaeologic discontinuity but instead a pedologic one. In this scenario, the Late Roman living surface would probably be located somewhere within the buried A horizon or correspond more or less to its upper boundary. This would imply that possible features such as earthen floors or fireplaces as well as upper parts of the dug features have been homogenized and destroyed by bioturbation processes, which have also caused artefacts to sink to the bottom of the A horizon and form an artefact line or layer. Knowing which of these two scenarios actually applies to this site would be important for the understanding of its post-depositional reworking, the integrity of discovered remains and estimation of data lost after the original deposition.

Nedelica near Turnišče

The multiperiod site of Nedelica near Turnišče (Fig. 11a) is located along a gently sloped longitudinal bar deposited by river Mura. The bar is composed of sandy gravel covered with sandy sediment. The sandy to sandy muddy[12] gravel (4* in Fig. 11: b, c, e) was deposited within the channel and the sandy sediment during occasional floods (Verbič 2006: 2; Šavel & Sankovič 2013: 6-7). In the geological report (Verbič 2006) there are three main layers recorded along most of the bar and these can be interpreted in terms of pedostratigraphy. Above the sandy gravel deposit (4*), lay a yellowish to reddish brown gravely sandy mud with iron oxides and signs of pseudogleying (3* in Fig. 11: b, c or SU 303 in Fig. 11: d) corresponding to the Bg horizon. Above it was a muddy sand layer rich in humus which gives it a dark greyish brown colour (2* in Fig. 11: b, c or SU 125 and 304 in Fig. 11: d) and corresponds to an A horizon. These two layers represent a soil formed on sediments of the longitudinal bar and thus a single pedostratigraphic unit. The soil was buried[13] as indicated by the lighter colour of the top layer (1* in Fig. 11: b, c or SU 1 and 2 in Fig. 11: d) which represents the modern ploughzone or Ap horizon and another pedostratigraphic unit. At the summit of the bar, the situation was somewhat different. There the buried A horizon (2* in Fig. 11: e and SU 4 (and 3?) in Fig. 11: f) was located directly above the sandy gravel (4* in Fig. 11: e and "gravel" in Fig. 12: f) and again under the lighter-coloured modern ploughzone (1* in Fig. 11: e and SU 1 and 2 in Fig. 11: f)(Verbič 2006: 2-4; Šavel 2007: 6-7).

That we are dealing with a buried soil under the modern ploughzone was already suggested in the geological report (Verbič 2006: 4), however, this information was omitted in the final publication of the site (Šavel and Sankovič 2013). Within the layer corresponding to the buried A horizon (2* in Fig. 11: b, c, e), the archaeological excavation recorded several different stratigraphic units in different parts of the site (eg. SU 125 and 4 in Fig. 11: d, f). They all have the same texture and dark brownish or brownish-black colour and seem to be differentiated primarily by lateral differences in coarse fragments, namely artefacts and gravels. No contacts and stratigraphic relations are reported between these stratigraphic units. They were interpreted as alluvial when containing gravels and cultural when containing artefacts. Such an example is the "Bronze Age cultural layer" SU 88 which contained a vast amount of Bronze Age pottery including even six whole vessels as well as some stone and pottery tools. However, it also contained some pottery from the Early Iron Age, Roman Period, Early Middle Ages and the Middle Ages. At this level, a number of Bronze Age and modern pits were detected while at the same time this layer "covered" other Bronze Age pits as well as an early medieval pit and an un-dated pit (Šavel and Sankovič 2013: 12, 58, 92-93, 95-96).

If this layer was to be understood as a depositional layer the presented situation of it covering a younger feature as well as its artefact assemblage would not make a lot of sense. However, if seen as archaeological remains in soil context it is possible to try to understand the situation. The mixed artefact assemblage can be understood especially through bioturbation processes within the A horizon. Whole vessels and a vast number of Bronze Age artefacts in the SU 88 are with no doubt related to deposition at the occupation level in that period wile a much lesser number of younger artefacts could be seen as infiltrated finds, probably primarily via bioturbation (Figs. 3 and 4). However, we cannot be certain whether the Bronze Age artefacts represent an archaeologic discontinuity or whether the mixed assemblage recorded as the

[12] Mud or muddy, used in the geological report (Verbič 2006), refers to a mixture of silt and clay fraction.

[13] The lighter colour of the ploughzone indicates new sedimentation, while the increasing thickness of the ploughzone from the top of the dune to its footslope is probably connected with transport of material by ploughing as mentioned in the publication (Šavel and Sankovič 2013: 7) and the geological report (Verbič 2006: 4).

FIGURE 11. (a) Geographic position of site Nedelica near Turnišče (from Šavel and Sankovič 2013: sl. 1). (b) Profile in trench 1 at the footslope of the longitudinal bar (from Verbič 2006: sl. 2). Layers representing the ploughzone or Ap horizon (1*), buried A horizon (2*) (which could be characterized as an anthropogenic *Au horizon after Howard 2017), buried Bg horizon (3*) and sandy muddy gravel (4*) are visible. (c) Detail of the profile in trench 1 shown in b with descriptions according to the geological report (from Verbič 2006: 2, sl. 3). (d) Archaeological drawing and description of the profile in trench 1 shown in b and c (Šavel and Sankovič 2013: 18, sl. 21). (e) Profile in trench 2 at the summit of the longitudinal bar, with descriptions according to the geological report (from Verbič 2006: 2, 3, sl. 6). (d) Archaeological drawing and description of the profile in trench 2 shown in e (Šavel and Sankovič 2013: 18, sl. 22). (g) Shallow remains of Bronze Age postholes, preserved within the buried Bg horizon (under SU 88 or the buried A horizon), while their boundaries in the A horizon are blurred or obliterated (from Šavel and Sankovič 2013: 79). (d) Shallow remains of postholes belonging to a Bronze Age timber structure preserved within the buried Bg horizon (from Šavel and Sankovič: 80).

SU 88 might represent an artefact line[14]. The remains of a few small whole vessels probably indicate an archaeologic discontinuity and at the same time that activity levels of younger periods indicated by infiltrated artefacts and the occupation levels of the Early Middle Ages and the Middle Ages indicated by features excavated at the site, must have been located somewhere higher within the profile. Namely, in order for the whole Bronze Age vessels to be preserved, they must have been protected by burial, otherwise, they would not have survived anthroturbation caused by subsequent activities and reoccupation of the site during younger periods. However, where the later activity and occupation levels were located is not clear as there were no layers or artefact concentrations recorded which could be interpreted as possible archaeologic discontinuities related to them. It is very possible that they were located within the reach of ploughing and destroyed by it.

The recorded situation regarding features could also be understood in soil context and through processes within the A horizon which cause the blurring of the upper boundaries of dug features (Fig. 3). This would explain why an Early Medieval pit was discovered under the Bronze Age occupational remains or in other words at the level of the Bg horizon, while for reasons indicated above it must have been dug from a level higher than the level of the Bronze Age artefacts within the SU 88. Many Bronze Age pits also discovered under the SU 88 were probably also affected by this kind of blurring, while some were still recognizable in the upper part of the buried A horizon or SU 88. Generally, all over the site, the majority of dug features dating from the Copper Age to the modern period were recognised only at the level of the Bg horizon (Fig. 11g–h). In the cases of most of them, this can probably be best explained by mixing processes within the biomantle or the A horizon (Fig. 3).

Dolenji Podboršt near Trebnje

On the larger part of the site Dolenji Podboršt (Fig. 12a–b), the following layer sequence was recorded (Fig. 12c). Above the limestone bedrock, there was a reddish-yellow loam layer (SU 1003) defined as remains of a terra rosa soil, which in some parts of the site was not present due to erosion. Above it lay a lithostratigraphically uniform yellowish-brown silty clay layer (SU 1002 + 1001), formed by slow rate colluviation and alluviation processes. The layer was massive with no recognisable sedimentary structure. The surface dark greyish brown silty clay layer (SU 1000, 0,25–0,35 m thick) represents the turf and ploughzone (Verbič 2013: 7-13; Masaryk 2013: 31). In terms of pedostratigraphy, this layer sequence represents two units. One is the partly eroded and buried terra rosa soil and the other is the soil above it.

Part of the colluvial-alluvial layer, documented as SU 1001 (Fig. 12c) (mostly 0,25-0,75 m and in parts up to 1,36 m thick) contained archaeological artefacts, spanning from the Lower Palaeolithic to the modern period but with predominant Bronze Age material. It was noted in some parts that pottery sherds predominate especially in the upper and lower parts of the layer while they are scarce in its middle part. Two concentrations of charcoal and several concentrations of pottery sherds reflected different levels within this uniform massive layer which were not recognisable in parts where such fragments were absent. Larger concentrations of pottery sherds were present especially in lower parts of the layer, some of them containing only Bronze Age sherds, many of which belonged to the same vessels. Larger sherds mostly lay in horizontal positions. Cuts of pits and one furnace were also recognised at several different levels within the layer while most of the cuts were recognised only at the level recorded as the SU 1002 and some at the level of the SU 1003 (Fig. 12c–d). In all cases, the recognised cuts represented only lower parts of dug features while their upper parts and surfaces from which they had been dug were not recognisable. This was not only the case with cuts of older periods but also in the case of a telephone cable ditch which was cut and backfilled during the 50s of the 20th century (!). The main difference between the SU 1001 and SU 1002 (Fig. 12c) was that the latter did not contain artefacts except for infiltrated ones. Namely, the whole site was riddled by burrows (Fig. 12c–d) and nests of small mammals who caused the movement of artefacts within the layers. The infills of their burrows within the SU 1002 sometimes contained artefacts which were usually in a vertical position and their origin was thus ascribed to the SU 1001. A number of pottery sherds displayed damage caused by scratching of small mammals (Fig. 12e), while all of the pottery was generally strongly weathered (Masaryk 2013: 7, 12-13, 22, 24, 25, 29, 31-34, 100-103, fn. 23; Masaryk et al. 2013: 45-46).

The characteristics of this site fit well with the model of developmental upbuilding (Fig. 7a), combined with faunalturbation by small mammals (Fig. 4) and possibly other types of pedoturbations which were already discussed

[14] There is no information about the position and orientation of the finds within the SU 88.

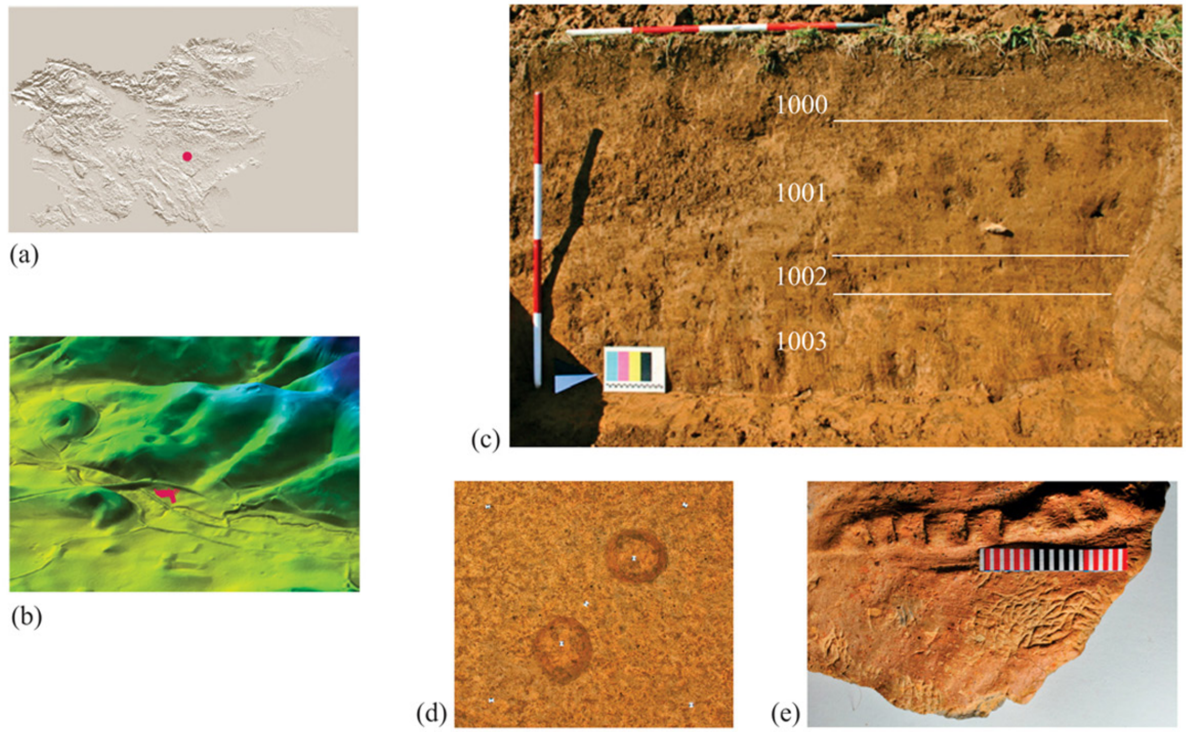

FIGURE 12. (a) Geographic position of site Dolenji Podboršt near Trebnje (from Verbič 2013: sl. 1). (b) The position of the site under a convergent slope (from Verbič 2013: sl. 4). (c) Profile of main layers at the site (from Verbič 2013: sl. 16). Layers of plough zone or Ap horizon (SU 1000), uniform lithostratigraphic alluvial/colluvial layer (SU 1001 + 1002), representing an overthickened B horizon with several levels of archaeological remains within SU 1001, as well as an eroded and buried Terra Rosa soil (SU 1003) are visible. (d) Shallow remains of pits recognised on the level of SU 1003 with visible remains of bioturbation or small mammal burrows (from Verbič 2013: sl. 17). (e) Damaged caused by small mammal claws on the pottery surface (from Masaryk et al. 2013: sl. 42).

by the excavators (Masaryk 2013: 100-103; Verbič 2013: 13). The upper parts of dug features were probably first blurred by processes of biomantle formation (Fig. 3) and even further by processes characteristic for the B horizon (SU 1001 and 1002) which was gradually growing upwards because of the slow sedimentation rate. The mentioned modern ditch demonstrates how quickly the processes in the A horizon which blur and destroy the upper boundaries of cuts actually operate. Due to the gradual sedimentation, the upward growing B horizon (Fig. 7a) encased the archaeological remains deposited on former surfaces which enabled different levels of artefacts to be preserved within it. It seems that the concentrations of Bronze Age sherds represented remains of relatively intact deposits and could be considered as archaeologic discontinuities. However, before being incorporated into the B horizon they were first subjected to the processes within the biomantle (Fig. 3). Therefore it is not certain how well they correspond to the surfaces on which they were originally deposited. On the other hand, translocation and damage of some of the artefacts caused by faunalturbation (Fig. 4) may have been operating throughout the formation history of the site up until the time of its excavation.[15]

[15] Before the start of the excavation, there was a large collony of the common vole (*Microtus arvalis*) present at the site (Masaryk 2013: 100).

Conclusions

The majority of the archaeological record is in one way or another part of the soil and therefore affected by soil processes which rework the remains of past human activities studied by archaeologists. During all of our interventions into the subsurface archaeologists constantly observe soils though we rarely see them and record them as such, which may have negative consequences for our understanding of the contexts we observe. Therefore, this paper[16] was an attempt to shortly discuss the importance that some of the soil formation and soil geomorphology processes have for archaeology. On the basis of this discussion, several broad conclusions can be drawn.

All layers observed during archaeological excavations may not be depositional. Therefore principles of archaeological stratigraphy and archaeological stratigraphic excavations in the reverse order of deposition cannot be applied to all layers differentiated on the basis of their composition, texture and colour. These principles apply only to geogenic or anthropogenic deposits but not to soil horizons which also manifest themselves as distinct layers. In the case of sites altered by soil formation, the archaeological remains are not situated in the archaeological stratigraphic context which is traditionally seen as composed of depositional layers separated by interfaces. Instead, it is situated in soil context where layers are not depositional and borders between them do not represent interfaces. In such circumstances, the recognition of texture and colour differences is important for the recognition of soil horizons to which the principles of pedostratigraphy and not archaeological stratigraphy apply. These may contain different levels with archaeological remains or blurred archaeological stratigraphy which may be recognised primarily through the observation of inclusions or coarse fragments. Therefore, during the excavation, soil horizons must not be perceived and excavated as whole sediment bodies but instead require slow meticulous excavations and observations focused on the distribution of coarse fragments.

The recognition of soils and archaeological remains in soil context is important for the understanding of some of the site formation processes. In this paper different scenarios of archaeological remains subjected to discussed processes have been depicted in the form of hypothetical illustrations of resulting soil contexts. These may prove useful in the initial evaluation of observed soil contexts at sites altered by soil formation. However, each depiction focusses on a single process, while in reality the archaeological record will always be subjected to a mix of processes, resulting in much more complex situations. Also, a large number of processes and possible scenarios have not been discussed. Furthermore, equifinality must always be taken into account as different sets of processes may result in similar archaeological soil context. Therefore, the depictions of possible scenarios are intended as help in thinking about the possibilities and asking the right questions while the actual formation processes which resulted in the observed archaeological soil context can only be deciphered through interdisciplinary scientific research.

[16] For a somewhat extended discussion of the topic in the Slovene language see Gruškovnjak 2019.

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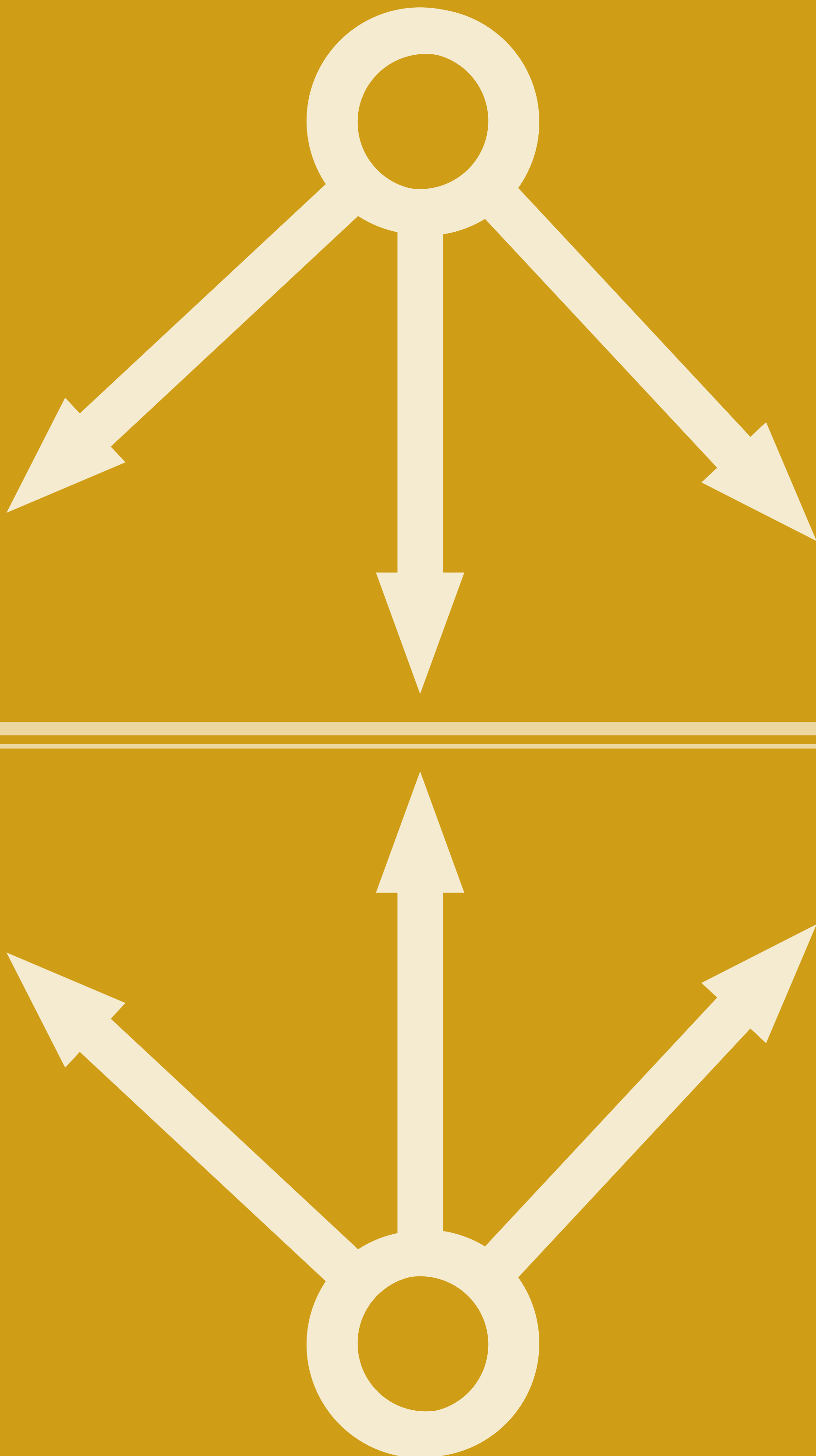

Possibilities of Retrospective Monitoring and Value Loss Assessment of the Site Damaged by Continuous Stone Exploitation: Sutilija hill above Trogir, Croatia

Filomena Sirovica
Lujana Paraman
Dinko Tresić Pavičić

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Filomena Sirovica
Archaeological Museum in Zagreb
Trg Nikole Šubića Zrinskog 19
HR – 10 000 Zagreb
fsirovica@amz.hr

Lujana Paraman
Trogir Town Museum
Gradska vrata 4
HR –21220 Trogir
lujaparaman@gmail.com

Dinko Tresić Pavičić
Kaducej Ltd.
Papandopulova 27
HR –21000 Split
dtresic@gmail.com

The paper analyses methodological possibilities of retrospective monitoring and value loss assessment on the archaeological records continuously subjected to harmful impacts using an example of prehistoric archaeological record preserved on Sutilija (St. Elijah's) hill in Seget Gornji above Trogir, Croatia, which is continuously subjected to stone mining that resulted in the vast devastation of the landscape, as well as the destruction of the archaeological features. This was the stimulus for the project focused on monitoring of the site with the objective to document its present state and to collect the data about changes in the landscape. Through comparison of the data collected by topographic survey and high-resolution 3D photogrammetry of the entire hill with the available archival spatial data (aerial photographs, cadastral maps etc.) a set of information was obtained that enables analysis of the changes caused by anthropogenic activities in different periods. Results of this type of analysis are suitable for the valorisation of the site, as well as a value loss assessment through different periods of contemporary stone exploitation. As the collected data enables chronological separation of the harmful impacts, the authors will present a methodological approach to the reconstruction of their effects and the possibilities that this type of analysis has for the assessment of value loss on continuously endangered archaeological sites.

Keywords: *Sutilija hill, hillfort, quarries, damaged archaeological record, retrospective monitoring, value loss assessment (VLA)*

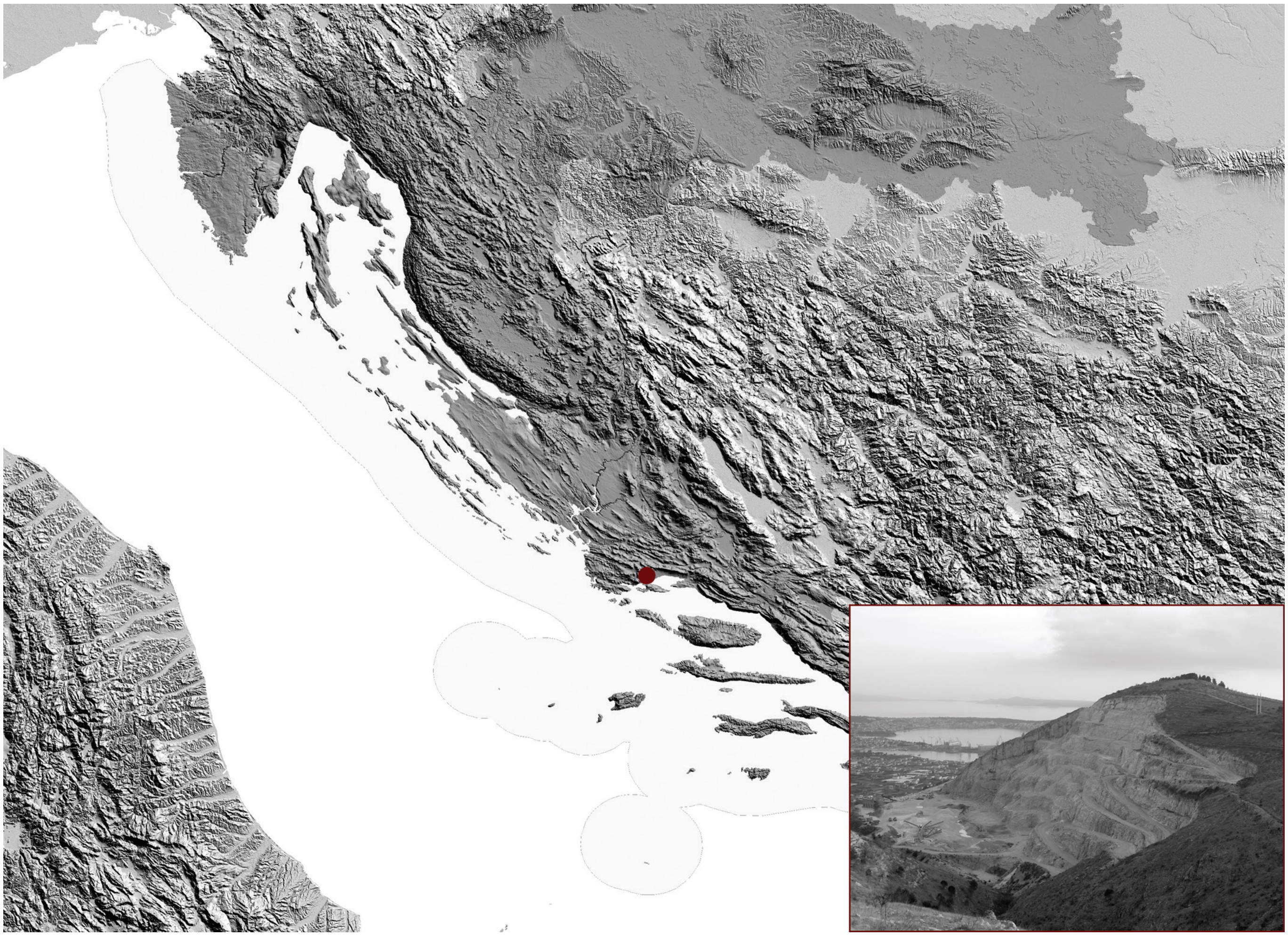

FIGURE 1. Geographical location of Sutilija hill above Trogir, Croatia (made by: D. Tresić Pavičić; photo by: L. Paraman; source: EU-DEM produced using Copernicus data and information funded by the European Union - EU-DEM layers).

Introduction

Sutilija (St. Elijah's) hill in Seget Gornji above Trogir (ancient Tragourion/Tragurium), Croatia (Fig. 1), is one of the most important sites for understanding the Late Prehistory and Protohistory of Trogir area as well as the history of quarrying in Dalmatia. This complex site with the continuity of anthropogenic activities, possibly from the Upper Paleolithic / Mesolithic to Modern Period, is characterised by two distinctive features: located on the top of the hill are the remains of the Bronze / Iron Age hillfort[1] and the medieval Church of St. Elijah, while the south and east slopes of the hill are occupied by the remains of quarries dated from the Roman to Modern Period. Regardless of these remains supervising institutions did not list and protect the site as cultural heritage until 2006.

As stone mining continues to this day, with three active quarries on the east and northeast slope of the hill, it is continuously subjected to harmful impacts. The shift from architectural-building to technical-building stone

[1] Sutilija was first mentioned by Cvito Fisković in 1957 (Fisković 1957: 218). The structures on the hill as well as the topography of the area were described by Ante Škobalj in 1970 (Škobalj 1970: 339, 341), while Ivo Babić interpreted the site as part of an organized network of Prehistoric hillforts in the coastal area of Trogir and Kaštela (Babić 1980: 62; Babić 1991: 32). In more recent studies, the site is understood primarily as Iron Age hillfort (Čače 1992: 36; Miletić 2008a), although archaeological remains indicate its Bronze Age origins (Kirigin 2010: 31, especially n. 24. On problems of distinguishing Bronze and Iron Age remains in the Eastern Adriatic see Barbarić 2010: 311-312; Kirigin 2010: 23-24). The finds of luxury Alto-Adriatico red figure pottery collected allegedly from the destroyed grave on the north side of rampart in the 1990s (Kirigin 2010) contributed to the understanding of hillfort as an important centre of local Iron Age community possibly Hili or Bulini mentioned by the historical sources (Pseudo-Skylax 22; Pseudo-Scymnos 403-413).

exploitation over the last 20 years resulted in the vast devastation of the landscape, as well as the destruction of the archaeological features and only in 2011 further expansion of the quarry was prohibited.

This was the stimulus for the project focused on monitoring of the site with the objective to document its present state and to collect the data about changes in the landscape. The project started in 2013 and encompassed a desk-based assessment of archival data, field survey directed towards the recording of anthropogenic features and surface finds, and topographic survey and high-resolution 3D photogrammetry of the entire hill. The objective of the survey was to document the present state of the site and to create basic documentation for tracing and monitoring changes caused by anthropogenic activities and to form the basis for spatial and archaeological structures analysis intended for planning further research.

At the same time, through comparison of the data collected by topographic survey and high-resolution 3D photogrammetry and the available spatial data (aerial photographs, cadastral maps etc.) a set of information was obtained that enables analysis of the changes caused by anthropogenic activities in different periods. Results of this type of analysis are suitable for the valorisation of the site, as well as chronological separation of the harmful impacts. As the collected data enables retrospective assessment of loss of value in different periods of contemporary stone exploitation, the aim of this paper is to present a methodological approach to the reconstruction of their effects and the possibilities that this type of analysis has for the assessment of value loss on continuously endangered archaeological sites.

Overview of conducted research

In 2013 the Trogir Town Museum started an archaeological research project of the Sutilija hill to emphasize the archaeological potential and value of the site, through documentation of archaeological remains from all periods and an attempt of their interpretation. The objective of this research is to expand the knowledge and more precisely determine the actual significance of the site, to raise public and governmental awareness about the necessity of its extensive protection and long-term monitoring. The first phase of research included desk-based assessment of available archival data and spatial information about the site: the old photographs and postcards, aerial photographs, maps and cadastral data. It was followed by a detailed topographic survey of the site[2] which included photographic documentation and topographic measurements of approximately 70 ha.[3] On collected data high-resolution 3D model was generated from which Digital Surface Model (DSM) and Digital Terrain Model (DTM) with ground sample distance of 7 cm/pix, and True Orthophoto with ground sample distance of 4 cm/pix were derived (Paraman and Tresić Pavičić 2015; Fig. 2). This high-resolution data gave a complete solution for documenting the present state of the hill while combined with other available data, such as aerial photographs and results of the field survey, serves as the basis for the development of long-term systematic monitoring of the site and surrounding landscape.

The second phase of the project included field survey of the entire hill and mapping the tool marks and rock cuts in the historic quarries.[4] The objective of the field survey was to determine the area of distribution and frequency of the surface material and general chronological information about the site. Due to the vegetation covering the hill, the finds were mostly visible on or near different drywall structures. Potsherds prevail among the finds, but the fragments of stone tools (whetstone and grinding stone, lithic material), pieces of iron slag, bone and shell material were also recorded. The analysis of the pottery suggests that more pronounced usage of the area happened from the Late Bronze Age to the Hellenistic Period. Although further research is required, the scarce material evidence from 2nd and 1st century BC suggest that human activities significantly decreased somewhere in the 3rd century BC. The most intriguing finds were collected on the highest terrace of the Seget-North quarry where the material from the damaged terrace and the destroyed speleological object, possibly a pit, is being washed down. The find of punctured sea snail *Collumbela rustica* along with several other lithic finds suggests possible anthropogenic activities on the hill already in the period of the Upper Paleolithic or in the Mesolithic.[5]

[2] With the financial support of the Croatian Ministry of Culture the topographic survey was carried out in 2015 in collaboration of Trogir Town Museum and archaeological company Kaducej Ltd.

3 Survey was conducted using unmanned aerial vehicle DJI Phantom and Global Navigation Satellite System Receiver Stonex S9.

[4] Field survey was conducted by the Trogir Town Museum and carried out in cooperation with Archaeological Museum in Zagreb. The survey of the historic quarries was carried out in cooperation with Mate Parica from University of Zadar, Department of archaeology, as part of the research for PhD thesis (Parica 2014).

[5] Another speleological object - a small cave, is located about 100 m south of the church, with recorded presence of Bronze and Iron Age as well as Hellenistic pottery.

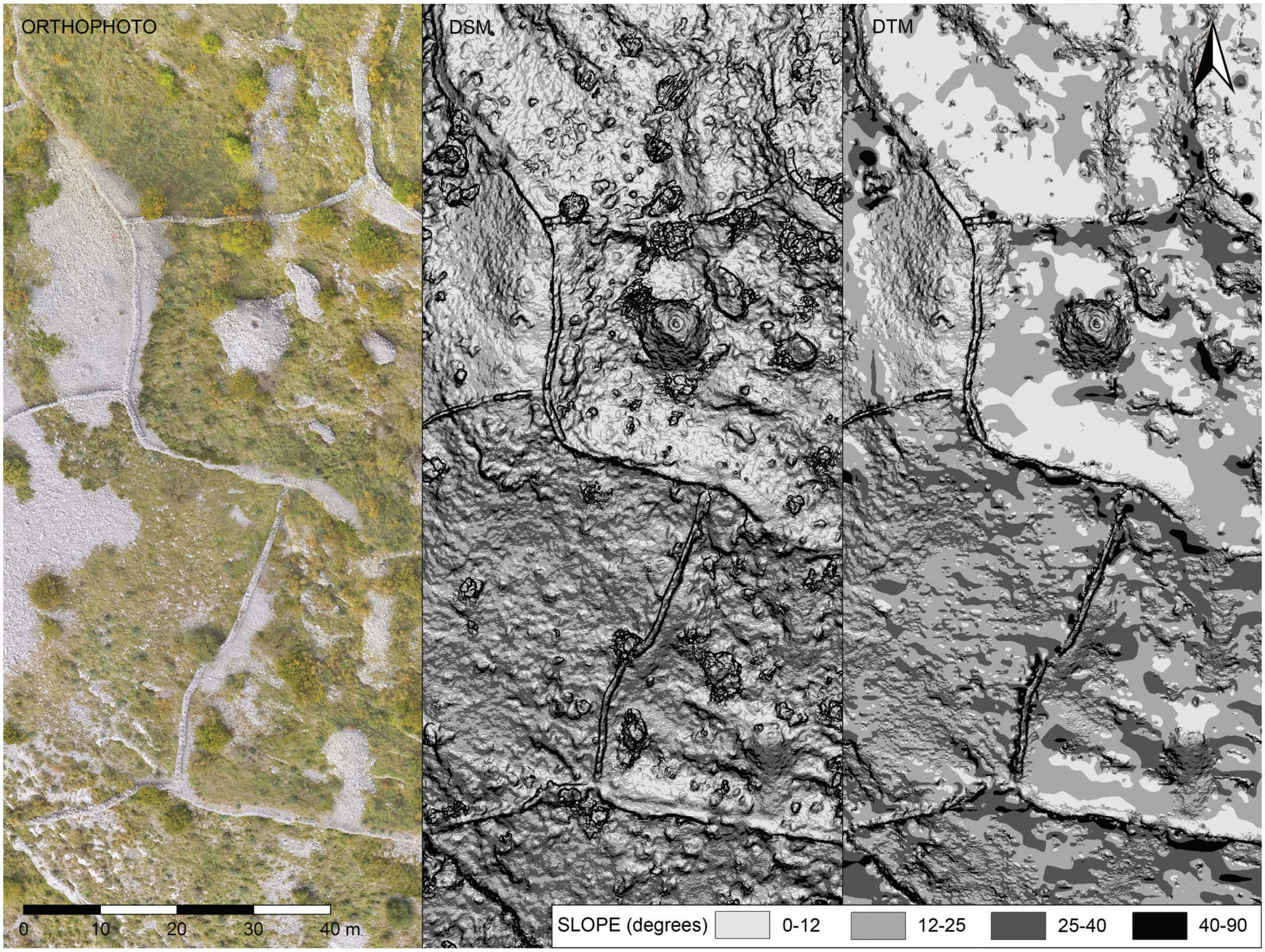

FIGURE 2. True Orthophoto, Digital Surface Model (DSM) and Digital Terrain Model (DTM) derived from high-resolution 3D model (made by: D. Tresić Pavičić).

The remains of the traditional quarrying by using so-called block method were documented and mapped. The technique of cutting a channel around the desired block in order to separate it from the parent rock, used from Roman to the Modern Period left the marks in the shape of rectangular rock cuts with the traces of hand tools (so-called *strije*) and cut channels (so-called *pašarini*) that are visible from the south to the east slopes of the hill. The difference in tool marks due to the use of heavier tools in the Roman Period and lighter tools in the later periods suggests the possibility of chronological distinction of the historic quarries, with the southern part of the slope being exploited in the Roman Period, and the western part in Medieval and Modern Period. However, most quarries were used during a longer period of time, as can be seen in Kačićeva kava, the biggest quarry on the south slope, where the remains of the exit ramp of Roman quarry were discovered in 1999 (Maršić 2007). Its interior faces are covered by tool marks from Roman to Modern Period and also by the contemporary cuts. The extensive stone exploitation over a period of 2000 years left a huge amount of waste material that covers the foot of the hill (Parica 2014: 88).

The stone mining continues to this day, with currently three active quarries located on slopes of the hill. While the traditional architectural-building stone exploitation was less destructive in its scope (but still overlaid the remains of historic quarries), the shift to technical-building stone mining after the World War II and producing of gravel on the northeast slope of the hill, which intensified during the 1970's and 1980's, resulted in greater destruction of the site and surrounding landscape. As the quarrying continued, in the last 20 years Seget-North technical-building stone quarry completely wiped out the 1/5 of the hill. The extent of this destruction may also be illustrated by the fact that between 2001 and 2011, when further expansion of the quarry was forbidden, the quarry increased its scope by a quarter, and 35 % of this expansion happened after 2006 when the site was for the first time listed as cultural heritage (Ministarstvo kulture Republike Hrvatske 2007a; 2007b; Narodne novine 12/2008). During that time the eastern end of the rampart was destroyed in the length of almost 60 m, along with lover eastern terraces and the potential graves north of the rampart. According to 2008 project of quarry's south cliff remediation, new expansion, which could have resulted in the destruction of both the hillfort and the historic quarries in the area of 2.6 ha, was expected (Rudarsko-geološko-naftni fakultet 2008). Fortunately, in 2011 further expansion of the quarry was prohibited and the new propositions allow exploitation of stone only in the current extent of the quarry (Ministarstvo kulture Republike Hrvatske 2011a; 2011b; Pašalić et al. 2016).

Retrospective Monitoring and Evaluation of the Site

The documentation collected within the Sutilija project includes historical and some newer aerial photographs taken during the last 50 years in 12 unequal intervals. They are acquired from the archive of the State Geodetic Administration of the Republic of Croatia (*Državna geodetska uprava Republike Hrvatske*, DGU) and the topographic survey conducted in 2015. Based on the analysis of photographs, a detailed plan of the site was created by mapping all visible features with the preliminary classification of drywall structures according to their visual

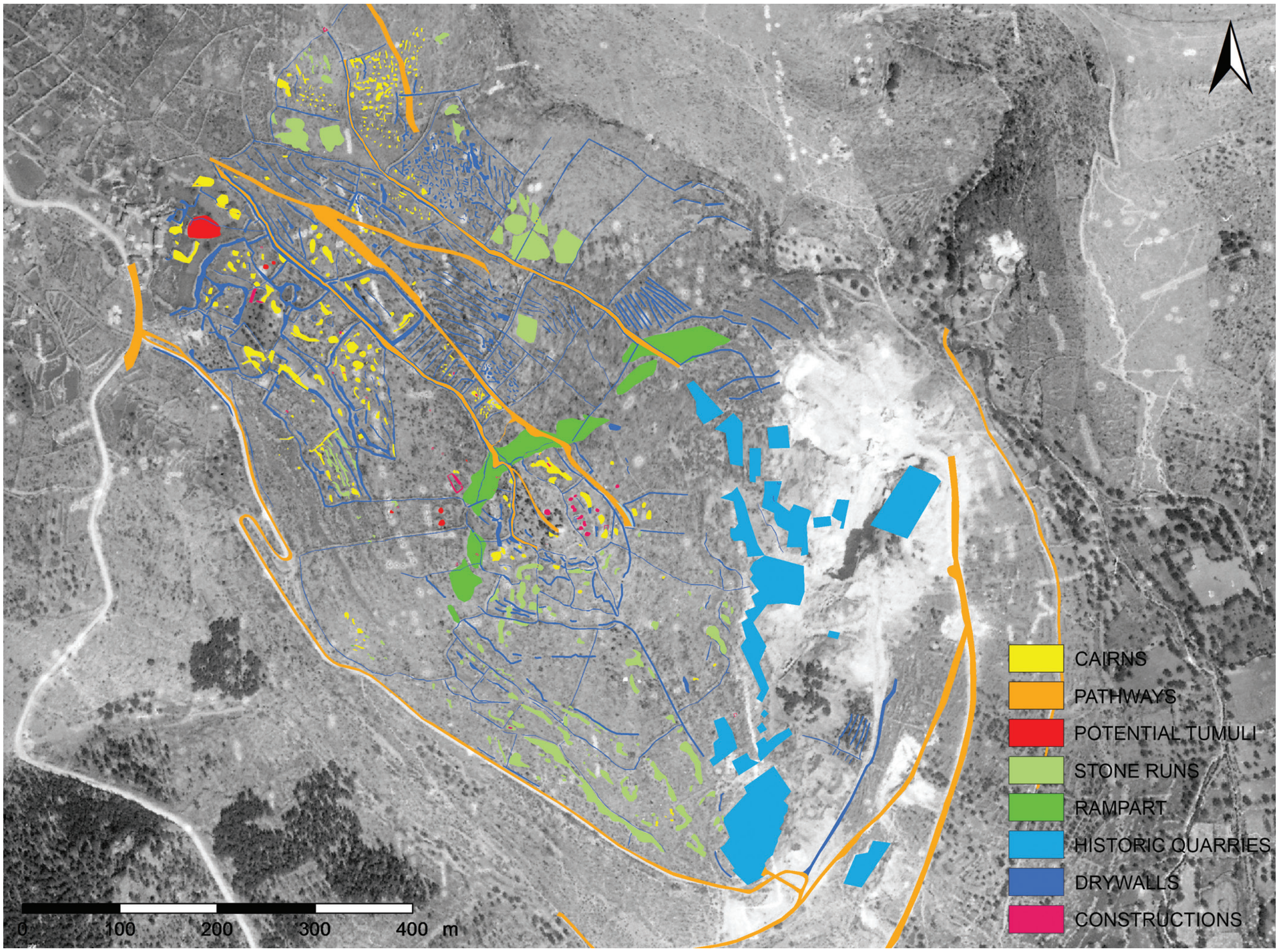

FIGURE 3. Plan of the site with classification of mapped features (made by: D. Tresić Pavičić; background: DGU, photo 1967_4465).

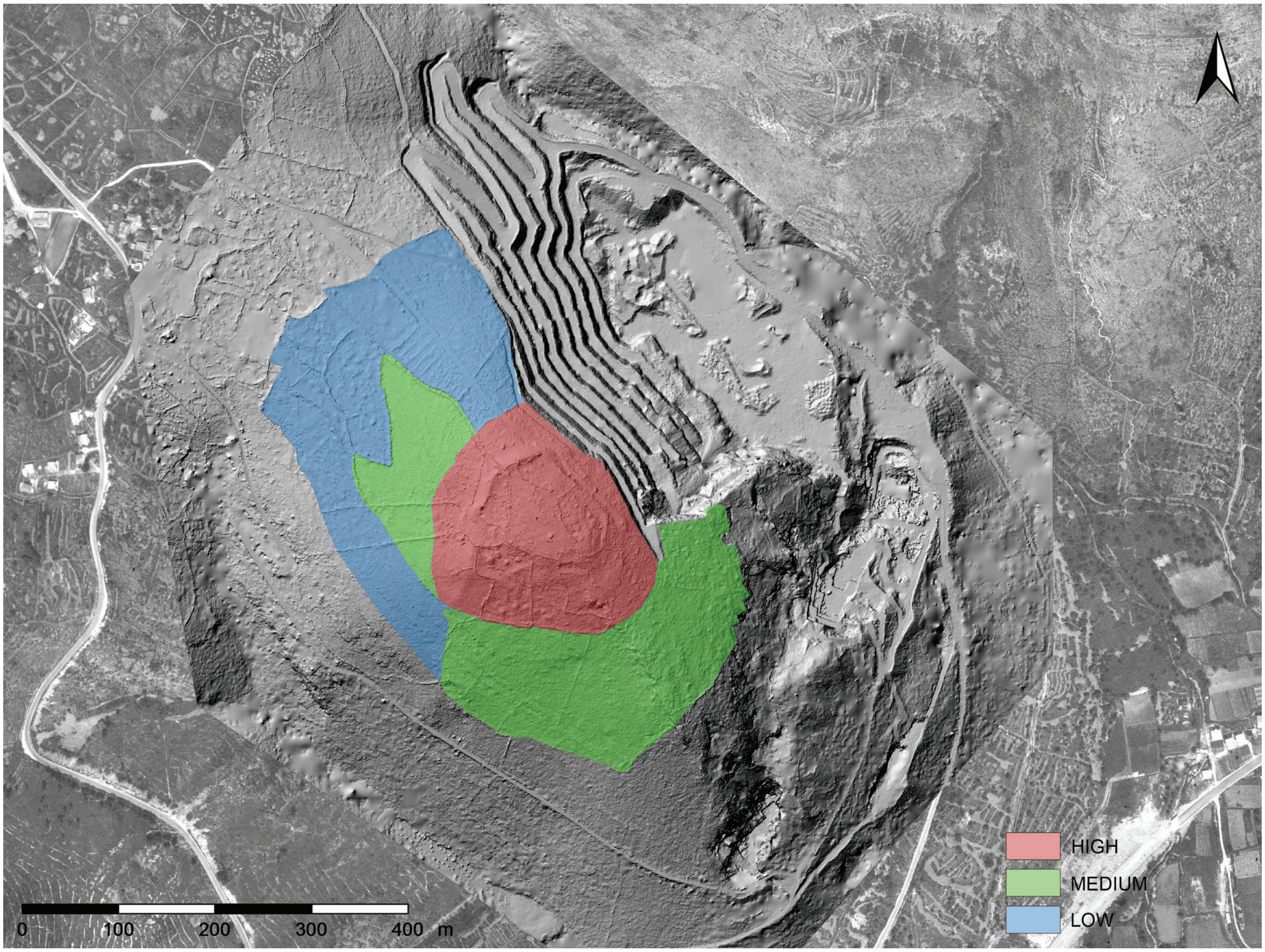

FIGURE 4. Frequency of the surface archaeological material in relation to DTM (made by: D. Tresić Pavičić; background: DGU, photo 1985_5364).

characteristic and present knowledge about their possible functions. Features were classified in 8 classes: boundary and terrace drywalls, pathways, medieval/modern constructions, prehistoric rampart, cairns, potential tumuli, historic quarries and stone runs (Fig. 3). This data was compared with the data collected during the field survey of the hill which gave an insight into the relationship between aboveground structures and distribution and frequency of the surface finds. Results of the survey show that surface material spreads over the area of about 9 ha with higher concentrations established in the central part and on the terraces on the western slope of the hill, the area covering about 4.5 ha (Fig. 4).

The procedure also included mapping of the quarry perimeter in different periods, which enabled the separation of 8 periods of the quarry expansion that were recorded in the years 1968, 1970's, 1985, 1997, 2001, 2006, 2009 and 2011. This data provided a possibility for chronological separation of the harmful impacts which enables the establishment of the methodological approach to the reconstruction of their effects and the possibilities that this type of analysis has for the assessment of value loss on continuously endangered archaeological sites.

The procedure was carried out according to a Value Loss Assessment (VLA) Model[6] which was used as a tool that can provide an insight into the possibilities of retrospective monitoring of loss of value through time but also as a method for predictive assessment of loss. The Model is based on systematic quantitative value assessments (see

[6] The VLA Model was developed as a part of the PhD thesis of one of the authors of this text (Sirovica 2015).

for example Darvill et al. 1987; Schofield 2000; Darvill 2001; Willems and Brandt 2004) developed within the practice of preventive archaeology, a procedure for the management of endangered archaeological remains. Accordingly, applying the VLA Model to already damaged archaeological records sets clear requirements that need to be fulfilled in order for the assessment to be valid. Because of that, the method was carried out through five stages: construction of the frame of reference, assessment of value before the harmful events, assessment of the spatial extent of damage, value loss assessment, and finally categorisation of calculated loss (after Sirovica 2019: 91).

The first stage of the process is the construction of the frame of reference, a temporally and spatially defined area within which the value assessments can be carried out. According to this requirement, multi-period archaeological records, such as the one at Sutilija, cannot be assessed on the basis of only one reference frame (Sirovica 2019: 79-81) and for trial application of the method; temporal boundaries were limited on prehistoric, i. e. Bronze to Iron Age archaeological record, for which a suitable set of data was collected. On the other hand, as such estimates basically serve to define the value of archaeological records for the purposes of national or regional archaeological heritage management; the spatial boundaries of the frame of reference were defined in accordance with the area of jurisdiction of the Ministry of Culture of Republic of Croatia Conservation Department in Trogir, which has supervision over Sutilija (Fig. 5). In this context, it can be claimed that prehistoric remains preserved at Sutilija are part of a widespread type of archaeological record that forms the basis for regional studies of the Bronze and Iron Age. It is preserved at a

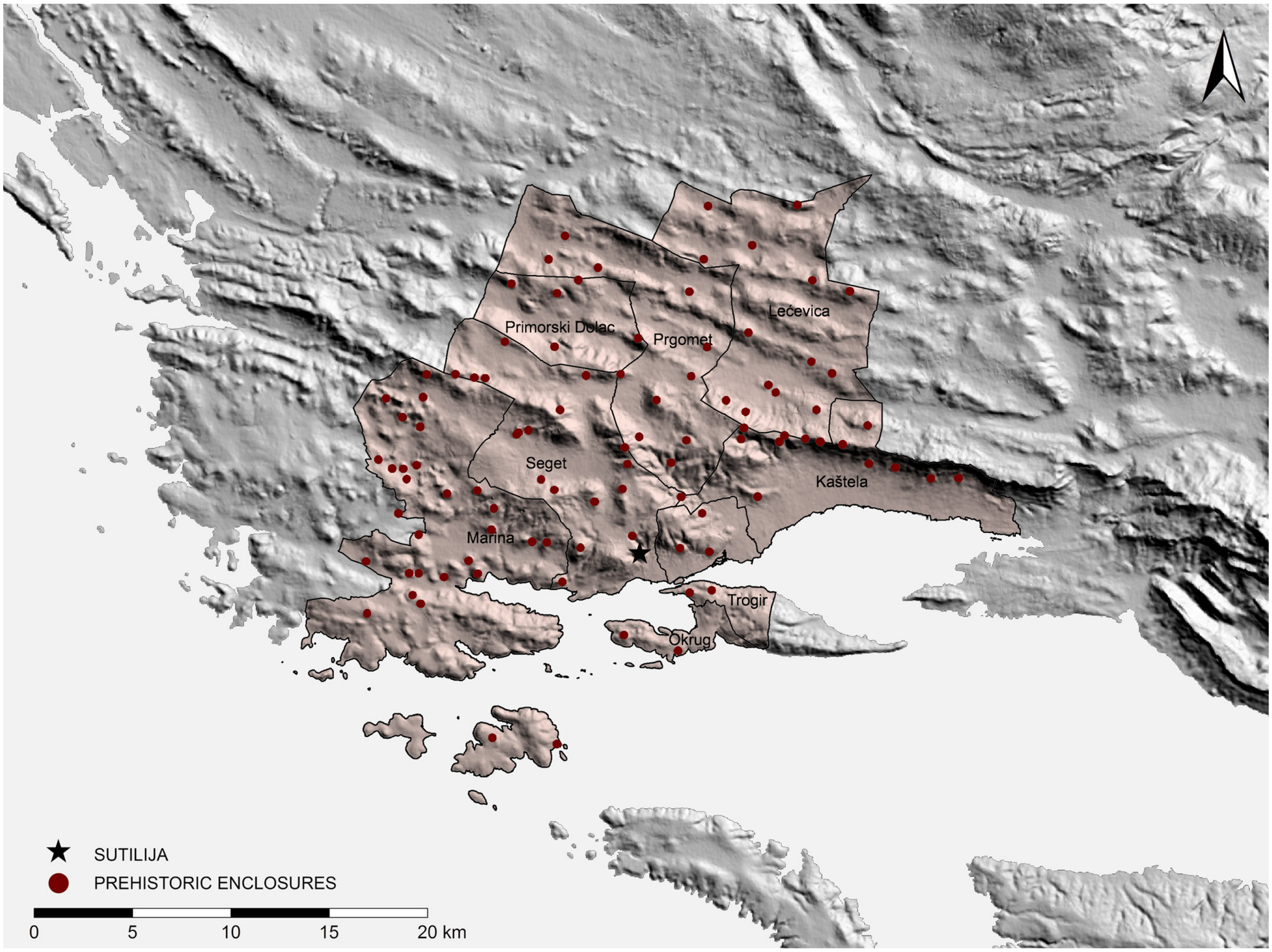

FIGURE 5. Spatial boundaries of the reference frame for value assessment of archaeological record at Sutilija (made by: D. Tresić Pavičić; background: EU-DEM produced using Copernicus data and information funded by the European Union - EU-DEM layers).

series of positions on which contemporaneous enclosures are established. At the same time, these sites show significant variations in certain characteristics, such as accessibility and location, conducted research, preservation, dimensions, presence of above-ground structures, distribution and frequency of surface archaeological material, and the presence of synchronic and diachronic context (Babić 1980; 1991: 31-42; Čače 1992: 34-36; 2001; Katić 1994; Burić 2000; 2008; Šuta and Bartulović 2007; Madiraca 2012; Miletić 2006; 2007; 2008b; 2009; Šuta 2009; 2010; 2013a; 2013b; 2016). Analysis of these specific features significantly influence the assessment of

VALUES	CRITERIA	QUALITATIVE VALUE ANALYSIS	QUANTITATIVE VALUE
SOCIAL VALUES	VISUAL VALUE	Sutilija hill, located on the western edge of Trogir field, dominates the surrounding landscape and offers a great vantage point of the field and coastal waters around Trogir. The prehistoric archaeological record is marked by visible structures and features; in particular by the remains of the rampart which are a visually impressive point in the landscape. The position of the site, near main communication between Trogir and hinterland makes it a significant part of the contemporary landscape. It can, therefore, be considered as a major element of the landscape identity, with great influence on the experience of the place and space.	3
	HISTORICAL VALUE	Historical development of the site is directly related to historical events in the wider Trogir region, especially in the late Iron Age and Hellenistic period, at the same time complementing the understanding of landscape usage in prehistory. The significance of the position as evocative stimuli is reflected through continuity of its usage as a sacred site from the Middle Ages, when the church of St. Elijah was built, and through the presence of local legends related to the place that contribute to its contemporary interpretation.	3
	ECONOMIC VALUE	Physical and symbolic characteristics of the site make it part of different segments of contemporary social life while immediate vicinity of heritage and tourist centres – Trogir and Seget enable its direct inclusion in existing tourist and recreational or educational and cultural offer. Although it is not possible to claim that such models of site utilization would provide direct economic benefits, as part of a wider tourist offer, it certainly has the potential to generate noticeable indirect value.	2
GENERAL VALUES	RARITY	Archaeological record at Sutilija hill can be compared to a large number of concurrent archaeological remains in the region. However, its scope, preservation and characteristics of visible structures and features, the quantity and variety of surface and subsurface archaeological remains, as well as the presence of imported Hellenistic finds indicate that the archaeological record is directly comparable with only one known archaeological site within the predefined frame of reference.	2
	GROUP VALUE	Within the predefined frame of reference, Sutilija is the only known Iron Age site with necropolis in the immediate vicinity of settlement remains. At the same time, the presence of stone mounds, as well as different prehistoric remains in the immediate vicinity indicates the pronounced synchronic context and the exceptional preservation of the prehistoric landscape. On the other hand, archaeological finds from earlier prehistoric periods, traces of stone exploitation from the Roman Period to modern times, elements of medieval sacral architecture and cemetery as well as other remains attest the continuous significance of the position and affirm the presence of exceptional diachronic context.	3
	REPRESENTATIVENESS	The prehistoric archaeological record at Sutilija site, despite many specific elements, can be considered as a representative archaeological record that contains characteristic features for both the period and the region. The record emerged in specific historical conditions and it is directly comparable to some of the known and preserved archaeological sites.	2

VALUES	CRITERIA	QUALITATIVE VALUE ANALYSIS	QUANTITATIVE VALUE
SCIENTIFIC VALUES	INTEGRITY	The position had indisputable spatial integrity accompanied by archaeological remains at the place of primary deposition, but the level of direct threat has not diminished since the middle of last century. The current state of the site demonstrates subjection to the long-term harmful impacts caused by human activities that have seriously undermined the integrity of the site and the wider landscape. Currently, the environment is relatively stable, without the possibilities for the occurrence of rapid changes, but the level of integrity value will depend on future management plans for the area.	2
	QUALITY	Despite the devastation, there is still a significant level of preserved archaeological remains: standing structures, features, deposits; which form readable stratigraphic sequence marked by the diverse archaeological finds. Presence of the well-preserved diagnostically relevant material indicates that in comparison to records of the same period in the region, it is a high-quality archaeological record.	3
	INFORMATIONAL POTENTIAL	Although it is an archaeological record of lower complexity, in comparison with other concurrent records in the region, it shows exceptional potential for obtaining data on formal features of archaeological remains and their contextual interrelations. It can enable considerations on the activities that caused its emergence and meaningful interpretations of the spatial and temporal dimension of human activities. At the same time, the information potential of the record is directly dependent on the integrity of the site – and varies depending on future interventions in the area and potential new devastations.	3
	INTERPRETATIVE POTENTIAL	It can be argued that the archaeological record contains clear interpretative potential, with the ability to fill the gaps in current knowledge. This is particularly pronounced considering the specific connection between Iron Age settlement and cemetery, as well as the relations with concurrent settlement remains in the area of Trogir. It has the ability to generate new knowledge through comparison with results of recent research of the period in which it has significance above the regional level.	3
TOTAL VALUE		**HIGH QUALITY RECORD**	**26**
VALUE INDEX (Vi = TV / 10)			**2,6**

TABLE 1. Value assessment of prehistoric archaeological record at Sutilija.

value understood as the relevance of individual archaeological record for contemporary society as well as the analysis of its general attributes and their informational potential. Therefore, it is possible to distinguish only one somewhat comparable site in the defined region: Sv. Nofar in Bijaći (Čače 1992: 35, 39; Čače and Milivojević 2017: 437, Map 1; Šuta 2011: 26; Šuta and Bartulović 2007: 14, 19); although several locations, where well-preserved structures and the presence of large quantities of prehistoric material were recorded, are likely to represent the remains of larger concurrent settlements: Oriješćak above Vinišće, Drid above Marina, Čurkovac above Bristivica, Grad above Blizna Gornja, Gradina near Mateljani in Bogdanović, Luko in Kaštel Sućurac (Čače 1992: 35-36; Katić 1994; Miletić 2006; 2007; 2009: 10; Šuta and Bartulović 2007: 19; Burić 2008; Šuta 2009: 153; 2016: 26-29); for which it can be presumed to have considerable potential for filling the large gaps in current knowledge about the time period in question.

The second stage consists of value assessment which was carried out according to a set of 10 predefined criteria separated in three categories: social, general and scientific value; complemented by numerical values for every parameter (Sirovica 2019: 77-84). By assigning points from 1 to 3 to each criterion, corresponding to the assessment of low, medium and high value; expression of value in the form of a number was enabled. From possible 30 points, Sutilija's prehistoric archaeological record gained 26, and it is rated as a high-value archaeological record with a value index, calculated as a ratio between the total score and a number of used criteria, of 2.6 (Table 1).[7]

Value Loss Assessment

For the successful application of the VLA Model to prehistoric archaeological record at Sutilija, it was necessary to estimate the percentage of damage (EPd) expressed as the ratio between the spatial scope of the destruction or damaged area (Da) and the total area of the comparable archaeological record (CAR; Sirovica 2019: 84).[8]

$$EPd\ [\%] = 100 \times \frac{Da}{CAR}$$

Defining the spatial extent of damage caused by the quarry required the analysis based on topographic features of the area, aerial photographs, historical and contemporary cadastral data, as well as archaeological analysis of aboveground structures and the results of the field survey. Combined, these newly acquired and historical data enabled the reconstruction of certain features of the hill in different periods and indicated clear differences between areas with different topographic characteristics. Accordingly, the prehistoric archaeological record was divided into 5 separate zones (Table 2) which differ in the configuration of the terrain, usage of space in recent periods, the types of above-ground remains of anthropogenic origin, the frequency of surface archaeological material, etc. Zones were labelled with numbers from 1 to 5 and descriptively defined as the central zone, the zone of pronounced activity, the zone of approach

ZONE	DESCRIPTION	TERRAIN	SURFACE MATERIAL FREQUENCY	STRUCTURES FREQUENCY	COMMON TYPE OF STRUCTURES	USAGE
1	CENTRAL ZONE	Plateau	High	Medium	Prehistoric rampart and boundary drywalls	Larger flat grassy terraces with church and graveyard, surrounded by large drywalls
2	ZONE OF PRONOUNCED ACTIVITY	Mild slope	Medium	Low	Boundary and terrace drywalls	Mild grassy slopes with vineyards at borderlines
3	PERIPHERAL ZONE	Steep slope	Low	High	Terrace drywalls	Narrow cascaded agricultural terraces (vineyards)
4	ZONE OF APPROACH	Mild slope	Medium	High	Pathways and drywall structures	Pathways surrounded with agricultural areas
5	PERIPHERAL ZONE	Steep slope	Low	Low	Stone runs	Infertile area of broad karstic slopes

TABLE 2. Classification of archaeological record at Sutilija by zones.

[7] Value assessment conducted within the VLA Model should be focused on the value that the archaeological record had before the damage occurred (Sirovica 2019: 81). As it was possible to determine 8 separate harmful events, essentially separate assessment of value for every one of them would be needed. However, as value is a changeable social construct and neither an objective category nor inherent property of things it should be emphasized that physical damage can have very different effects on different categories of value. By analysing the value of the archaeological record at Sutilija in three categories, it can be argued that stone exploitation did not significantly change the value in first two categories, although it should be pointed out that this claim is possible only from the present perspective and potential past values according to the same or different criteria or parameters are not ascertainable. On the other hand, the value necessarily decreases in the third category, especially in the terms of integrity that is continuously harmed throughout all assessment periods, but also directly threatened before the first quarry activities. As the value according to the integrity criterion should be considered decreased already with the appearance of the direct threat, the value of the archaeological record can be considered decreased by that criterion and with that somewhat uniform for all time periods.

[8] According to the VLA model, calculations are performed based on the two-dimensional spatial data so the damaged part can only be analysed in relation with those parts of the record for which it can be presumed to possess similar characteristics in three-dimensional space. As the definition of a CAR represents the most important part of the process that depends on the professional assessment of the depositional processes, the procedure requires the definition of the area for which it can be claimed to contain archaeological remains of comparable quality and informational potential (Sirovica 2019: 83).

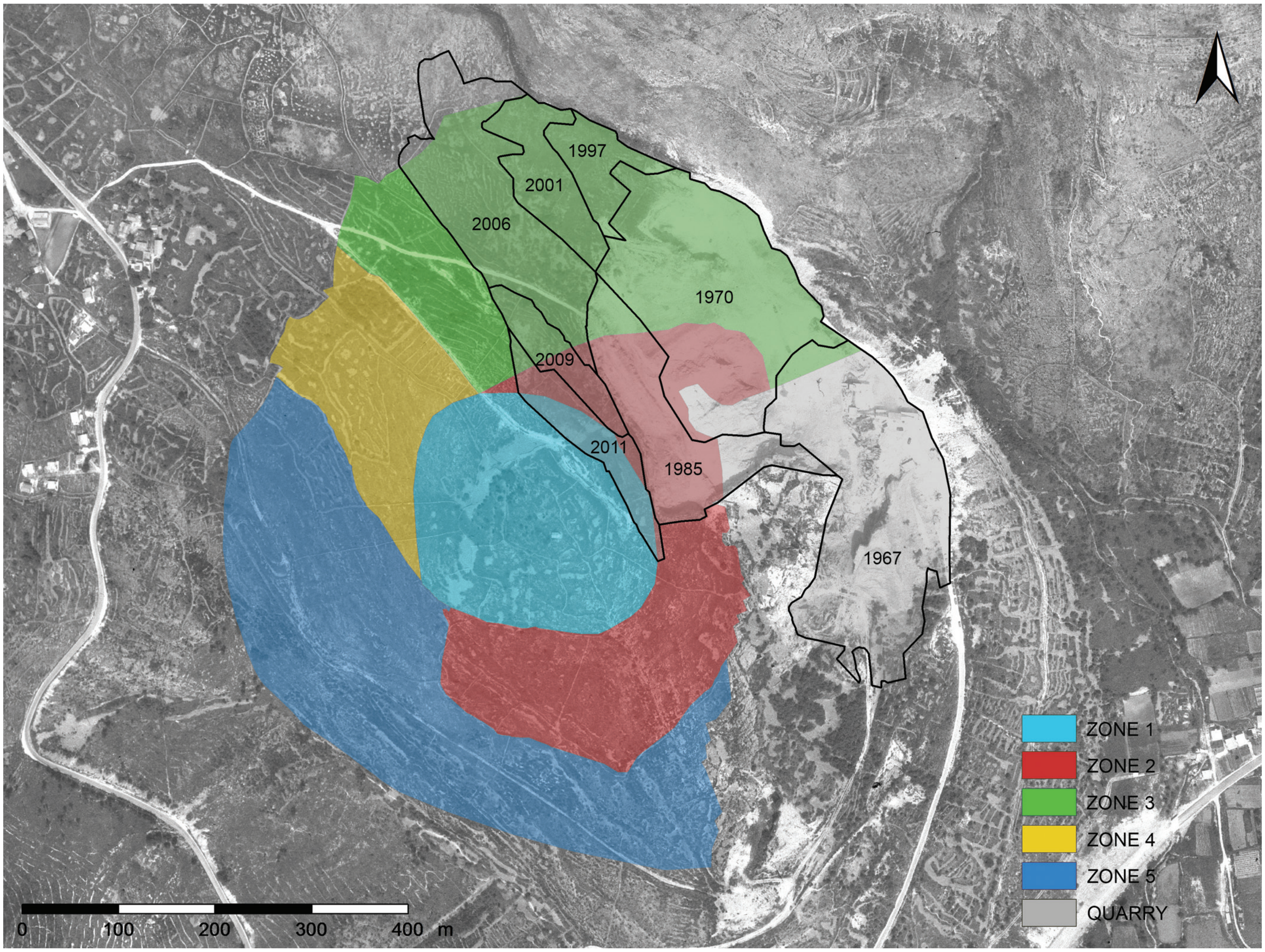

FIGURE 6. Zones of comparable archaeological record (CAR; made by: D. Tresić Pavičić; background: DGU, photo 1985_5364).

and two peripheral zones.[9] This procedure enabled the determination of spatial units that can be defined as areas of CAR (Fig. 6).

In accordance with this, harmful impacts per Zone in a specific period were calculated (Table 3; Fig. 7, 8). The data derived shows that Zone 3 suffered the most extensive damage and to this day 79% of its surface disappeared. This process started more than 50 years ago and lasted until 2011. Zone 2 was first affected in the 1970s, and it will be subjected to extensive destruction for the next decade. After a prolonged stagnation, minor damage was again visible in 2006, and by 2011 39% of this area was destroyed. On the other hand, interventions in Zone 1 started only in 2009, but until 2011, as much as 10% of the area was destroyed. If the collected data is considered in total, it can be emphasized that from the total area of all three zones, almost half of it was destroyed in the last 50 years while in relation to the complete prehistoric archaeological record on Sutilija, in this time period almost third of it disappeared (Fig. 9).

As an attempt to get a meaningful and well-founded assessment of damage, the relationship between the value of the archaeological record and the extent of the damage was examined. In the VLA model, loss of value represents the relationship between the attributed value and

[9] The area of historic quarry was not included in the analysis as it today also represents an element of heritage and can be considered a specific type of archaeological record with different temporal and spatial characteristics. As it was also subjected to extensive damage, it needs a separate evaluation.

	Da m²				DaG m²			
	Z1	Z2	Z3	CAR	Z1	Z2	Z3	CAR
1968	N	N	1775	1775	N	N	1775	1775
1970s	N	8062	29194	37256	N	8062	30969	39031
1985	N	13280	2350	15630	N	21342	33319	54661
1997	N	N	6448	6448	N	21342	39767	61109
2001	N	N	9628	9628	N	21342	49395	70737
2006	N	348	20840	21188	N	21690	70235	91925
2009	N	2822	3071	5893	N	24512	73306	97818
2011	5150	2755	552	8457	5150	27267	73858	106275
	EPd %				EPdG %			
	Z1	Z2	Z3	CAR	Z1	Z2	Z3	CAR
1968	N	N	2	1	N	N	2	1
1970s	N	11	31	17	N	11	33	18
1985	N	19	3	7	N	30	36	25
1997	N	N	7	3	N	30	43	28
2001	N	N	10	4	N	30	53	32
2006	N	1	22	10	N	31	75	42
2009	N	4	3	3	N	35	78	45
2011	10	4	1	4	10	39	79	49

Table 3. Calculation of EPd and its growth per Zone through time.

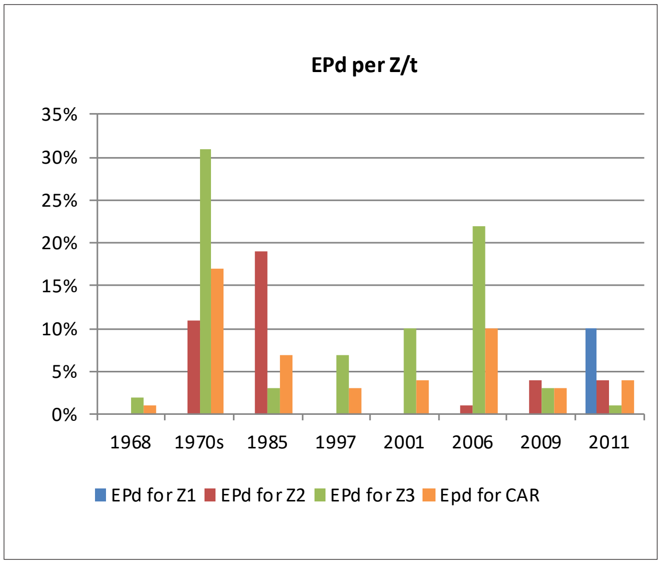

FIGURE 7. EPd per Zone through time.

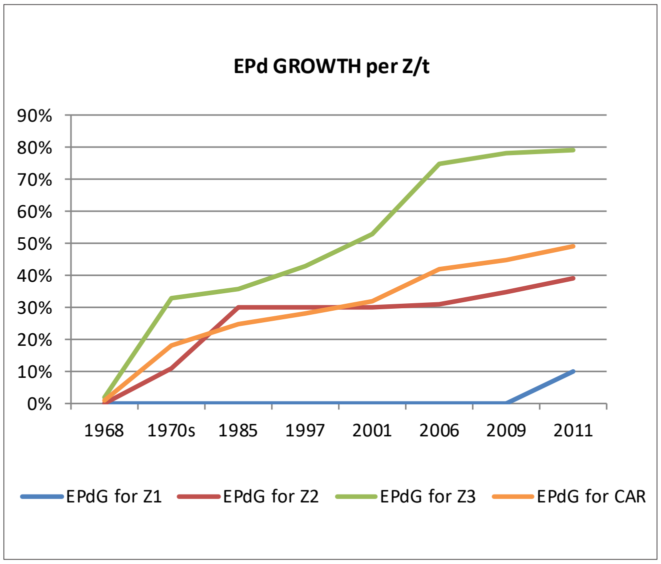

FIGURE 8. Growth of EPd per Zone through time.

the harmful impact. In accordance with the Model, the estimation of loss (L) on highly valued archaeological records, like the one at Sutilija, requires the use of logarithmic equation which can treat any damage as significant (Sirovica 2019: 142-143).

$$L = Vi \times (\mathrm{ceil}\,(5 \times \ln\,(\frac{EPd}{20} + 1)) + 1)$$

Regardless of the equation used, in VLA Model the loss will always result in values ranging from 2 to 30. This wide interval of values requires categorization that can enable meaningful expression of loss of value. In the recommended procedure categorization of loss (Lc) is carried out by a linear distribution of the obtained values using the equation which can express the loss in 5 classes corresponding to the estimates from minimal to the total loss of value (Sirovica 2019: 91, 142-143).

$$Lc = \mathrm{ceil}\,(\frac{L}{6})$$

According to logarithmic equation loss of value was calculated for each of the defined zones and comparable archaeological record in total (Table 5). The calculations, therefore, include the data on loss of value for each of the considered periods of quarry expansion (Fig. 10) and then the growth of loss with the expansion of quarry through time (Fig. 11). The substantial loss occurred in the second period and then, after a prolonged period of moderate expansion of the quarry, the loss has again drastically increased at the beginning of this century.

But the loss calculated in this way has a wide range of values (the lowest is 2.6, and the highest is 23.4) which is why it is necessary to express it in a way that will allow ranking the severity of damage. The equation for the linear distribution of obtained results enables the gradation of loss (Table 6). By this procedure loss on Sutilija for each of the Zones in periods of quarry expansion is mostly expressed as minimal or moderate, i. e. with grades 1 and 2, but three times in a single period loss reached category 3 which is expressed as significant (Fig. 12). By observing the increase in damage over the years (Fig. 13), it can be noticed that in Zone 3 the loss grows from minimal (1) to significant (3) already in the second period. About a decade later it will become severe and expressed with grade 4. In the same period loss in Zone 2 becomes significant (3) and, after a prolonged period of stagnation, in 2006 severe loss (4) is documented. The expansion of quarry between 2009 and 2011 will cause moderate damage in Zone 1 expressed with grade 2. If we consider the affected area in total for all three zones,

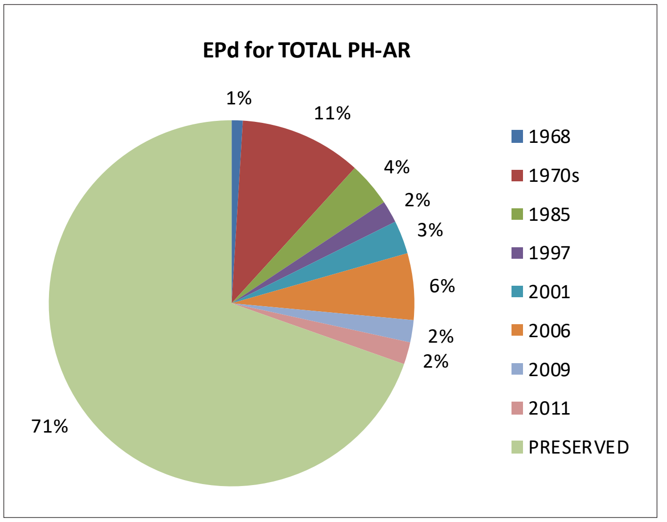

FIGURE 9. Epd for complete prehistoric archaeological record (PH-AR) on Sutilija per time period.

LINEAR CATEGORISATION OF VALUE LOSS		
LOSS OF VALUE	CATEGORIZATION	STATEMENT
2 – 6	1	MINIMAL LOSS
6,1 – 12	2	MODERATE LOSS
12,1 – 18	3	SIGNIFICANT LOSS
18,1 – 24	4	SEVERE LOSS
24,1 – 30	5	TOTAL LOSS

TABLE 4. Outcome of linear categorisation of value loss with graded statements for obtained results (Sirovica 2019: 91, Fig. 42).

	L				LG			
	Z1	Z2	Z3	CAR	Z1	Z2	Z3	CAR
1968	N	N	5.2	5.2	N	N	5.2	5.2
1970s	N	10.4	15.6	13.0	N	10.4	15.6	13.0
1985	N	13.0	5.2	7.8	N	15.6	18.2	15.6
1997	N	N	7.8	5.2	N	15.6	18.2	15.6
2001	N	N	10.4	5.2	N	15.6	20.8	15.6
2006	N	5.2	13.0	10.4	N	15.6	23.4	18.2
2009	N	5.2	5.2	5.2	N	18.2	23.4	18.2
2011	10.4	5.2	5.2	5.2	10.4	18.2	23.4	20.8

TABLE 5. Calculation of loss and its growth per Zone through time.

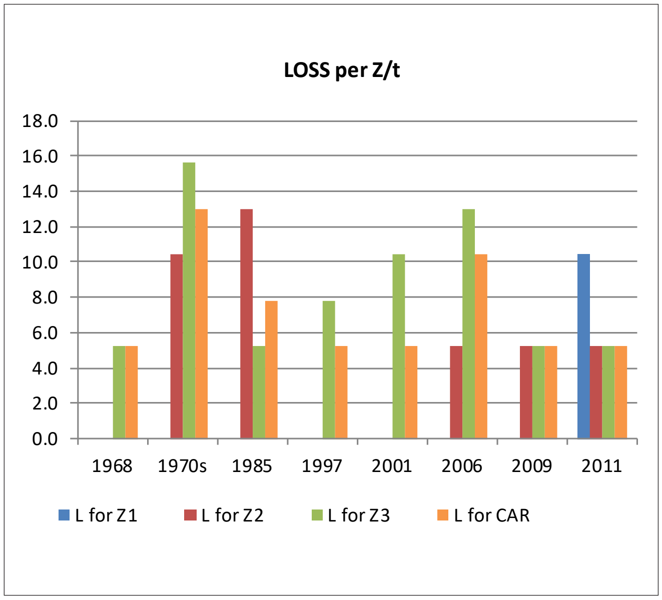

FIGURE 10. Loss per Zone through time.

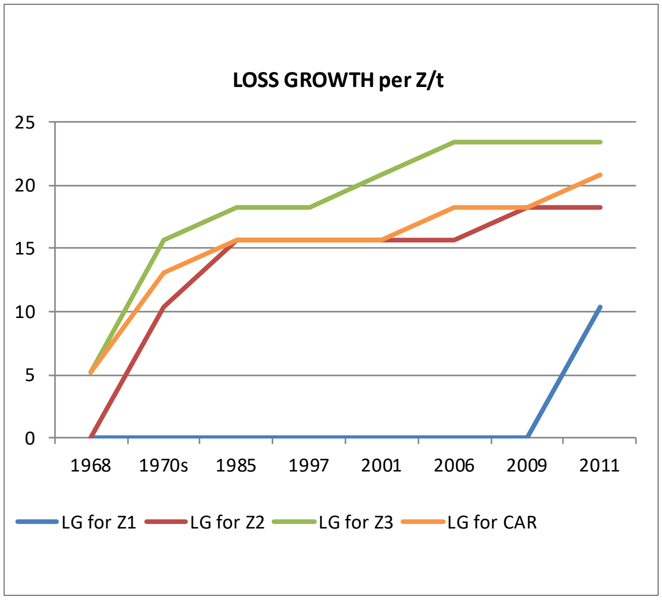

FIGURE 11. Growth of loss per Zone through time.

already in the 1970s the loss becomes significant and expressed with grade 3. After this period, the expansion of quarry is moderate, and the loss of value does not show visible growth. However, at the beginning of this century, with re-intensification of the quarrying activities, the loss is again rapidly increasing, and until 2006 it becomes severe and expressed with grade 4.

Visible damages to the archaeological record can be monitored until 2011 when further expansion of quarry was prohibited. However, according to the plans for quarry expansion from 2008 (Rudarsko-geološko-naftni fakultet 2008; Fig. 14) it is possible to make some anticipative assumptions on possible effects of planned activities on prehistoric archaeological record at Sutilija

	Lc				LcG			
	Z1	Z2	Z3	CAR	Z1	Z2	Z3	CAR
1968	N	N	1	1	N	N	1	1
1970s	N	2	3	3	N	2	3	3
1985	N	3	1	2	N	3	4	3
1997	N	N	2	1	N	3	4	3
2001	N	N	2	1	N	3	4	3
2006	N	1	3	2	N	3	4	4
2009	N	1	1	1	N	4	4	4
2011	2	1	1	1	2	4	4	4

TABLE 6. Categorisation of loss and growth of categorised per Zone through time.

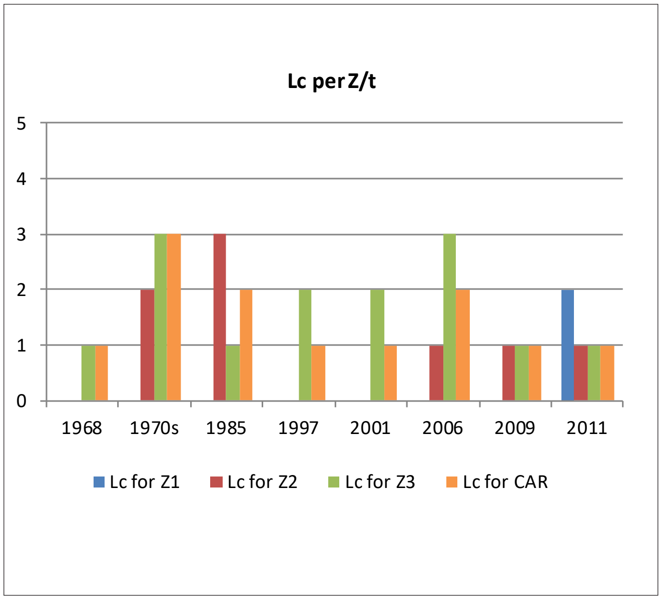

FIGURE 12. Categorisation of loss per Zone through time.

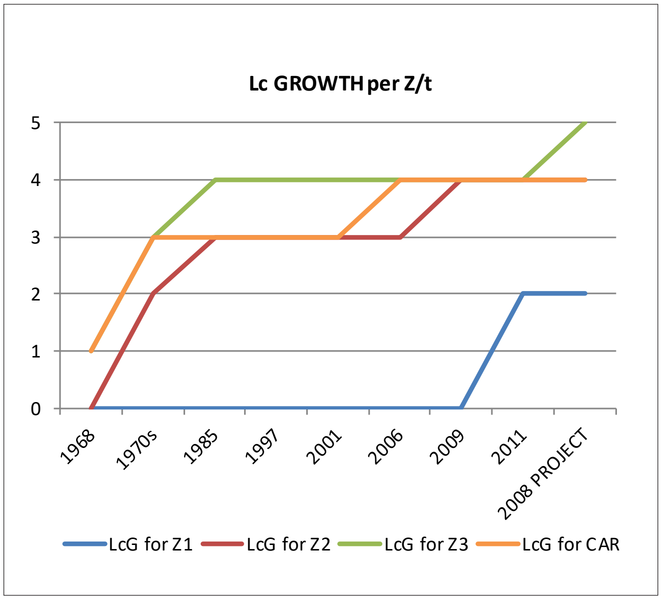

FIGURE 13. Growth of categorised loss per Zone through time.

(Table 7, Fig. 13). The new expansion would again seize all three zones in a total area of 0.7 ha or the new 3%. This would result in damage estimated to 12% in Zone 1, 46% in Zone 2, and 80% in Zone 3, while the damage in all three zones would for the first time increase over 50 %. Nevertheless, the calculations and categorisations of loss would mostly remain the same, but it is important to emphasise that with the actualisation of the planned quarrying the loss in Zone 3 would become complete and expressed with grade 5.

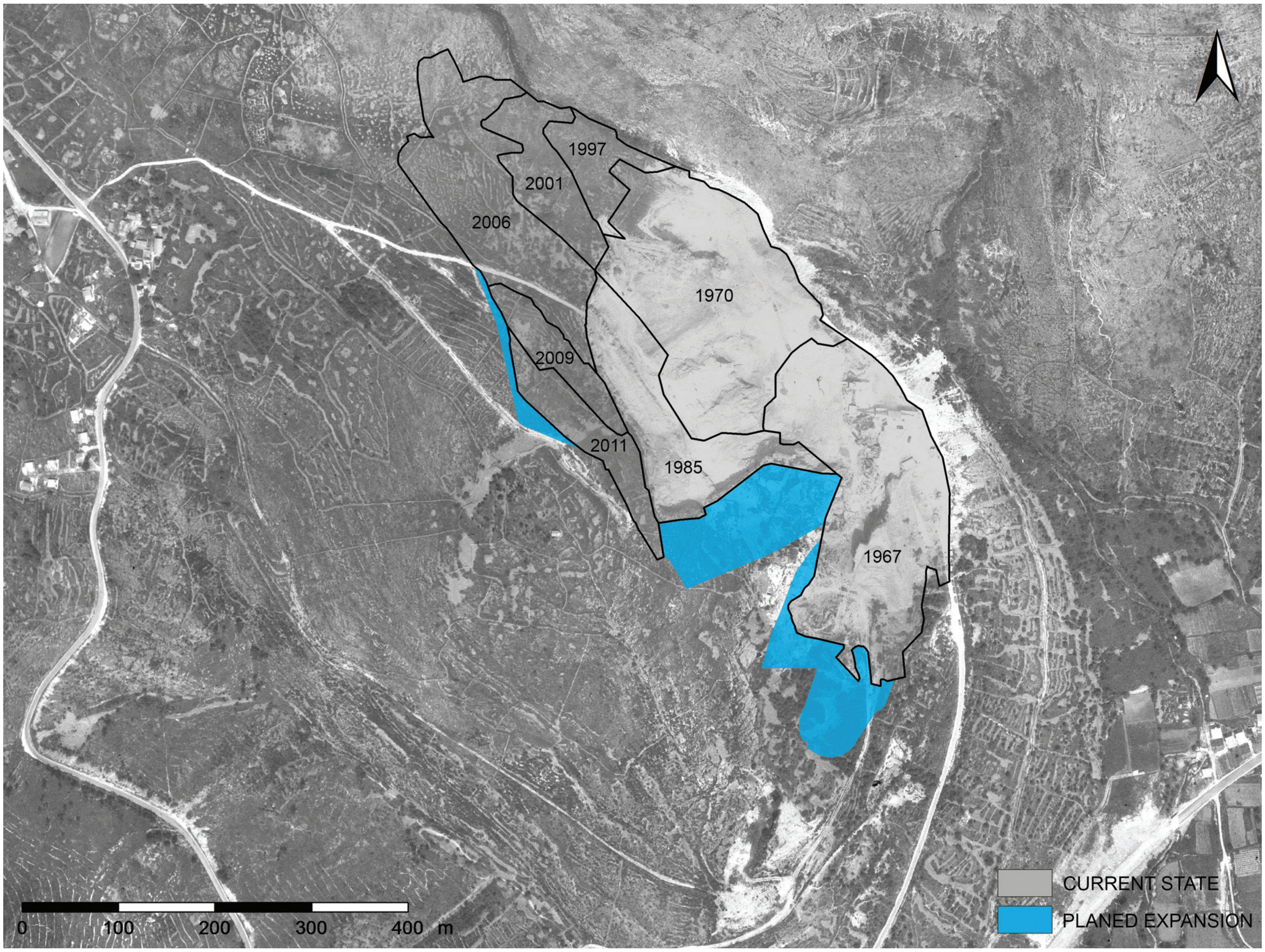

FIGURE 14. 2008 project of quarry expansion (made by: D. Tresić Pavičić; background: DGU, photo 1985_5364; source: Rudarsko-geološko-naftni fakultet 2008).

	Da m²	DaG m²	Epd %	EPdG %	L	LG	Lc	LcG
Z1	1139	6289	2	12	5.2	10.4	1	2
Z2	4767	32034	7	46	7.8	18.2	2	4
Z3	989	74847	1	80	5.2	26	1	5
CAR	6895	113170	3	52	5.2	20.8	1	4

TABLE 7. Predictive value loss assessment for planned quarry expansion.

Concluding remarks

The documentation collected as a part of the Sutilija project enabled the retrospective monitoring of the damage caused by the exploitation of stone, and the percentage of destruction was retrospectively calculated for the period of 50 years. The results of this type of analysis were suitable for the valorisation of the site and value loss assessment through different periods. The approach was developed in accordance with the possibilities of retrospective monitoring of a single archaeological site or entire landscapes (Storemyr 2004; Hamandawana et al. 2005; Skar et al. 2006; Mlinkauskienė 2010; Risbøl et al. 2014; Popović 2017) in situations where they are systematically subjected to harmful impacts and significant changes. Available data for this procedure included historical photographs and archival cadastral maps as well as topographic data and high-resolution 3D photogrammetry which enabled mapping of the visible features and reconstruction of characteristics of the hill permanently destroyed by the stone exploitation. This enabled retrospective analysis of the quarry-affected area and the extraction of data required for the application of VLA Model. Although the Model is not developed as a tool for objective and accurate calculation of loss, it is capable of performing archaeological analysis of damage in numerical relations (Sirovica 2019: 146). Thereby argued statements on the loss of value and meaningful ranking of loss is enabled, which can give a deeper understanding of the destroyed parts of the archaeological record and corroborated conclusions on the severity of damage. Accordingly, the aim of the presented approach is to broaden the understanding of the effects caused by long-term impacts on archaeological records and to enable the development of appropriate procedures within archaeological heritage management by means that capacitate the process of documenting changes and defining their scope. In everyday management practice, such an approach can greatly facilitate the analysis of similar situations and give strong arguments to the statements about damages on archaeological records.

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Beyond networks and macro-scale analysis: unravelling micro-histories of pottery at Early Bronze Age Samos, Greece through an integrated methodology

Sergios Menelaou

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Koç University
Research Center for Anatolian Civilizations
(ANAMED)
İstiklal Caddesi No: 181
Merkez Han
TR – 34433 Beyoğlu
P.O.B. 260 İstanbul

Department of Archaeology, University of Sheffield
Minalloy House
10-16 Regent Street
GB – S1 3NJ Sheffield
sergioslim89@hotmail.com

The study of pottery has historically served as a testing ground for archaeological theories, both due to its abundance in the archaeological record and its multifaceted use in the development of various methodological tools for the investigation of issues of exchange and external influence, technological tradition, social organisation, economic trends, and other cultural associations in past societies. Nevertheless, ceramic studies have largely extended the range of tools and techniques beyond traditional approaches that focus on stylistic, morphological, and typological attributes aiming at constructing chronological sequences or reconstructing large-scale networks of interaction. In fact, recent years in Aegean studies have witnessed an increasing concern towards the technological significance of pottery and its social context from a rather scientific-processual perspective. The project of Early Bronze Age (EBA/EB) Heraion on Samos Island, east Aegean (Greece) has successfully demonstrated that questions of ceramic production, consumption, and distribution can be meaningfully approached through the integration of different scales and levels of analytical enquiry. This has been achieved following a chaîne opératoire approach and the combination of various levels of analysis from typology, phasing, and contextual study of the entire ceramic assemblages covering the third millennium BC, with macroscopic analysis, thin section petrography, and microstructural analysis. This paper provides a brief overview of specific aspects of this project with the aim to highlight the significance of adopting a holistic approach in ceramic studies of well-defined, insular prehistoric environments.

Keywords: ceramic analysis, micro-scale, technology, provenance, Samos, Aegean, Early Bronze Age

Introduction

Despite continuous developments in ceramic studies in many areas of the Aegean (especially Crete and the Cyclades) and Greek prehistoric Archaeology in general, the ever-growing amount of data and new projects in the eastern Aegean and western Anatolian littoral region have followed a more conservative trajectory. In fact, the study of pottery in what forms today's political borders between Greece and Turkey (Fig. 1) is still largely used for its stylistic, morphological, and typological attributes with the aim to construct chronological schemes (cf. Rice 1996 with references; Orton and Hughes 2013: 3-12), determine the geological/geographical provenance based on a simple equation of similarities between pottery classes or even to reconstruct large-scale networks of interaction. However, in recent years there have been notable attempts to overturn this with the initiation of more interdisciplinary projects (cf. Alram-Stern and Horejs 2018a) that involve the application of archaeological scientific methods and less commonly the characterisation of technological practices and reconstruction of changes and/or continuities in the ceramic manufacturing process, as is commonly the case in the established research tradition of EBA Crete (e.g. Wilson and Day 1994; Day et al. 2006; Mentesana et al. 2019).

The integration of new methodologies in ceramic analyses (Tite 1999) has followed the example of projects carried out since the 1980's in a more systematic manner in the central and southern Aegean (Day et al. 2006; Hilditch 2018 with references on previous work; Papadatos and Nodarou 2018 with further bibliography), which have successfully demonstrated that questions of production, consumption, and distribution of pottery can be approached in a more meaningful way and old assumptions should be challenged through new studies of archaeological material. Recent synthetic works and case studies on various cultural/geographical regions tend to integrate traditional and modern aspects of pottery studies (e.g. Orton and Hughes 2013; Hunt 2016; Ownby et al. 2016; Sibbesson et al. 2016). This shift towards a combination of robust analysis with traditional approaches has proved to be favourable, as it integrates aspects of typology, context, and technological reconstructions with the aim to reveal cultural changes.

The almost complete absence of integrated, archaeometric projects from the eastern Aegean has impeded a better understanding of the island societies (Lemnos, Lesbos, Chios, Samos) often thought of as intermediaries in the transmission of finished products, ideas, and people from East to West, i.e. from Anatolia to the central and west Aegean, on the basis of geographical proximity. Nevertheless, this hitherto absence of such projects has been challenged by the holistic study of the third millennium BC pottery from the island of Samos. This paper employs an integrated ceramic analytical programme at the island settlement of Heraion (Menelaou et al. 2016; Menelaou 2018), focusing on the methodological aspect of this research and its articulation with a well-informed archaeological and theoretical background. A case study of the full characterisation of one of the main fabrics recovered at Heraion is presented with the aim to stress out the effectiveness in using a micro-scale approach as a means for analysing intra-site developments of a ceramic system, craft traditions and technological choices over time, as well as to gain a better insight in the consideration of provenance.

Beyond the (re)construction of macro-scale Aegean-Anatolian networks

Until relatively recently the reconstruction of patterns of regional and interregional trade and interaction was the primary focus of prehistoric Aegean and Anatolian ceramic studies, being tested further in archaeometric works through chemical/elemental analysis and the employment of a range of mineralogical and geochemical methodologies and identification of reference groups (Day et al. 1999; Day and Kilikoglou 2001). The identification of ceramic provenance has been particularly central in the reconstruction of trade networks and exchange patterns (Tite 1999: 202-203), following theoretical assumptions that favour the circulation of certain wares or vessel types in the explanation of socio-cultural or economic changes.

Narratives and concepts of large-scale exchange networks, cultural interaction and connectivity, and technological transfer, alongside developments in craft technology and specialisation, distinctive patterns of production and consumption, and increasing complexity comprise the main characteristics commonly considered to be reflected in the material culture of the third millennium BC in the region under examination (cf. Kouka 2002; Şahoğlu 2005). Pottery has held a key position in investigating these issues, mainly through typological and morpho-stylistic analyses, often creating assumptions of a deterministic nature that favour the identification of similarities in style and shape between different sites.

Following the various intellectual developments of Aegean Archaeology, a number of popular theoretical models have been put forward in the study of connectivity and mobility (Knappett and Nikolakopoulou 2015; Knappett and Kiriatzi 2016; Alram-Stern and Horejs 2018b: 11-12; Leidwanger and Knappett 2018). More particularly, within the context of the culture-historical approach, the notions of trade, migration or diffusion of culture were usually invoked to interpret material similarities or differences, and exogenous factors were seen as the trigger for these changes. As such, the concept of cultural *koine* was - and still is - particularly popular. This is highlighted by Kouka (2002: 299; 2015: 230), who speaks about a "cultural *koine*, which was recognized in the east Aegean islands and western Anatolian littoral from the 4th through the 3rd millennium BC" and further exemplified by Horejs (Horejs et al. 2018: 41) in her work on Aegean-Anatolian networks "from the presence of common styles and techniques of the eastern Aegean *koine*, communities in this region were integrated into greater networks of the eastern Aegean and western Anatolia". Despite its usefulness in grouping together particular classes of material culture over wide geographical areas, the concept's connotation to shared 'cultures' and macro-regional processes or even identities (Galanakis 2009) runs the risk to dismiss the importance of complex and varied micro-scale social processes and the conscious role of the agents (including producers and consumers) involved in such dialectics. Thus, favouring the notion of cultural homogeneity in the material expression, at the expense of a coherent picture of small-scale developments at a local level, seems somewhat challenging.

On the other hand, the world-systems model was introduced in the archaeological theory, with adaptations of the more general sociological and economically-driven concept and terminology established in the 1970s (Rice 1998: 45-47), of which most popular is the core/centre-periphery approach. Its utility for conceptualising large-scale interactions during prehistory and its deficiencies have long been discussed in the context of post-colonial theory and critiqued of neglecting the agency of the individual or even inappropriately applied (cf. Stein 1998; Kohl 2011: 79-82). This is particularly prominent in the investigation of contacts and exchanges between insular and mainland sites. The eastern Aegean and western Anatolian region constitutes a good case study in the identification of such core-periphery archaeological interpretations, where the islands only a few kilometres away from the Anatolian mainland have been largely overlooked on their own right and instead have been typically approached as being peripheral and passive in the adoption of novelties (cf. Menelaou 2018).

Network Analysis comprises another popular approach in the identification of similarities in material culture between different regions, usually concerned with the detection of trade patterns in a regional and interregional scale and variations in social and economic structures. This model largely follows an economic and environmental determinism, according to which communities need to interact with one another to promote change in social, political, and economic aspects. Networks are expressed through graphs with connecting points between sites that represent nodes or links. Although widely used and while these models provide useful visualisations for the reconstruction of macro-scale narratives, current network theory is in some ways a poor fit for networks of the ancient past (Knappett 2013: 7-10). Especially in the case of maritime interaction and connectivity models, the environmental and social factors that facilitated travel and communication in the Aegean (e.g. distance, geographical proximity, weather conditions, technologies of mobility, skills in navigation, etc.), as highlighted by Tartaron (2018: 62), cannot be captured by simply drawing lines and links between different geographical nodes. Frontiers and boundaries between sites and regions are dynamic, often unpredictable, and can be easily transformed over time. Nevertheless, Broodbank's (2000) work on the EBA Cycladic interaction networks, using a proximal point analysis, demonstrated an ideal case study for modelling intra-regional, maritime small-world connections.

This brief theoretical background highlighted just a few of the methodological and interpretational attempts to conceptualise large-scale interaction. A caution is provided against a 'top-down' detection of connectivity and the process of identification of common patterns, while a shift to emphasis to the local, micro-regional scales seems imperative in order to better comprehend the cause of the intensification of interactions during the third millennium BC. This can be achieved or at least approached more tangibly - in the case of pottery - with the combination of integrated methodologies (traditional/archaeological and analytical/archaeometric) with a well-informed theoretical framework. In the case of ceramic materials, what can be identified are the source (geological/geographical provenance) and the final consumption place. Islands are ideal case studies for exploring such dialectics of space and circulation, as they provide well-defined units of investigation.

Archaeological context and geographical setting

The position of Samos in the eastern Aegean (Fig. 1), which includes the offshore islands (Lemnos, Lesbos, Chios, the Dodecanese) and the opposite Anatolian coast, have been overwhelmingly neglected within Aegean-Anatolian prehistoric Archaeology (Kouka 2002; Şahoğlu 2005; Horejs 2017), in contrast with the western, northern, and southern Aegean, where the material record has been intensively investigated. A similar pattern is also observed in the representation of archaeometric projects in this region. Nevertheless, this region forms a significant interface between the Aegean basin and the Anatolian plateau, itself linked through long-distance exchange with the early urban complex societies across the Eastern Mediterranean.

FIGURE 1. Map showing Heraion on Samos and selected sites mentioned in the text.

Samos Island is situated in a very advantageous geographical area, on a maritime artery that links communication networks between East and West, and perhaps should be seen as a 'bridge' between western Anatolian littoral - Çukuriçi Höyük, Miletus, Liman Tepe, Tavşan Adası so to name a few contemporary sites with Heraion - and the Cycladic islands or even the west coastlands of Mainland Greece. In her thorough study of the network of maritime communication routes in the Aegean during the Neolithic and the EBA, Papageorgiou (2002) proposed that two main routes/passages facilitated the communication between Samos and the rest of the Aegean. More particularly, Samos is the last landfall before the Gulf of Kuşadası, if one is following the Route B and is sailing from the South, crossing the passage between the islands of Rhodes, Kasos, and Karpathos, as well as the passage between the Dodecanese and the Cyclades (Papageorgiou 2002: 163-164, 303-321), and the first on the principal route (Route Z) from Asia Minor to the central Aegean and Mainland Greece or in reverse (Agouridis 1997: 8). Samos, due to its nodal position in the eastern Aegean, is assumed to constitute the geographical and cultural link between western Anatolia and the central Aegean during EBA. Particularly important in this communication are the two arteries extending from the interior of Asia Minor: the Gulf of Ephesus northeast of Samos formed by the Kaystros or Küçük Menderes River, and the Meander Valley to the southeast formed by the Büyük Menderes River (Papageorgiou 1997: fig. 4).

This paper focuses on the Heraion settlement, which is situated on the south-central plain of Samos, the most fertile area on the island (Kouka and Menelaou 2018: fig. 1). The historiography of past research projects and excavations carried out at prehistoric Samos and Heraion, in particular, are presented in detail elsewhere (Kouka 2015: 224-225; Menelaou 2015: 25; 2017: 181-182; Menelaou et al. 2016: 482; Kouka and Menelaou 2018: 119-121).

The results briefly discussed in this paper derive from a combined analysis of three different ceramic assemblages excavated at different times and different areas of the settlement. More particularly, pottery excavated by Milojčić (1961) in the 1950's in the area between the Hera Temple and the North Stoa, as well as underneath the Pronaos that dates to the second half of the third millennium BC (phases Heraion I-V which correspond to EB II mature/developed through EB III late); by Weisshaar and Kyrieleis in 1981 north of the Sacred Road which revealed four architectural phases dating to EB I and EB II early (with earlier evidence dating to the Chalcolithic/Ch; Kyrieleis et al. 1985: 409-418, figs. 35-43; Kouka 2002: 286, tab. 1); and the pottery from the recent excavations undertaken by Kouka (2009-2013) in trenches immediately to the north of the later investigations (Kouka 2015: 225-228, figs. 1-3; 2017: 163-167), corresponding to five architectural phases, that revealed a continuation of the settlement from the Ch to the end of the Middle Bronze Age. The combination of all aforementioned ceramic assemblages at Heraion has allowed the formation of a complete ceramic sequence with no chronological gaps (Kouka and Menelaou 2018: tab. 1). Since previous studies of EB ceramics from Heraion have focused on establishing a relative chronology and a basic typology for comparisons with the rest of the East Aegean, based mainly on stratigraphical observations and variation in morphological and stylistic terms, the present paper provides a good opportunity to examine how different aspects of a ceramic system articulate with each other.

Methodological framework

Having established the theoretical and archaeological background of this project we can now move on to the methodological significance of this paper. The almost complete absence of such work at the eastern Aegean and Samos, as well as recent access to suitable ceramic datasets from the old and the new excavations at the Heraion settlement, has enabled the author to test methodologically the significance of micro-scale analysis at a well-defined insular place.

The present project has focused on analysing the full spectrum across the assemblages, i.e. the range of wares, fabrics, and shapes, an approach that has been extensively developed by Wilson's and Day's work in Crete (cf. Wilson and Day 1994; Wilson et al. 1999). Initially, this has been achieved through phasing and contextual analysis which enabled a good understanding of the local chronological sequence of the settlement (cf. Kouka and Menelaou 2018). This project builds upon various levels of analysis in the context of whole assemblages including:

a) Morphological examination at a macroscopic level, namely the examination of pottery by the naked eye and with the aid of a USB Digital Microscope, and its stratigraphic classification into wares, fabrics, and shapes/types in a diachronic manner. This allowed us to identify technological stages such as raw material choice, paste preparation, forming techniques, surface treatment modes, and firing, examined in accordance with typological patterns and morpho-stylistic features. The macroscopic analysis enabled a first, preliminary characterisation of local and suspected non-local fabrics, and quantification of their diachronic frequency was made.

b) Petrographic analysis of a large number of representative samples selected on the basis of macroscopic features, covering all periods, wares, and macroscopic fabrics (see Whitbread 2016 for description process). Ceramic petrography, namely the microscopic examination of ceramic thin sections, allows the identification and characterisation of the main mineral and rock types comprising the non-plastic inclusions (composition, quantity, shape, grain size and distribution), the examination of the optical properties of the clay matrix and the assessment of the textural associations of the above components (microstructure, colour, optical activity), which in turn enabled characterisation and grouping of the thin sections, reconstruction of technological practice (raw material processing and clay preparation, firing characteristics, forming techniques), and, where possible, the suggestion of provenance (geological and/or geographical).

c) Petrographic examination of both published and unpublished comparative material from predominantly contemporary sites across the Aegean and western Anatolia.

d) Microstructural analysis via Scanning Electron Microscopy-Energy Dispersive X-ray Spectroscopy (SEM-EDS), which established the micromorphological characterisation of the fabrics and surface of the samples under examination (firing temperature, surface treatment, microstructure). Such data can provide information on the types of clay used for slips in comparison to the composition of the body.

e) Geological prospection including the identification of potential raw material sources, collection and experimental analysis (ultimately by petrography) of clays, following the careful examination of Samos's geological background. Their comparison with the ancient pottery fabrics allowed the suggestion of geological and geographical provenance. This was also supported by an ethnographic study and examination of modern ceramics and tiles or bricks from kiln sites across the island.

f) Chemical analysis with Wavelength Dispersive X-ray Fluorescence (WD-XRF) is currently in progress. Bulk chemistry was not employed during the original stage of the analytical work, but a relative estimation and assessment of local *versus* non-local fabrics was made through a combination of contextual, macroscopic, and petrographic information.

This research project employed a theoretical approach which concentrates explicitly on the social dimensions of technological practice, according to which technology is a socially constituted dynamic process of combined social and material engagement (Dobres 2000: 125). Following a *chaîne opératoire* approach, an attempt to reconstruct all stages of the manufacturing process was made and a more detailed view of local developments has been gained. This popular approach in ceramic studies concentrates on the step-by-step reconstruction of the related past technical system and the social, cultural, and economic acts in the process of making and transformation of raw materials to a finished product affecting the potters' actions in the manufacture of pottery (e.g. Lemonnier 1993; Roux 2016). It, therefore, represents a shift away from solely morphological and stylistic patterns of object-driven approaches. Therefore, for every step of the manufacturing process different techniques were applied. Not all manufacturing steps are reconstructed equally, i.e. the fabric characterisation, processing of raw materials, surface treatment are better studied, whereas the interpretation of forming methods and firing conditions varies in confidence, depending on the available data.

Two basic insights were achieved:

1. The identification of patterns in the ceramic manufacture and technology at a local level, which enabled the reconstruction of the operational sequence of the pottery production process through the *chaîne opératoire* approach. This micro-scale analysis allowed the reconstruction of choices made by individual potters and workshops, the diachronic transmission of technical skills, crafting choices, and the emergence of local technological traditions and ceramic styles.

2. The examination of stylistic, typological, and fabric influences, as evidenced by macroscopic and microscopic features, and thus the determination of provenance, where possible, through the identification of the geological and/or geographical source of raw materials.

Reconstructing the operational sequence of a ceramic group from Heraion

The wealth of ceramic evidence at Heraion has offered the potential to explore intra-site technological practice, as well as inter-site relations at a regional level through a comparative examination of thin sections from other sites and extensive bibliographical research on form/finish/fabric comparanda and vessel parallels from across the Aegean and Anatolia during the Ch-EBA. This section

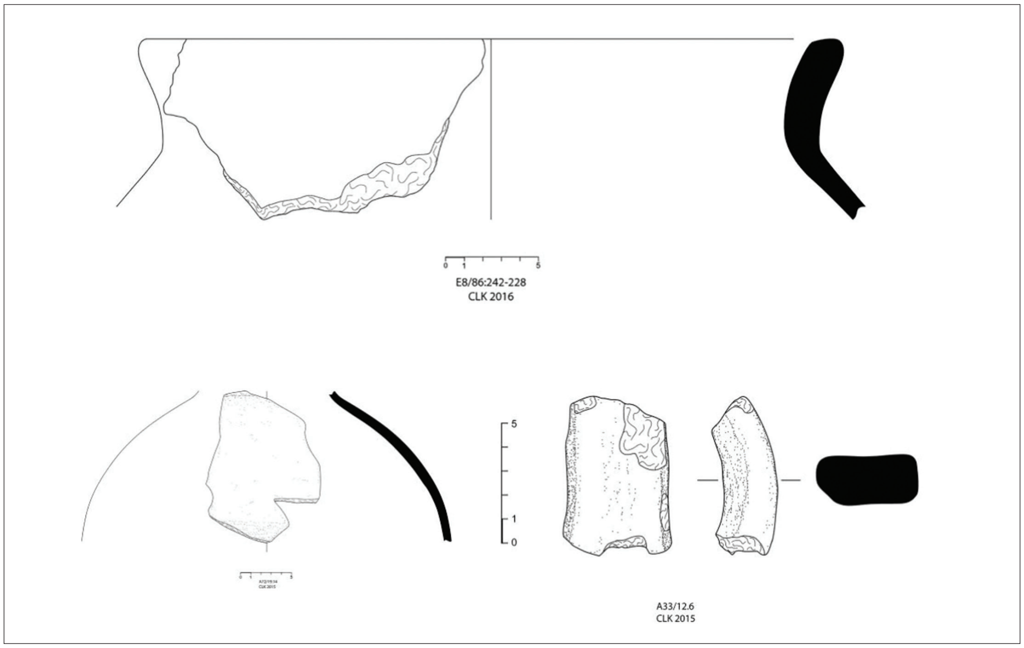

FIGURE 2. Illustrations of selected storage jars from Heraion.

deals with selected data from the overall holistic study (Menelaou 2018). Preliminary observations, mainly typological and morphostylistic, have been presented in short studies in a diachronic manner, alongside contextual, architectural, and chronological information (Menelaou et al. 2016; Kouka and Menelaou 2018; Kouka et al. forthcoming).

The systematic diachronic study of pottery from Heraion has produced significant patterns of production and exchange. Regarding pottery production, the variation in fabrics and distinct technological features within each implies that there must be several production centres operating in parallel in the vicinity of the site or some perhaps beyond the environs of Heraion itself. The majority of the pottery dated to the early phases of the EBA fall into the metamorphic fabric(s), which comprise more than half of the total analysed samples. These might reflect both a number of workshops and varied raw material sources in the vicinity of Heraion. Combined with the macroscopic information, the petrographic analysis revealed some important associations between shape, assumed function, fabric, and ware. From the diachronic examination of fabrics *versus* shapes, it appears that no differentiation can be detected between clay recipes used for large or medium/small-sized vessels or ware-specific groups in the Ch-EB I periods. In the subsequent period, there emerges a more varied picture with fabrics used for the manufacture of particular vessel types or even a range of similar fabrics that could reflect the existence of several production centres that produce the same types in similar or different recipes (Menelaou 2015; 2017; Menelaou et al. 2016). This could point out distinct manufacturing traditions and markedly different clays that can be explained from a chronological and technological perspective. Furthermore, the integration with macroscopic results has enabled the establishment of a detailed basis for the characterisation of the local ceramic technological tradition and the reconstruction of potential links of interactions with other Aegean and Anatolian sites through a detailed contextualisation of Samos within a regional framework from the Ch to the end of the EBA (Menelaou 2018).

Within this framework, this paper examines one ceramic class and some of the key trends deriving from its analysis. The *chaîne opératoire* approach is applied, and it is attempted to reconstruct all technological stages of the manufacturing process from raw material collection and characterisation of the clay composition to forming, surface treatment, and firing. Finally, the geological and geographical provenance is suggested within an intra- and inter-regional context. The various analytical methods are discussed where appropriate within each sub-section. The following discussion is broken down into five separate stages from the procurement and collection of the raw materials for pottery manufacture to finished products and their morphological characteristics. The 'Porphyritic Intermediate Volcanic Rock Fabric Group' (Menelaou 2018) corresponds predominantly to EB I-II developed storage vessels, i.e. wide-mouthed open jars/deep bowls, pithoid jars with vertical handles of a circular or oblong cross-section and usually a collared neck, as well as larger vessels with circular handles that can be characterised as pithoi (Fig. 2).

Clay composition and raw materials preparation

This fabric group was first characterised macroscopically due to its distinctive hard texture and coarse petrology and subsequently described in detail petrographically. It is characterised by a medium-coarse/coarse clay paste with reddish yellow/reddish brown (5YR 6/6, 2.5YR 6/6) matrix, usually exhibiting a core-margin differentiation of dark grey/black (7.5YR 5/1) and reddish yellow/red (5YR 6/6) colour respectively. Its main petrological features comprise of frequent to common, sparkling golden angular to sub-angular inclusions, fine to medium angular dark translucent/glassy inclusions, chalky-white fragments, as well as a frequent amount of organic temper (Fig. 3). In petrographic terms, these were identified predominantly as volcanic rock fragments of intermediate composition (andesite grading into dacite) and their constituent minerals (varying amounts of plagioclase feldspar, amphibole, biotite, pyroxene, quartz). In almost all samples there is a considerable amount of burnt-out vegetal temper appearing as elongate voids. It is overall a homogeneous, very consistent fabric group in terms of composition, although there are minor differences between samples. Despite some variability with respect to coarseness and roundness/angularity of the non-plastic inclusions, their range in both size fractions indicates that a relatively unprocessed clay consistent with *in situ* weathering was most probably in use, with the finer examples representing a better-processed paste.

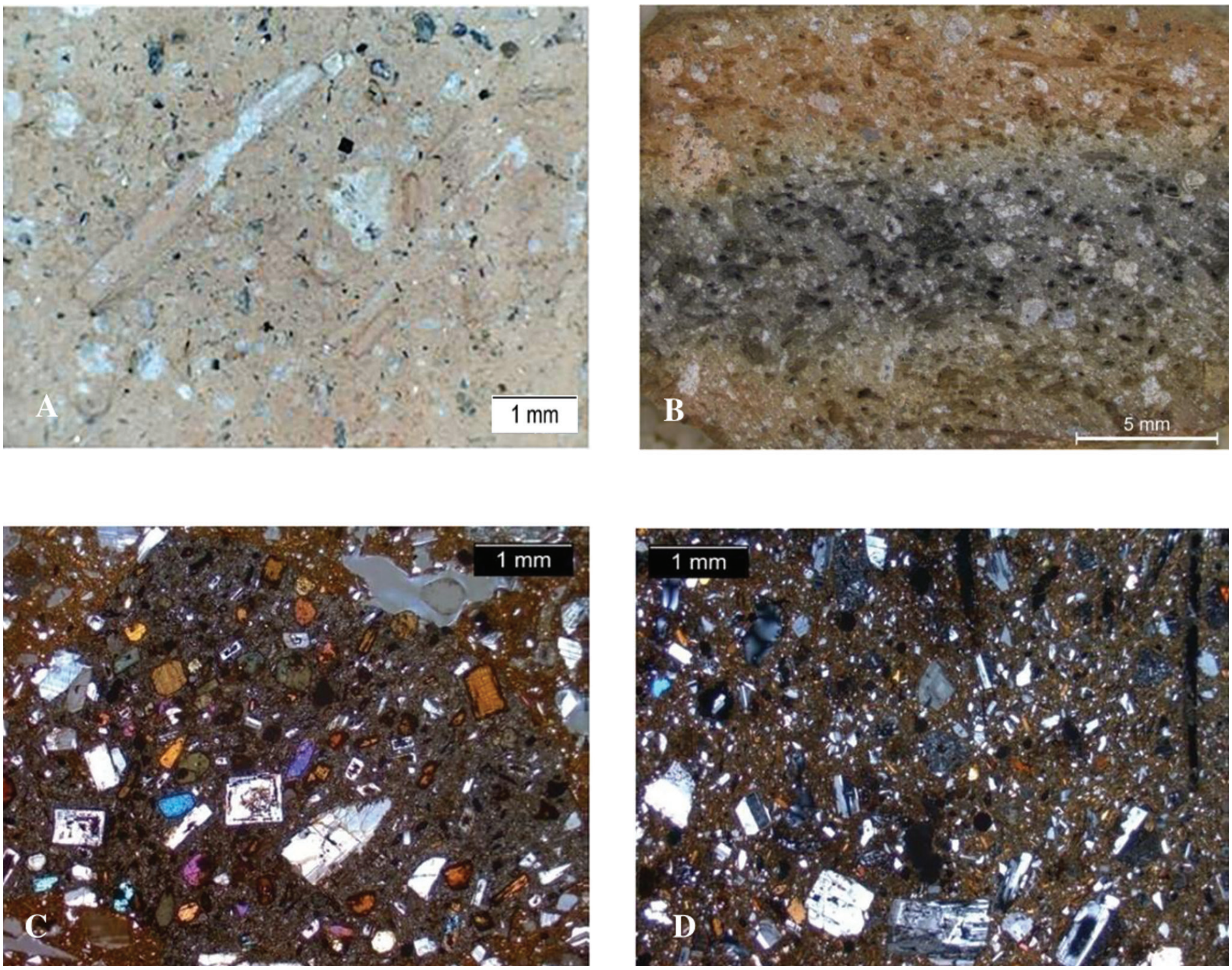

FIGURE 3. Fabric photographs of selected samples. A-B. Macrographs taken with a USB Handheld Digital Microscope; C-D. Micrographs taken in crossed-polars with a petrographic microscope.

FIGURE 4. Ceramic body sherds exhibiting clay layering (photographs taken by S. Menelaou, no scale).

Forming techniques

Although surface modification often affects the visibility of the forming and finishing techniques employed, including the orientation of inclusions and voids, some examples provide evidence for the identification of handbuilt methods. More particularly, some sherds exhibit evidence for, what is preliminarily believed to be, the use of slab-and coil-building methods, according to the identification of distinct superimposed layers of clay. This is more clearly identified macroscopically in body sherd sections, but can be better observed close to rims or handle attachments and the base of the pots, where the wall is thicker (Fig. 4). The slabs/flattened coils are identified petrographically by elongate voids or the differential orientation of inclusions created upon the formation of the vessels (Fig. 3D). Similar techniques, namely sequential slab construction or multi-layering methods, have been identified in the Neolithic and Chalcolithic central Zagros region and the Iranian plateau (Vandiver 1987: 20), and more recently also at Pre- and Protopalatial Phaistos in Crete (Todaro 2018). Ceramics made with this technique are also linked with the use of vegetal tempering, which affects the plasticity of the clay.

Finishing and surface treatment

The examination of surface treatment and finishing techniques was achieved mainly by macroscopic examination, combined with SEM study of the microstructure. This fabric group is associated with well-slipped and burnished vessels which stand out due to the quality of their red (10R 5/6) - or rarely black - non-calcareous surface finish (Fig. 5A-C). Some examples were also identified petrographically (Fig. 5D). The iron-rich slip layer, also confirmed by the high Fe spectrum values of the EDS analysis, ranges in thickness (0.02mm to 0.04mm) and is clearly separated from the clay body (Fig. 5E-F). The majority of vessels appear with a lustrous surface and have only their exterior slipped and burnished, while their interior surface exhibits a characteristic scored treatment (Milojčić 1961: pl. 31:2; Kouka and Menelaou 2018: 127). Scoring is shown by parallel horizontal or perpendicular striations which appear more regular below the rim (Fig. 5B); occasionally these are oblique and overlap with each other. More rarely, the creation of burnished interior surfaces may relate to the utilisation of the vessels to hold liquid or foodstuff. Given that burnishing and the creation of a lustrous surface is particularly time-consuming it is more likely to suggest that it relates to a decorative habitus and tradition of the producers of these vessels, or even acted as a sign of quality, rather than just serving functional purposes.

Firing procedure

Macroscopic observations have established a first understanding of the firing regime of this pottery group, based on colour and variation of the sherd breaks, combined with a comparison of colour and optical activity of the micromass in petrographic thin sections (Fig. 5D). However, more secure information was extracted from the SEM analysis. The majority of samples show a pronounced colour differentiation with a darker core that relates to the common presence of partially-combusted vegetal temper. This effect could either imply a fast-

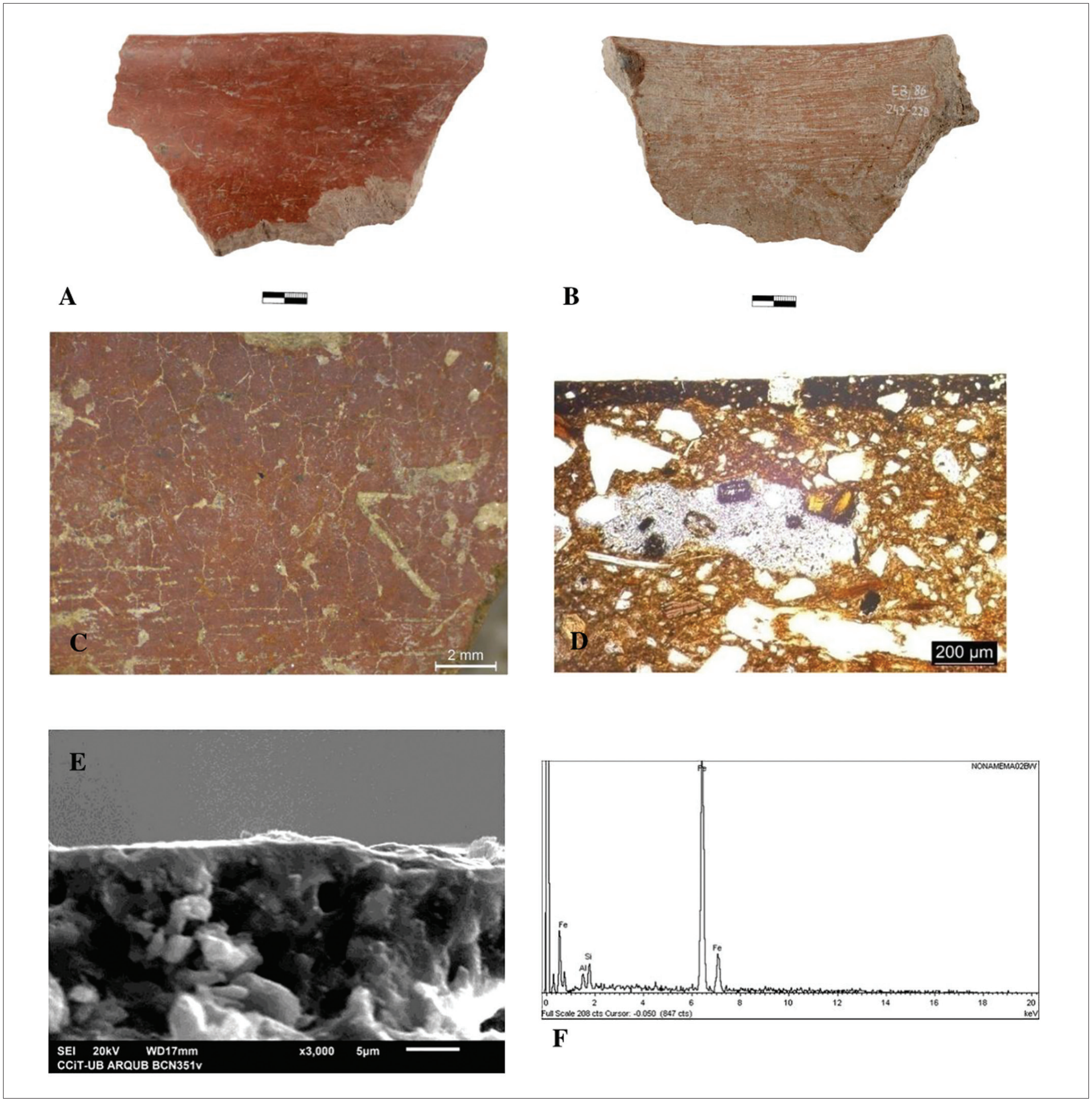

FIGURE 5. Examples of the red slipped and burnished vessels and surface treatment examination. A. Exterior surface of a storage jar with a lustrous thick slip; B. Interior surface of a storage jar with traces of scoring; C. Macrograph of the surface treatment mode; D. Micrograph of the exterior slip layer; E. Slip layer identified with SEM; F. SEM-EDS element spectrums showing a high amount of Fe on the slip surface (all images taken by S. Menelaou).

firing process, perhaps in an open environment, where the carbon deposits were allowed to build up through a complete lack of oxygen. However, the firing was too short for the process to complete full oxidation (Kilikoglou and Maniatis 1993: 438). SEM analysis suggested that almost all samples - except for one or two dated to the later EBA phases - were low-fired and thus appear to be non-vitrified, but some rounding on the edges of the clay pastes occurs, and this is defined as an intermediate stage between no vitrification and initial vitrification with an estimated temperature of 750-800°C.

Morphological features

The main vessel types forming this group are the wide-mouthed open jars and the pithoid jars/pithoi. The former type is characterised by straight walls and a usually thickened rounded rim with a wall thickness between 0.9cm and 1.5cm and a rim diameter of 25cm to 36cm. Its form and style find close typological parallels at Emporio V-IV on Chios (Hood 1981-82: 359-360, fig. 164:888) dating to EB I. The latter type is characterised by a collared neck or funnel-necked profile, being slightly flaring or carinated on the inside. The upper part of the rim is usually rounded or flattened. There are two types of vertical handles, i.e. oblong or sub-rectangular and circular in cross-section. The thickness ranges from 1.3cm to 2.2cm for the body, 2cm to 3.2cm for the rim and the rim diameter ranges from 24-26cm to 36-40cm for the larger vessels. Typological and stylistic parallels have been identified at Troy II, Poliochni Blue-Green corresponding to EB I-II early (Bernabò Brea 1964: LIV:f, LXXVII:f, g, i) and Emporio IV-II on Chios corresponding to EB I-II late (Hood 1981-82: figs. 187:1284-1285, 1290-1292). Other, minor vessel types in this fabric identified at Heraion are the winged jar and the steep-necked jug with a long cut-away spout. The former is typical for Troy II late (EB II late), Aphrodisias BA 4 corresponding to EB IIIA (Joukowsky 1986: 394, figs. 327 and 426.4) and Poliochni Yellow on Lemnos corresponding to EB II late (Bernabò Brea 1976: pls. CXCIV, CVCV:b,e). The origin of the steep-necked jug has been attributed to southwest Anatolia and close typological parallels are known from Troy III-V corresponding to EB III (Blegen et al. 1951: 29, pls. 59a: Shape B20, 72:33.179), in late EB II-early EB III contexts at Bakla Tepe (Şahoğlu 2008: 157, fig. 2g), Poliochni Yellow (Bernabò Brea 1976: pl. CCX:c) and EB III Vathy on Kalymnos Island (Benzi 1997: 386, pl. 2b:5722).

From micro-histories to macro-narratives

The presentation of this distinctive ceramic group from Heraion and the reconstruction of all stages of its manufacture have allowed meaningful insights into the technology and provenance of vessels, otherwise studied in terms of their shape and surface treatment (Milojčić 1961: 40, pls. 31:2 and 48:35). The combination of technological information, from clay composition to firing, suggested a potentially non-local provenance for this group that is primarily consisted of large storage jars and pithoid jars/pithoi dating to EBA I-II early and less commonly to EB II late-III periods. The first evaluation of this pottery group implied a local production both due to its frequency and diachronic span at the settlement, but a more careful examination of its technological features, compared to other Samian groups that have been confidently ascribed with local provenance, further suggested a most likely off-island provenance. This was also supported by observations based on geological literature, supplemented by raw material prospection and experimental analysis of clays and sediments from Samos, which did not identify any possible correlations with the on-island geology. Overall, the composition of this fabric is not diagnostic for Samos. The limited Neogene volcanic bodies that penetrate the metamorphic substrate in the margins of the Mytilinii basin are characterised by basaltic tuffs and minor trachydacites, while more acidic lavas and rhyolitic tuffs occur in the Karlovassi basin (Menelaou 2017: 184-185).

An extensive, but not exhaustive, fabric, style, and shape/type study of pottery from contemporary Aegean and Anatolian sites has established some possible connections with Samos. The morphological and stylistic features provide links with a number of western Anatolian and less commonly southeast Aegean sites, but these do not allow to pinpoint the possible source of importation of these vessels on Samos. The combination of shape/style with fabric and other technological features may help narrow down the suggested geographical area of origin.

Starting from the west Aegean, this intermediate volcanic fabric is macroscopically linked with Macroscopic Group 1 or petrographically with Fabric Group 1 recorded at Kolonna on Aegina in the Saronic Gulf (Gauss and Kiriatzi 2011: 47-49, tab. 12, figs. 17, 29-31; Kiriatzi et al. 2011: 93) and the 'Dark Volcanic Macroscopic Group' from Dhaskalio on Keros (Hilditch 2013: 474, V10). Despite the strong similarities, a closer examination of the Heraion fabric revealed some important mineralogical, compositional, and textural differences with the Aeginetan fabric, on the basis of presence/absence of pyroxenes *versus* amphiboles and biotites.

Stronger parallels were identified in the east Aegean and western Anatolia. More specifically, potential macroscopic fabric and finish links are suggested here with the 'Obsidian Ware' from Emporio on Chios, which is thought to be imported at Chios and spans Phases VII-II (Late Neolithic to EB II) (Hood 1981-82: 168-169, figs. 187:1284-1285, 1290-1292, 204:1642). This group at Emporio is distinguished by the presence of hard, shiny, black angular particles that resemble obsidian and it corresponds to large storage jars/pithoi during Phases V-IV corresponding to EB I (Hood 1981-82: 308, 358, 434, pl.

80 no. 1362). Similarities exist also in shape and surface treatment. The latter appears with the characteristic scoring traces, as those known from Heraion, and have been linked by Hood (1981-82: e.g. pl. 104:2397, Period II) with the 'Scored Ware' large storage jars known to have been imported in middle-late Troy I and II from further east in Anatolia (Blegen et al. 1950: 39, 53-54, 222). Similarly, the 'Early Aegean Ware' (Blegen et al. 1950: pls. 251-252, 409-410; 1951: pls. 175:15-17, Troy IV, 250, Troy V levels), which is presumably imported at Troy from the Greek mainland or the Cyclades, has the same characteristics. It corresponds to closed vessels with a thick red slipped exterior surface and a scored interior and it was found at Troy I-II levels. Potentially similar wares/fabrics were recently found in survey material at Bozköy-Hanaytepe in the Troad (Yilmaz 2013: 868-869, fig. 11) and Halasarna on Kos, at the latter site predominantly dated to the EB I-III, that are suggested to be locally produced (Georgiadis 2012: 24-25, 49, fig. 8:Kt.108, Kt.Lh.5-6). Other typological, and potentially also fabric, parallels have been identified at Poliochni Blue-Green (EB I-II early) on Lemnos (Bernabò Brea 1964: LIV:f, LXXVII:f, g, i). Perhaps similarities should also be searched with the Red-Slipped and Burnished Ware from the Neolithic site of Ulucak in the Izmir region, according to its macroscopic fabric/ware characteristics and frequency at this site (Çilingiroğlu 2012: 27-28).

In terms of clay composition and petrographic analysis, similar andesitic fabrics have been recorded in Late Bronze Age pithoi from Troy, which have been assigned with a local provenance related to the Ezine volcanic outcrops and the fluvial deposits about 10-20 km away from the site (Kibaroğlu and Thumm-Doğrayan 2013: 48-49, fig. 2d). Further petrographic analysis of pottery from Troy VI-VIIA demonstrated the common presence of altered and fresh volcanic rocks in all assumed local fabrics and vessels typologically considered as 'Island Wares' and connected to the nearby islands of Samothrace, Lemnos, and Lesbos were proven to be indistinguishable from the local Trojan fabrics (Krijnen 2014: 25). Another fabric of similar composition has been recently identified petrographically in the Neolithic pottery from Emporio and Agio Gala on Chios, which is taken as a local product on the basis of the presence of calc-alkaline andesite and basalt volcanic bodies (Pe-Piper et al. 1994). Nevertheless, the Chian fabric differs from that from Samos by the presence of fewer pyroxenes and the predominance of altered biotite and amphibole crystals (B. Lambrechts pers. comm., January 2017). The volcanic fabrics from EB Liman Tepe in the Izmir Gulf represent most likely local products and relate to volcanic bodies in the Karaburun peninsula (Day et al. 2009: 341). Its composition and texture is similar to a local volcanic fabric at Heraion (Menelaou et al. 2016: 485, tabs. 1-2, Fabric 3: Altered Volcanic, fig. 4b; Menelaou 2017: 187-188, fig. 7). Other parallels in inland western Anatolia derive from the southwest Konya plain, which is dominated by andesitic and dacitic volcanic rocks (Gait et al. 2018: 109-111, fig. 1).

Perhaps the best fabric/ware matches derive from EBA Miletus and Tavşan Adası Phase 2 (EB II late-IIIA) in western Anatolia, both of which are situated in important geographical nodes immediately opposite and south of Samos. The frequency and compositional features of these fabrics at the aforementioned sites are currently under study by other researchers (personal communication with Dr J. Hilditch and Prof. F. Bertemes) and their publication will allow a better comparison with the ceramic group recovered at Heraion. Thus, although this group is undoubtedly non-local and the potential published parallels point to western Anatolia, its provenance remains open until more comparative material and analytical results from the eastern Aegean and western Anatolian region, where similar geological formations are encountered, become available which will allow a closer geographical resolution.

A better picture of the neighbouring regions, that could represent the provenance areas of the fabric in question, is given by the geological literature. According to geochemical and petrographic analyses, the Neogene volcanic units of the Karaburun peninsula east of Chios in the Izmir region are represented by olivine-bearing basaltic-andesites to shoshonites and related pyroclastic rocks (Karaburun volcanics), high-K calc-alkaline andesites, dacites and latites (Yaylaköy, Armağandağ and Kocadağ volcanics), mildly-alkaline basalts (Ovacik basalts), and rhyolites with trachyte-like porphyritic outcrops (Urla volcanics) (Helvaci et al. 2009: 185-186, fig. 3; Ersoy et al. 2012: fig. 1). Common volcanics are also widely distributed in the areas to the north and south of the Karaburun peninsula, with the former being characterised by high-K and calc-alkaline products (Lemnos Island) and alkali basaltic lavas to the east in western Anatolia (Biga peninsula, Troas), high-K andesites, dacites, and rhyolites (Lesbos Island and the opposite coast and mainland), as well as alkaline olivine basalts, calc-alkaline rhyolites, dacites, and andesites outcrops in Chios. The latter exhibits a comparable geochemical signature with northwest Anatolia andesitic-dacitic rocks (Innocenti and Mazzuoli 1972: 87), although differences occur in the composition of rhyolite outcrops (Helvaci et al. 2009: 188). Southwest Anatolia, the Bodrum peninsula area, and the Dodecanese islands of Kos, Yali, and

Nisyros include younger volcanic rocks (Upper Miocene to Quaternary) and are characterised by trachytes, rhyolites, and basalts (Helvaci et al. 2009: fig. 2).

This case study of a single ceramic group has highlighted the interconnected nature between questions of technology and provenance in pottery manufacture, particularly prominent in the investigation of micro-scale developments of a given site. This in extension has provided a better view of intra-regional maritime connectivity and the circulation of storage (perhaps transport) jars already from the beginning of the third millennium BC, in a cultural/geographical area where interaction mechanisms and exchange networks comprise a hotly-debated topic.

Conclusions

This paper has tried to demonstrate how a micro-scale perspective, focused on the social dimensions of technology through the *chaîne opératoire* approach, can allow the closer examination of the potters' choices at each manufacturing stage. In extension, isolating specific technological steps and acknowledging variability can allow the discrimination between different traditions and products of different potting communities, i.e. the distinction between local and non-local pottery groups. The case study of the EBA Heraion on Samos Island has demonstrated that questions of production, consumption, and distribution of pottery can be meaningfully approached through the application of a holistic, integrated methodology combined with a sophisticated theoretical background that concentrates on the social dimensions of technological practice. Only by understanding the small-scale developments and changes in a craft practice as pottery making we can move on bigger narratives of connectivity and mobility. An integrated, diachronic analysis of total ceramic assemblages has proven to be a very effective approach, particularly when combined with the examination of comparative data from other contemporary sites. Aside from its significance in terms of an integrated, multi-technique methodology, this paper has argued for the conceptual importance of a multi-scalar approach in the study and interpretation of change in the interrelated ceramic system of production, exchange, and consumption. More importantly, this approach has shifted away from generalised models in the identification of networks as the sole possible framework for addressing past interactions and connectivity in ceramic studies. Apart from the micro-scale study of pottery at an intra-site level, the comparative examination of pottery sherds and/or thin sections from a number of central and east Aegean and western Anatolian sites has enabled the identification of imports and the establishment of a first understanding of the connections between Samos and other contemporary sites and its participation in various networks of interaction.

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Image analysis of Archaeological Ceramics and its Application to the Identification of Prehistoric Production Technologies

Ki Suk Park
Ralf Milke
Erik Rybacki
Sabine Reinhold

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Ki Suk Park, Ralf Milke
Institut für Geologische Wissenschaften
Freie Universität Berlin
Malteserstraße 74-100,
D – 12249 Berlin
ki.suk.park@fu-berlin.de
milke@zedat.fu-berlin.de

Erik Rybacki
Deutsches GeoForschungsZentrum GFZ, Section 4.2
Telegrafenberg
D – 14473 Potsdam
uddi@gfz-potsdam.de

Sabine Reinhold
Deutsches Archäologisches Institut
Im Dol 2-6, Haus II
D – 14195 Berlin
sabine.reinhold@dainst.de

Recent advances in microscopy, scanning techniques and digital data processing have allowed image analysis of archaeological objects. In this study, 2D/3D image analysis will be applied for the main topics of ceramic pottery production: resource gathering, firing degree and shaping techniques. The basic images were acquired by the polarized light microscope, SEM and 3D µ-CT. The segmentation and parametrization of structural elements were performed by Matlab. In order to characterize ceramic pastes, shape parameters such as size distribution, circularity and sphericity of coarse sand grains provided quantitative information. Pore topology dominated by the clay/ceramic sintering can give qualitative and quantitative data for the pyrometamorphic degree of the ceramics. Sphericity, surface area, volume, Euler characteristic and curvature of open and closed pores are the possible parameters describing the topology and topological changes. They allow us to estimate the existence of various firing states. Shaping techniques of the ceramic body were identified by three-dimensional alignments of segmented pores and sand grains. A continuous and separate building of the structural part, hand shaping or wheel-shaping/thrown can be suggested by this method. Despite the heterogeneity in mineralogical and chemical composition, grain size distribution and firing state of most archaeological ceramics, it is expected that the direct measurement of the visual element and its parametrization enable us to identify various techniques employed for the prehistoric ceramic production. This method will contribute to reconstructing technological styles of prehistoric material production with easier and faster availability and accessibility.

Keywords: *pottery production, shape parameters, pore topology, shaping techniques, image analysis, 3D µ-CT*

Introduction

In the past twenty years, there have been rapid advances in microscopy, scanning and image processing techniques (Ketcham and Carlson 2001; Cnudde and Boone 2013). Above all, the application of high resolution X-ray computed tomography (CT) clarified the internal structure of fossils, meteorites, and textural differences in magmatic, metamorphic and sedimentary rocks and soils related to sintering (Dierick et al. 2007; Brun et al. 2010; Voltolini et al. 2011; Yin et al. 2016; Bauer et al. 2017; Selden and Penney 2017). This technique is supported by mass data processing accompanied by progress in the central processing unit (CPU) and graphics processing unit (GPU) and the data transport system. This allows image visualization and segmentation as well as the complex calculation of the geometry of the studied objects. Advanced image acquisition and analysis have huge research potential in archaeology and archaeological sciences. Thanks to the mobility of digital data, researchers can perform the analysis in relatively boundary-free conditions without the necessity to transport the fragile archaeological objects over long distance and time.

In previous studies, polarized light microscopic images or scanned images of cross sections or thin sections of ceramics were used for the identification of forming and shaping techniques of ceramics (Lindahl and Pikirary 2010). Alignments of grains or pores provide visual evidence for the shaping methods such as coiling, moulding or wheel shaping/throwing proved by the rotational kinetic energy (Carr 1990; Courty and Roux 1995; Roux and Courty 1998). X-radiography or 3D micro X-ray computed tomography (3D µ-CT) can provide the grain size or pore size distribution and the existence of organic materials or heavy minerals in the ceramics (Berg 2008; Kahl and Ramminger 2012; Sobott et al. 2014). However, most prehistoric objects above all ceramic sherds are heterogeneous in chemical/mineralogical composition and consolidation/metamorphic degree of the sediments/clays. This results in difficulties in the segmentation of a representative region of interest (ROI). Thus, it is necessary to determine the proper conditions for image acquisition and segmentation of heterogeneous composite materials in which every component is chemically and physically connected to each other. In this paper, 2D- and 3D-image analysis of the archaeological ceramics will be briefly introduced. Pores and grains will be segmented and measured directly from 2D and 3D images at various scales. From those segmented images, parameters related to their shapes will be derived, in order to study traditional topics about the prehistoric production technologies of the ceramics: resource gathering, firing degree and shaping techniques (Fig.1).

Several examples for the application are provided from the researches about the ceramics excavated at Ransyrt 1 (Middle/Late Bronze Age) and Kabardinka 2 (Late Bronze/Early Iron Age) in the North Caucasus, Russia (Reinhold et al. 2018; Park et al. 2019a; 2019b). The archaeological site, Ransyrt 1 is located on the plateau

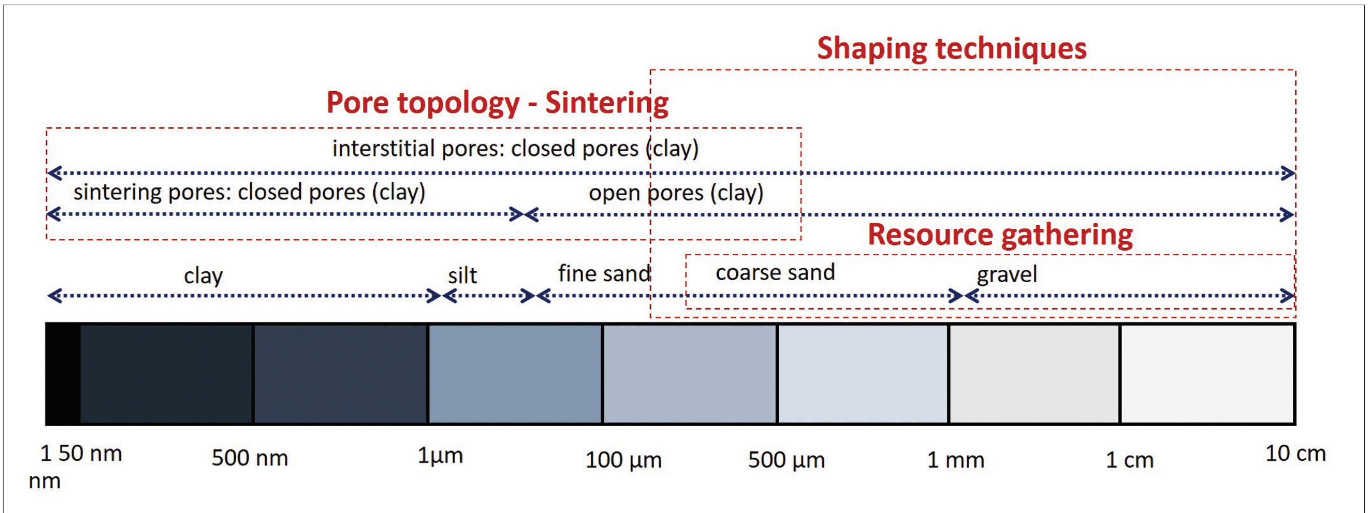

FIGURE 1. Various scales of the studied objects in the archaeological ceramics and associated topics in the ceramic production technologies, respectively: resource gathering by coarse sand and gravel. Pore topology-sintering by closed pores (sintering, interstitial) and open pores. Shaping techniques by large pores, coarse sands and gravels.

with the height of 1850 m above sea level, while another site, Kabardinka 2 lies on the lower plateau with 1400 m a.s.l. (Reinhold et al. 2018). Ransyrt 1 ceramics contain four groups of mineralogical composition of the grains: 1) quartz and K-feldspar, mica-chlorite intergrowths with traces of albite and kaolinite; 2) quartz and K-feldspar, mica-chlorite intergrowths and plagioclase and alteration products; 3) Plagioclase and clinopyroxene; 4) quartz, K-feldspar and calcite. In many samples, quartz and K-feldspar build a fine mixture in grains. In the meanwhile, ceramics from Kabardinka 2 have different mineralogical combinations: 1) quartz and K-feldspar often accompanied by kaolinizing phases; 2) quartz, K-feldspar, mica-chlorite intergrowths and plagioclase, mostly Ca-plagioclase from anorthite to labradorite in a subhedral or euhedral form located in the altered volcanic glass and kaolinizing phases; 3) quartz, K-feldspar, calcite; 4) quartz, K-feldspar, calcite and mica-chlorite intergrowth; 5) random combinations of quartz, K-feldspar, plagioclase, mica-chlorite intergrowths, calcite, kaolinizing phases, alteration product similar to olivine or amphibole, clinopyroxene, and SiO_2-rich porous and vitreous grains. The dominant chemical composition of the ceramic matrix composed of all grains smaller than 50 µm for both sites is different from each other. In Ransyrt 1 ceramics, there are Ca/Mg-rich objects, while Kabardinka 2 samples have Fe-rich sherds. Despite these differences, illite is identified as the dominant clay mineral for the whole ceramic samples.

Image processing: Image acquisition, reconstruction and segmentation

Images of the ceramics were acquired at different scales and with different spatial resolutions. In order to characterize the ceramic pastes in terms of the morphology, sand grains in the ceramics are analyzed. In this study, 2D digital images were acquired by polarized light microscopy with a pixel size of 3.27^2 and 10^2 µm^2. For the 3D image processing, samples were scanned by 3D µ-CT (nanotom 180NF, GE phoenixIx-ray) with tube voltage and current of 140 kV and 96 µA, respectively. In total, 1080 images at angular steps of 0.33 degree were taken with an acquisition time of 1000 msec/image. The voxel size was 9.49 µm^3, to compare to the 2D image analysis using 10^2 µm^2 per pixel. The whole area and volume of the sample were ROI because most prehistoric ceramics contain a huge grain size distribution. The selected magnification of the sample, as well as pixel/voxel size, were enough to represent the corresponding sample. The acquired images were reconstructed as a volume file using the phoenix datos|x reconstruction software with a beam hardening correction (BHC) factor of 8. An edge enhancement filter was applied for the reconstruction.

The second topic, pore topology in 2D was measured by scanning electron microscopy (SEM), JEOL JXA 8200 Superprobe with an acceleration voltage of 15 kV. The scanned area was 300 x 300 µm^2 with a pixel size of 1^2

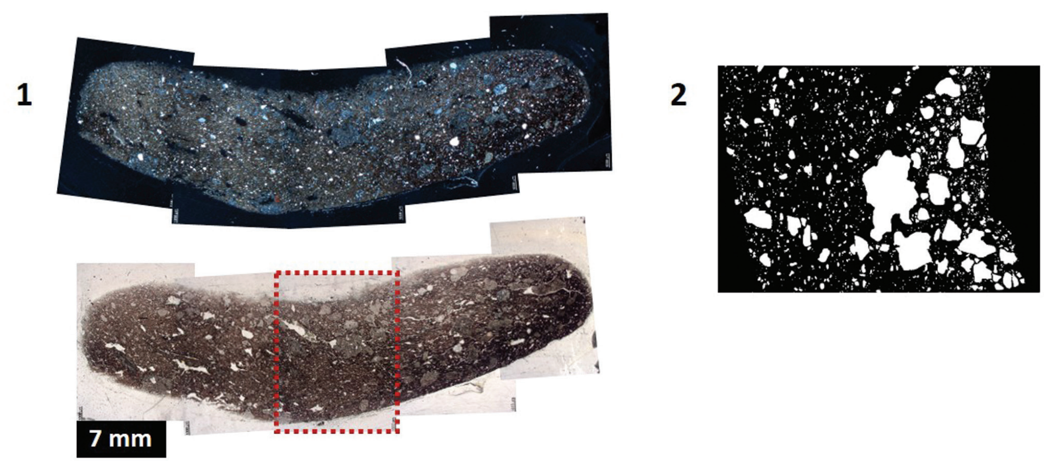

FIGURE 2. 1. Polarized light microscopic images (cross and plane polarized light) of the cross section (pixel size: 3.27^2 µm^2); 2. Segmented image of sand grains (white) from a BSE image (pixel size: 10^2 µm^2).

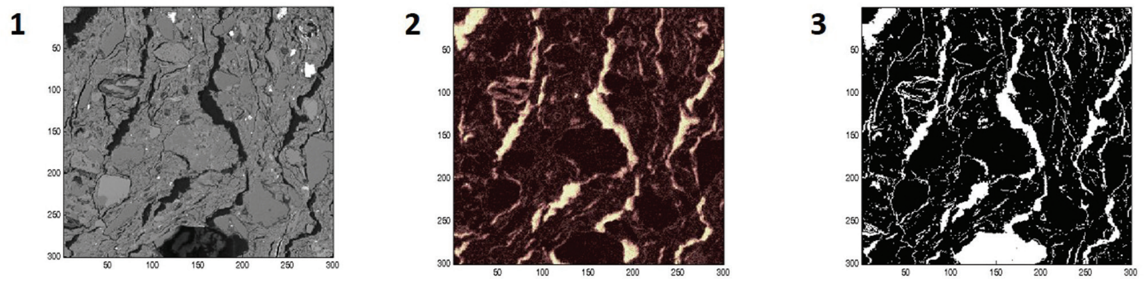

FIGURE 3. Visualization of the 2D matrix according to the intensity of BSE (1; black: pores) and Carbon (2; dark brown) and segmented image of pores (3; white) from the matrix (measurement area=300x300 µm², pixel size: 1² µm² (images modified from Park et al. 2019b, Figure S2).

µm², which allowed to capture various types and sizes of pores in the ceramics. In a 2D matrix, the intensity of Carbon and back scattered electrons (BSE) was presented. The 3D porosity was measured by µ-CT with different tube voltages (103-129 kV) and currents (70-80 µA) according to the sample. The acquisition time for 1080 images ranged from 750 to 1000 msec/image and the voxel size from 1.05^3 to 3.85^3 µm³ as well. For the image reconstruction, the BHC factor was set to 9-10, to minimize artifact effects.

The ceramic formation technique was estimated from the inner structure of the ceramics measured by the 3D µ-CT. The alignment of sand grains and large pore complexes were taken into consideration to determine the structural formation. Thus, the whole ceramic sherd should be within the ROI, and this caused a relatively larger voxel size of 9.49^3-30.27^3 µm³. The corresponding condition was set to tube voltages of 102-140 kV, currents of 70-103 µA, the acquisition time of 500-1250 msec/image according to the sample. The scanned images were reconstructed with a BHC factor of 8, and the edge enhancement filter was applied.

The image segmentation process for the 2D and 3D data sets was performed by programming with the Matlab software. For the polarized light microscope images, colors were converted into gray values, and sand grains were segmented using the corresponding thresholds (Fig. 2). From the 2D matrix of the intensity according to the measuring element per pixel (1^2 µm²) by SEM, objects were segmented by the pore threshold (Fig. 3). Because Carbon can be influenced by the quality of the sample preparation or calcite grains as well, BSE intensities can indicate more precise pore topology in most cases.

All 3D objects presenting pores and grains measured by µ-CT were segmented using multiple thresholds for the ROI. Due to the heterogeneity of structural elements and the asymmetric form of the investigated samples, a different threshold depending on the scanning area was used for the segmentation (Fig. 4). The normal vector to the mass center of the individual sand grains can be derived too so that the external physical force to the grains and ceramic matrix can be visualized (Fig. 5).

Image analysis

The numeric properties of segmented objects from the 2D images were calculated by the CPU using 8-connectivity/neighborhood. If the adjoining pixels are connected along the horizontal, vertical, or diagonal direction, the connected object is defined as the same region. For the defining 3D objects, 6- and 26-connectivity/neighborhood of voxels were calculated by the mixed procedure of CPU and GPU. 6-connectivity counts voxels connected if their faces touch, while 26-connectivity takes voxels connected if their faces, edges, or corners touch as the same region.

Shape parameters of coarse sands

Coarse lithoclastic sand grains bigger than 250 µm present in the ceramics can be investigated using 2D image processing. Their maximum length, circularity, sphericity 1 and sphericity 2 of the ellipse that has the same normalized second central moments as the individual segmented object serve for the differentiation of the ceramic pastes (Wadell 1932; Krumbein 1941; Barrett 1980):

Circularity:

$4\pi A/P^2$ (A: area; P: perimeter), (1)

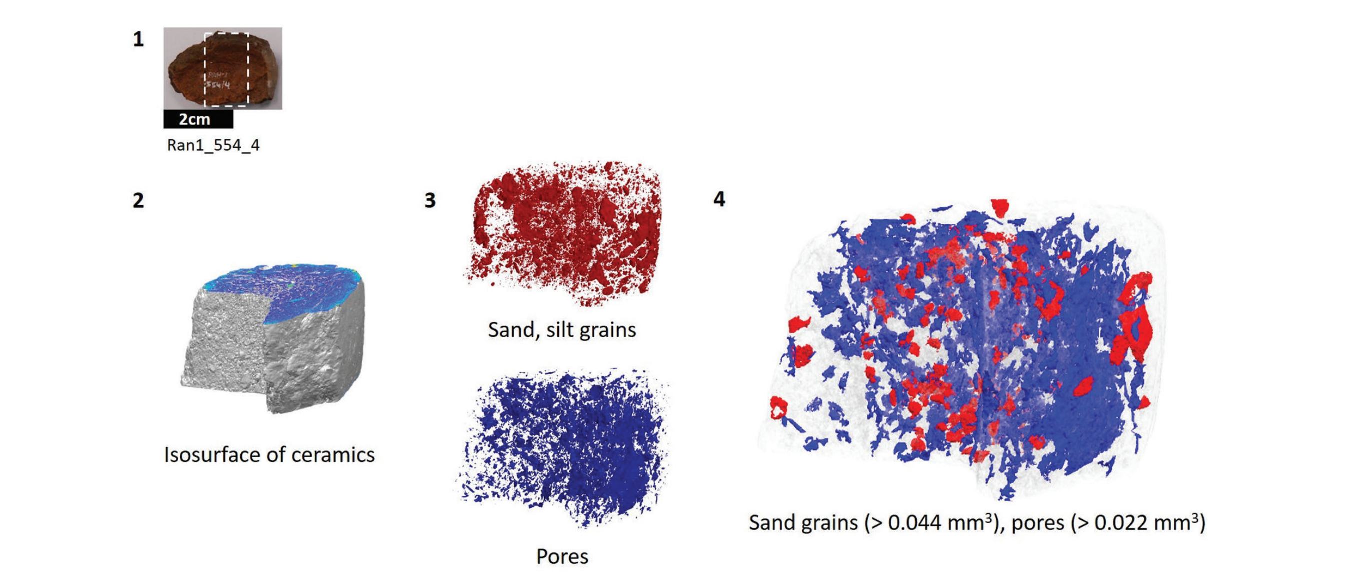

FIGURE 4.1. Original ceramic sherd (Ran1_554_4) and its ROI in the box of the white dashed line; 2. Isosurface of the sample with Isocaps of the exposed cross section derived from the reconstructed 3D image; 3. Segmentation of sand/silt grains (red) and pores (blue) from the reconstructed 3D image; 4. Segmentation of sand grains bigger than 0.044 mm^3 (red) and pores bigger than 0.022 mm^3 (blue) in the ceramic body (transparent light grey). (geometric magnification, voxel size: 24.31^3 μm^3).

Sphericity 1 (elongation):

$$D_F,\ max) / D_F,\ min\ (D_F\text{: Feret diameter}), \qquad (2)$$

Sphericity 2 (elongation):

$$a / b \text{ (a : major axis, b : minor axis)}. \qquad (3)$$

These parameters were illustrated in Figure 6. Because most sand grains are composed of various mineralogical phases, the shape parameters derived from each grain are more representative for geological conditions of the origin of ceramic pastes than parameters derived from each single mineral phase. The shape parameters de-

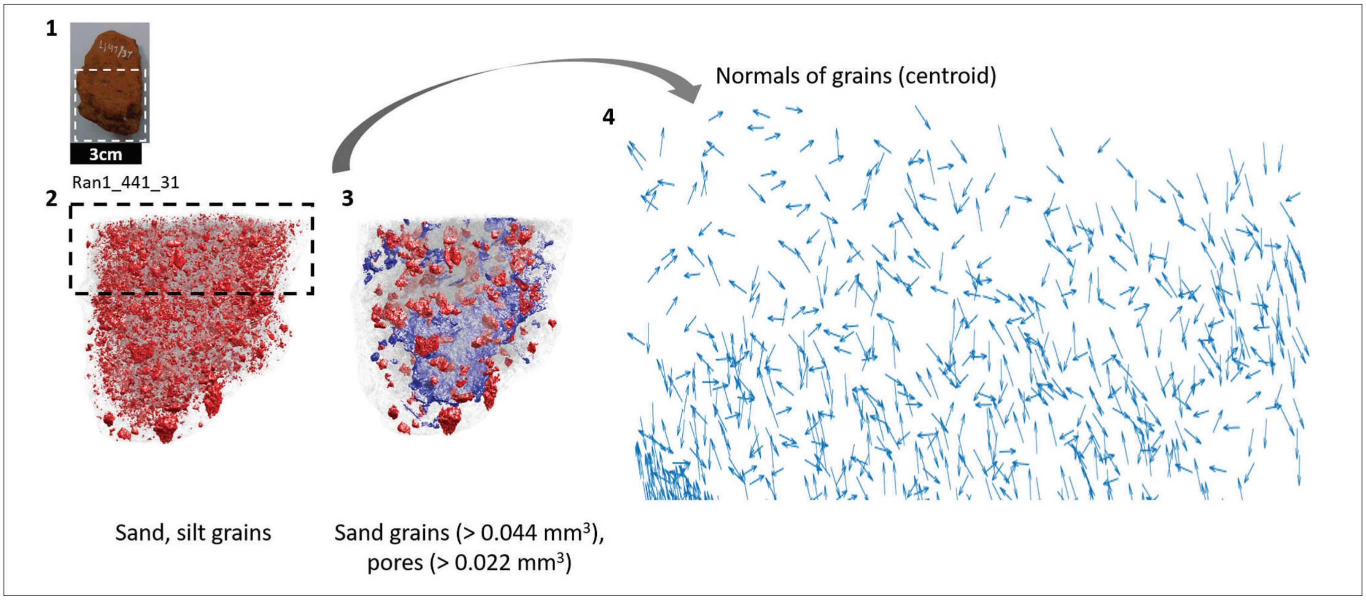

FIGURE 5. 1. Original ceramic sherd (Ran1_441_31); 2. Segmented sand and silt grains (red) in the ceramic body (transparent grey) from the reconstructed 3D image; 3. Segmented sand grains bigger than 0.044 mm^3 (red) and pores bigger than 0.022 mm^3 (blue) in the ceramic body (transparent grey) from the reconstructed 3D image; 4. Normal vector (small arrows in light blue) of mass center of grains in the black dashed lines of 5.2. This indicates the direction of force to the grains. (geometric magnification, voxel size: 28.21^3 μm^3).

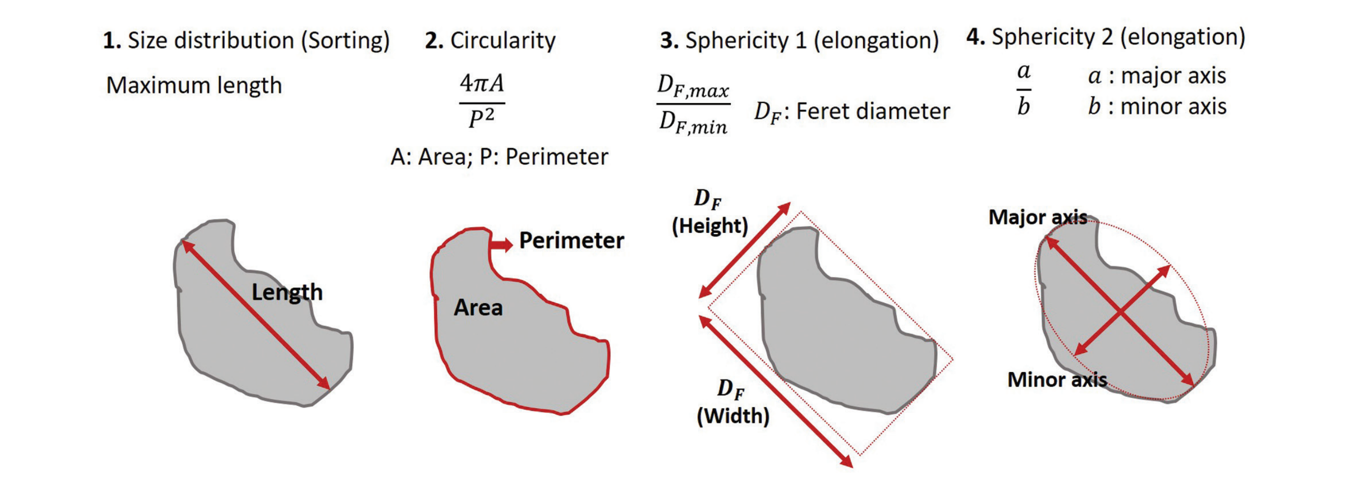

FIGURE 6.Shape parameters for the sand grains in archaeological ceramics. 1. Size distribution based on the maximum length of the grain; 2. Circularity calculated from the area and perimeter; 3. Sphericity 1 calculated from max. and min. Feret diameter. Indicator of an elongated degree; 4. Sphericity 2 calculated from major and minor axis of the weight centered sphere of the grain. Another formula for an elongated degree.

rived from 3D images may give more precise value, especially the length of grains because the two-dimensional measurement cannot due to the sand alignment.

Pore topology

Pore topology ranging from submicron to a few hundred micrometer scale could indicate the pyrometamorphic degree of the ceramics because it is influenced by the clay sintering according to the firing temperature (Okuma et al. 2017). In the case of the solid sintering in the homogeneous shape and composition, its topological changes provide thresholds of each sintering stage: (i) contact between neighboring solid particles; (ii) interconnected channels with cylindrical pores; (iii) formation of closed pores (Coble 1961; Okuma et al. 2017). The procedure of clay sintering can be described by similar steps, too (De Jonghe and Rahaman 2003). The initial stage can be described by the formation of sharply concave necks between the individual solid particles, while the intermediate stage forms a 3D interpenetrating network of solid particles and continuous, channel-like pores with high curvatures. The final stage of sintered clay shows isolated and closed pores accompanied by the extensive removal of pore volumes.

However, most archaeological ceramics are composed of heterogeneous components such as clay mineral, quratz and other rock-forming minerals. This influeces pore topology in the initial and pyrometamorphic state. The sintering of those composites occurs as a mixed process of the densification process by the grain boundary diffusion, lattice diffusion from the grain boundary and plastic flow and the coarsening process by the surface diffusion, lattice diffusion from the surface and vapor transport (De Jonghe and Rahaman 2003). Despite these difficulties in the morphological description, the pore space formation was classified into several simplified steps related to the ceramic firing: (i) drying and shrinking of the clay paste; (ii) dehydration in the low temperature firing interval between 100 and 200°C, creating interstitial pores; (iii) continuous increase in porosity by chemical reactions such as dehydroxylation of clay minerals, dissociation of carbonates, reactions between other constituent mineral phases between 400 and 800°C; (iv) liquid phase sintering with interconnected pores of irregular shape and partial melts; and (v) final state of the ceramic fabric varying from non-vitrified to completely vitrified (Ferrer et al. 2015). Direct measurements of the heterogeneous archaological ceramics in 2D and 3D proved that the general topological changes in micrometer scale are led by the clay sintering process (Park et al. 2019b). This is related to the earlier beginning of the clay sintering, in comparison to the other mineralogical components such as quartz. However, another abundant mineral in ceramics, calcite or organic phases such as plants rests are exceptional case, because their contribution to the pore topology is not related to the sintering of solids. Those features should be separately evaluated.

According to the morphological changes led by clay sintering, 2D and 3D representations of the complex pore geometry can be employed for the pore topology description of archaeological ceramics (Vogel 1997; Vogel et al. 2010). Euler characteristic can provide an unbiased estimation of pore topology, possible for a 3D cutout of arbitrary shape and volume V (Vogel and Roth 2001). Figure 7 shows the parameters which describe the pore topology. The Euler characteristic (χ) was calculated from 2D and 3D images using the following formula:

$$\chi_{2D} = n(\text{objects}) - n(\text{pores}), \quad (4)$$

$$\chi_{3D} = n(\text{objects}) - n(\text{pores}) + n(\text{cavities}). \quad (5)$$

n(objects), n(pores) and n(cavities) mean the total numbers of objects, pores and cavities, respectively. Because the 3D micro-tomographic data were reconstructed with voxels in a cube form, Euler characteristic was acquired by the Euler-Poincaré Formula (Vogel and Roth 2001; Legland et al. 2007):

$$\chi_{3D} = n(\text{vertices}) - n(\text{edges}) + n(\text{surfaces}) - n(\text{volumes}). \quad (6)$$

Due to the very heterogeneous shapes existing in the samples, the calculation used the 6-connectivity of pixels. The orientation of the pores can provide additional evidence of the sintering stage. In 2D image analysis, the angle between the x-axis and the major axis of the ellipse that has the same second-moments as the region referred to as θ was used. It ranges from -90 degrees to +90 degrees. In 3D processing, Euler angles for the x- (φ), y- (θ) and z-axis (ψ), returned as a 1-by-3 vector were considered. These angles were calculated with Matlab based on the right-hand rule (Shoemake 1994; Lehmann and Legland 2012). Figure 8 shows the comparison between the 2D- and 3D porosity according to the pyrometamorphic degree (Park et al. 2019a; 2019b).

Additionally, curvatures of the pore space can describe local bending of the pore surface representing local sintering degree (Fig. 9) (Cohen-Steiner and Morvan 2003; Meyer et al. 2003). For example, one of the algorithms

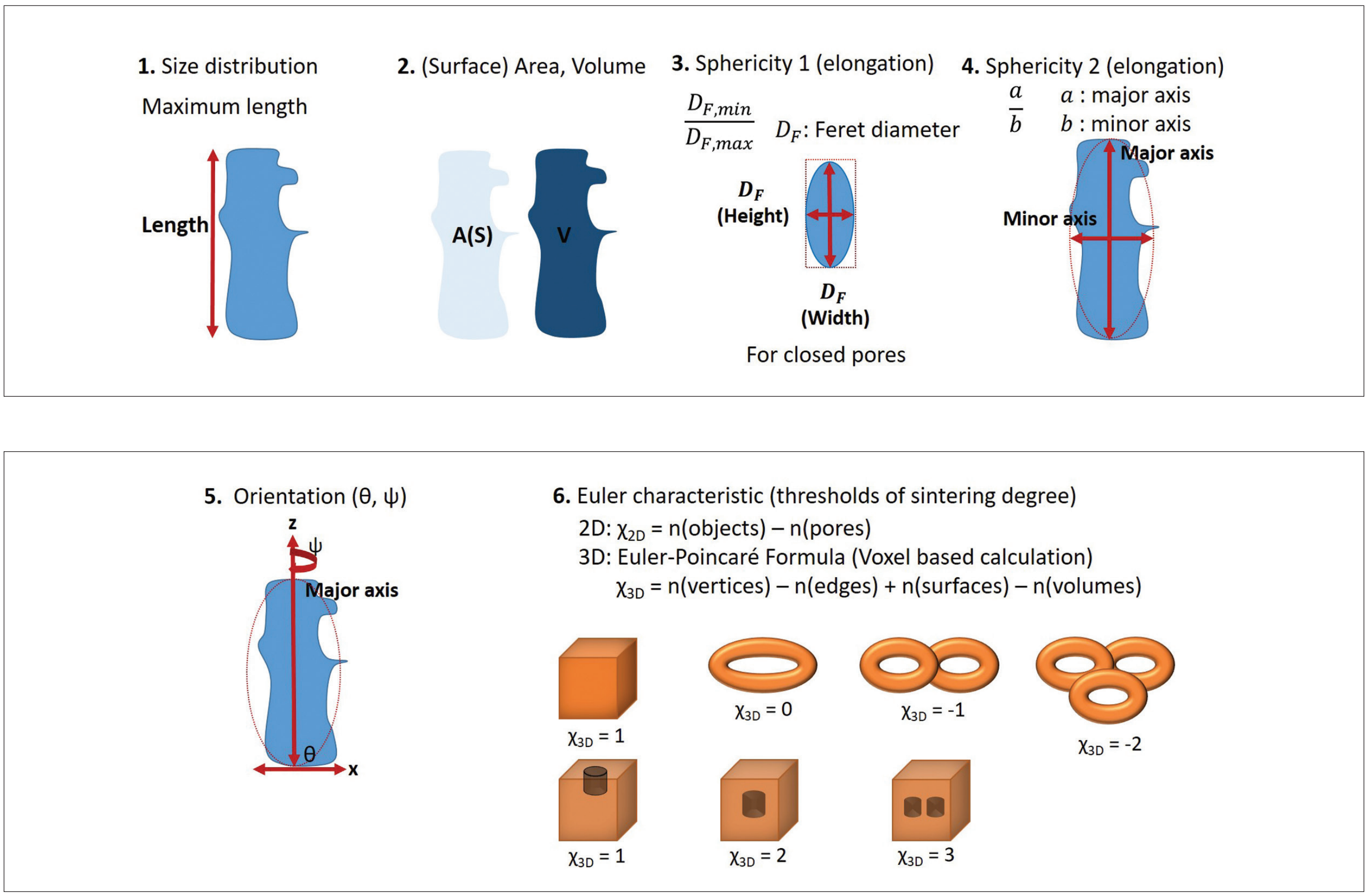

FIGURE 7. Shape parameters for the pore topology. 1. Size distribution based on the maximum length of the grain; 2. Surface area and volume of pores; 3. Sphericity 1 calculated from max. and min. Feret diameter. Indicator of an elongated degree of the closed pore; 4. Sphericity 2 calculated from major and minor axis of the weight centered sphere of the grain of pores; 5. Orientation around y- (θ) and z-axis (ψ) of pores; 6. Euler characteristic for 2D and 3D. For 3D images reconstructed by the hexagonal voxel (digitalized 3D images), Euler-Poncaré Formula can be employed for this characteristic.

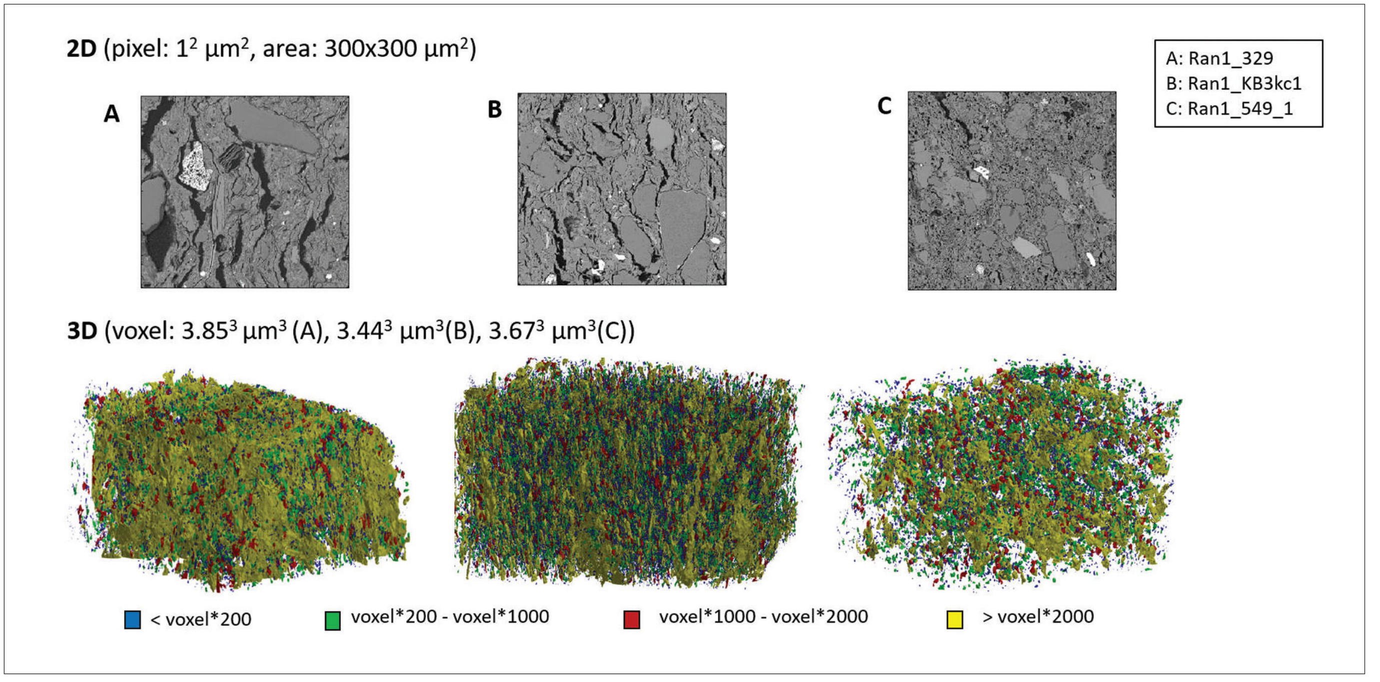

FIGURE 8. Comparison of the pore topology between 2D (pixel size of 1^2 µm^2, unit area of 300^2 µm^2 for the sample A,B,C) and 3D images (voxel size of 3.85^3 µm^3 for A; 3.44^3 µm^3 for B; 3.67^3 µm^3 for C) of three samples varying in the degree of pyrometamorphic degree/sintering (estimated by Park et al. 2019a). Estimated firing temperature for A: 700-850 °C, B: 700-850 °C and C: 950-1050 °C. The segmented pores in the samples presented different colors according to the volume size (blue for the relatively small pores, green for the mid-small ones, red for the mid-big ones and yellow for the relatively big pores) become smaller and less interconnected from A to C. (Park et al. 2019b).

for the mean curvature operator using triangulation of the 3D object can be another parametrization of this surface was suggested by Meyer et al. (2003):

$$K(xi)=\frac{1}{2Amixed}\sum_{j\in N1(i)}(cot\alpha ij + cot\beta ij)(xi - xj),\ K=1\text{-}3 \qquad (7)$$

Alignment and formation

Using the alignment of macropores and sand grains, the inner structure of bottom and wall fragments were investigated. This does not focus on the finishing and decoration of the ceramics expressed at the surface. For the clearer and more compact visualization of the pores and grains, 26-connectivity is used for the segmentation. Figure 10 shows an example of the pore alignment indicating the separate formation of the bottom and wall part and flattening of the bottom plate (Park et al. 2019b).

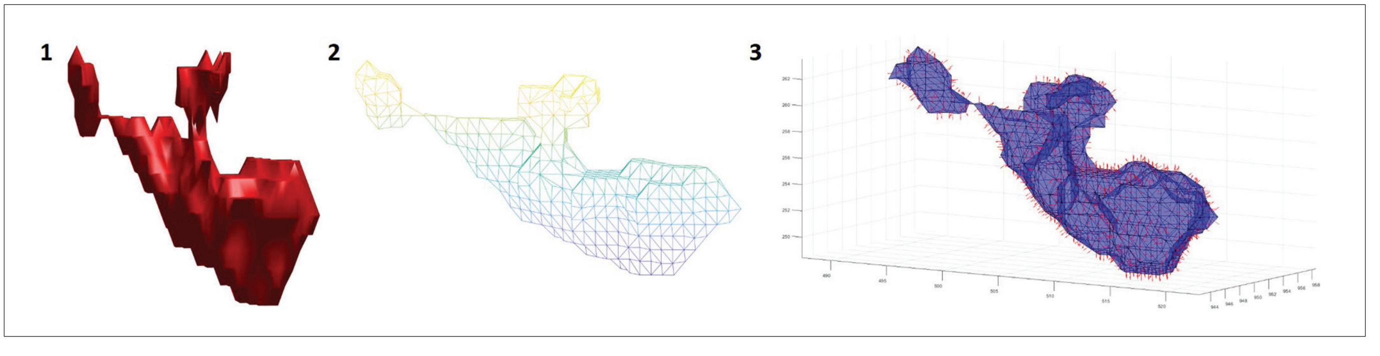

FIGURE 9. 1. Segmentation of an individual closed pore (red) in a ceramic object; 2. trimesh (various colors) of the segmented pore in 9.1; 3. normal vector (small red arrows) to each triangular surface (transparent blue) derived from 9.2 indicating a microscale force to each area.

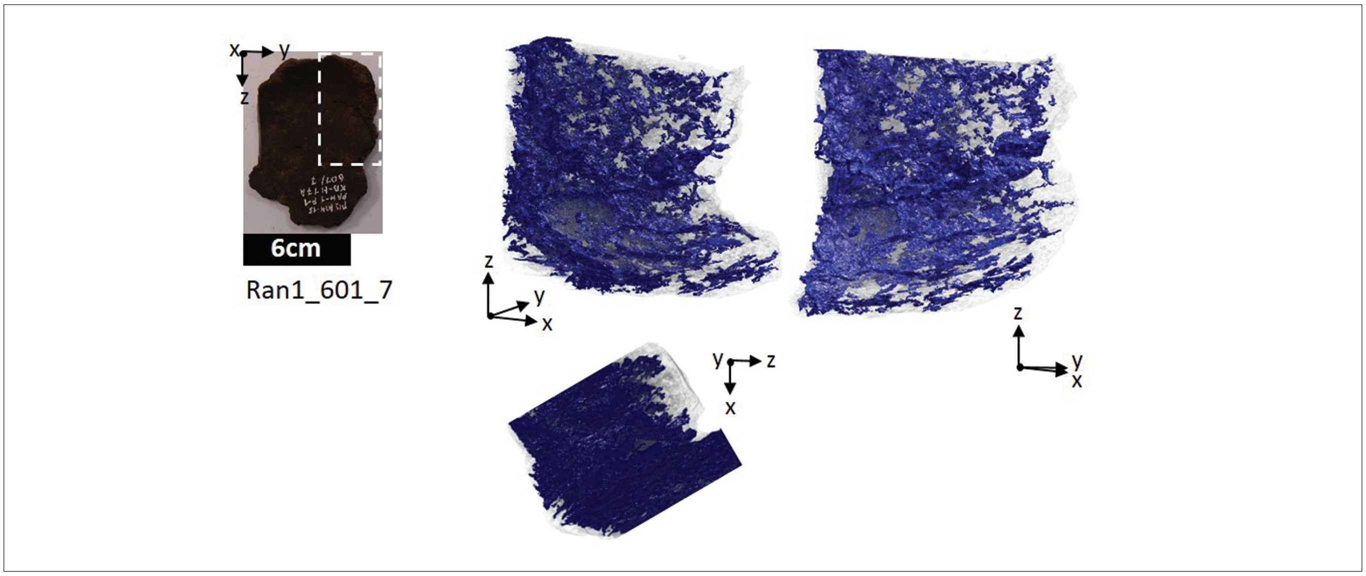

FIGURE 10. Alignment of the large pore complex (blue) of the ceramic object (Ran1_601_7; transparent grey) discovered at Ransyrt 1. Region of interest (ROI) in the box of the white dashed line. The large pores are concentrated in the wall and the bottom part, seperately and there is no clear pore complex connecting both parts. This example shows a separate formation of the bottom and wall part (wall on the bottom) and oriented parallel pressure/stress from the surface. (Park et al. 2019b, modified).

Using these segmented pore images, other examples of this study could identify various inner structures indicating continuous construction from the bottom to the the wall part by pulling or double layers for the bottom part. The direction of the large pores present in these samples was vertical or horizontal with relatively high deviations. These traces would be caused by hand-shaping process. Sharp and shallow edges from the surface were identified in some samples, which can be interpreted as surface flattening by potters. Besides of these objects, other studies proved various shaping techniques such as pinching, slab-building, coiling, drawing, moulding and wheel-throwing can be identified (Carr 1990; Berg 2008).

If the grain size distribution or its standard deviation is small, it will be easier to identify the shaping method.

Conclusion

According to the rapid signs of progress in digital processing for microscopy and scanning techniques, research on the direct measurements of the structural elements of archaeological ceramics is growing fast. As a consequence, this methodology is becoming more and more important in archaeology and archaeological sciences. Advanced parametrization of segmented objects can provide quantitative information for the various topics in archaeological ceramic studies. Despite heterogeneous structural and mineralogical/chemical elements in archaeological ceramics, shape parameters and alignments of the sand grains and pores can provide possible tools contributing to classification of ceramics according to resource gathering, pyrotechnology and shaping techniques. The development history of sediments reflect the shape parameters of grains which can indicate the geological/geographical locations. Topological changes of pores in the ceramic matrix generally led by clay sintering will provide qualitative information about the firing degree of the samples. In the meanwhile, pore complex in macroscale is mainly caused by the human force during shaping. In the low fired ceramics, this pore complex still remains, so that the formation methods of the ceramics can be reconstructed.

Like the other analytical instruments, it is clear that the image analysis alone cannot solve the whole questions related to heterogeneous ceramics. However, if appropriate scales of measurement areas, spatial resolutions, shape parameters and connectivity for the calculations are employed according to the purpose, the 2D- and 3D-image analysis will provide main or supporting evidence to distinguish the heterogeneous objects from each other. Furthermore, it will contribute to the identification of technological styles in prehistoric material production.

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New insights on antler technology from Vučedol – Kukuruzište Streim

Slavica Bošnjak
Dora Šimić
Danijela Roksandić

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Slavica Bošnjak
Poljaci 8
HR – 21210 Solin
slavicabosnjak9@gmail.com

Dora Šimić
Vučedol Culture Museum
Vučedol 252
HR – 32000 Vukovar
dorasimic989@gmail.com

Danijela Roksandić
Department of Archaeology
Faculty of Humanities and Social Sciences
University of Zagreb
Ivana Lučića 3
HR – 10000 Zagreb
daroksan@ffzg.hr

The technology of processing hard animal material is an important segment in the study of prehistoric societies. This paper's main focus is on the exploitation of hard animal material, especially antlers from the Vučedol eponymous site (Late Copper Age). It deals with antlers as raw material, as well with the osseous industry of Vučedol culture, more specifically with its manufacturing technology. Findings from both old and recent excavations show well-known manufacturing techniques of processing osseous material. Interestingly, findings from recent excavations at Vučedol - Kukuruzište Streim show new elements in the manufacturing process – use of metal tools.

Keywords: *osseous material, antler, manufacturing technology, Vučedol culture.*

Introduction

Faunal remains had been an important part of prehistoric societies but they have also been severely neglected in archaeological studies. Recently, they have been given more attention and there is a growing number of papers concerning this particular subject. A better-suited term for faunal remains would be "hard animal tissues" (*matières dures animales)* because it includes bones and teeth, antlers and horns, ivory, molluscs and egg shells (Poplin 2004: 11; Sztancs et al. 2010: 40; Vitezović 2010: 23, 27), but most commonly used terms are "osseous

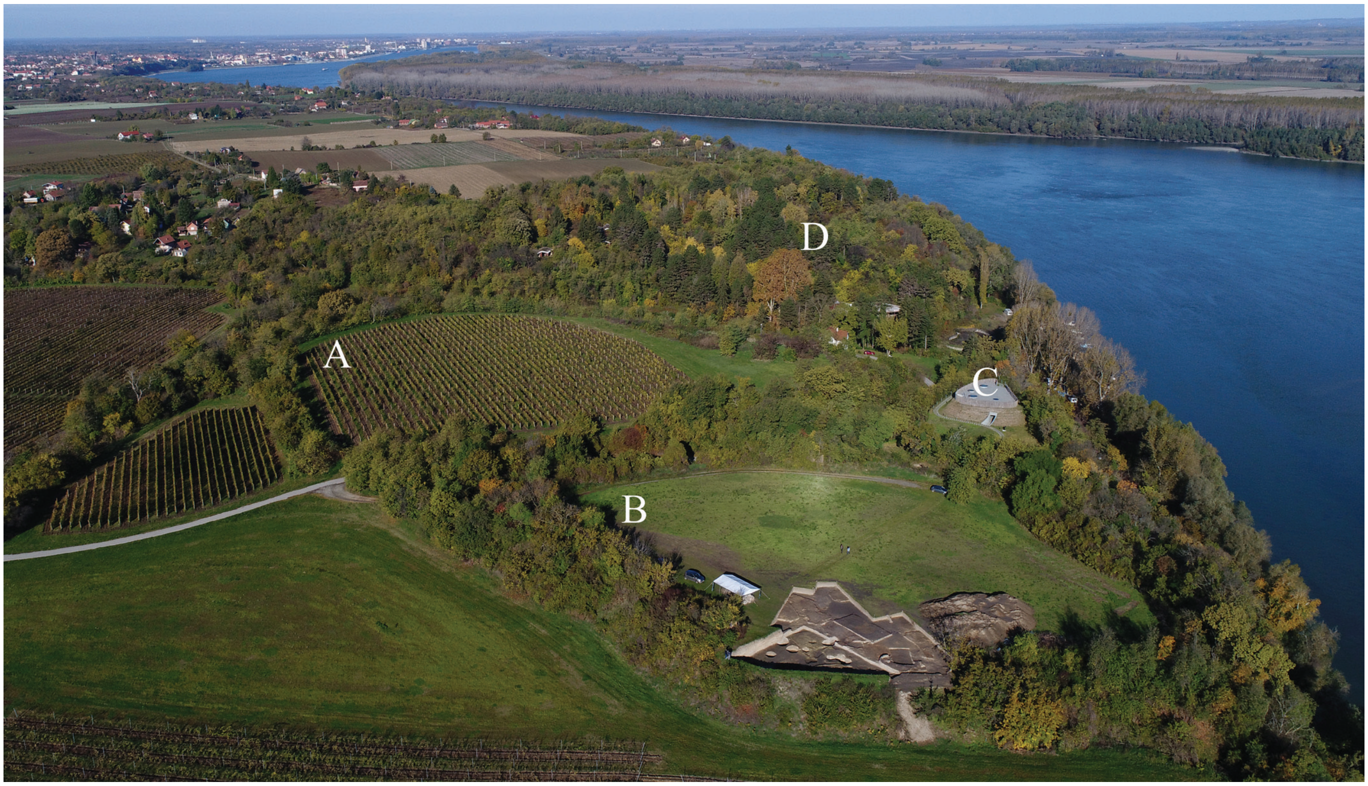

FIGURE 1. Vučedol site a) Vinograd (Vineyard) Streim b) Kukuruzište (Cornfield) Streim c) Gradac d) Vinograd (Vineyard) Karasović. (Vučedol Culture Museum photo archive)

material" and "bone material". Because of its characteristics, osseous material was used very early in human history and remained important even in later periods (Choyke 2010; Sofaer et al. 2013: 482). This type of material was widely available and accessible. Furthermore, it is extremely durable, well preserved in archaeological layers and suitable for making a wide range of artefacts ranging from functional to decorative and ritual pieces. Because of well-preserved osseous finds and traces left on them, we are able to gather information about everyday life in prehistoric societies, their manufacturing technology and even the function of the artefacts themselves. Osseous material has a key role in reconstructing and understanding manufacturing processes of organic material and it could prove the existence of various perishable technologies, activities and trades (Semenov 1976: 4-7; Choyke 1984: 14).

Vučedol site, research history and overview of available data

Vučedol site, situated on the right loess bank of river Danube near the town of Vukovar, is well known for its eponymous Late Copper Age culture. Vučedol culture dates between 3000 and 2400 BC (Durman and Obelić 1989; Horvatinčić et al. 1990; Forenbaher 1993: 247-48, Fig. 6). The eponymous site consists of four positions: Vinograd and Kukuruzište Streim (Vineyard and Cornfield Streim), Vinograd Karasović (Vineyard Karasović) and Gradac (Fig. 1). Its long research history started in the late 19th century with J. Brunšmids excavation of Vinograd Streim (Dimitrijević 1979: 267-70; Solter 2018). That excavation was followed by the famous 1938 campaign at Gradac led by R. R. Shmidt (Schmidt 1945). In 1960s S. Dimitrijević conducted excavations of all four Vučedol locations (Dimitrijević 1979: 267-80). Systematic and more extensive excavations started in 1984 at Vinograd Streim which were conducted by Department of Archaeology, Faculty of Humanities and Social Sciences of the University of Zagreb in cooperation with Vukovar Municipal Museum. Because of the Croatian War of Independence, excavations were stopped in 1991, continued later in 2001 and were finally completed in 2011 (Durman 1984; 1985; 1987a; 1987b; Durman and Forenbaher 1989; Durman and Balen 2005; Balen 2006; 2007; 2008; Durman and Hutinec 2011; Hutinec 2012). Excavations at Vinograd Streim proved that Vučedol culture occupied that position from its early to the late classical phase, known as phases A, B1 and B2 according to the periodization of S. Dimitrijević (Dimitrijević 1979; Balen 2018: 70). Most recent excavations are those of Kukuruzište Streim that had started in 2012. Although, two excavations were previously carried out, first by S. Dimitrijević in the 1960s and second by A. Durman in 1981 (Tasić 1995:170; Durman et al. 2013; 2014; 2016), they remain unpublished. Most recent systematic and rescue excavations of Kukuruzište Streim are being conducted by Department of Archaeology, Faculty of Humanities and Social Sciences of the University of Zagreb in cooperation with Vukovar Municipal Museum and Vučedol Culture Museum and are still ongoing (Durman et al. 2013; 2014; 2016).

There is a number of zooarchaeological studies conducted on the animal remains from Vučedol culture sites (Drobne 1964; Jurišić 1988a; Jurišić 1988b; Hincak 1995; Kosanović 1998; Kučera 1999; Kužir et al. 1997; Mihelić et al. 1998; Mihelić et al. 2013; Trbojević 1998; Tušek 2000; Trbojević-Vukičević 2002; Tušek et al. 2003; Trbojević-Vukičević 2006) but not many of them deal with archaeological aspects of the cultures osseous tools nor their manufacturing technology. Nevertheless, some attempts were made to incorporate these kinds of studies in overall publications of Vučedol culture sites (Dimitrijević 1956: 412; 1979: 314-15; Korošec et al. 1969: 18-19; Balen 2005: 56-58; Toškan 2009; Rajković and Balen 2016: 83-84; Vitezović 2018).

Antler and horn at the Vučedol site mostly derive from two families of *ruminantia* well known to European archaeology: deer (*Cervidae*) and cattle (*Bovidae*) (Cornwall 1964: 67; Kučera 1999: 6). Animal remains from few excavated sites in Eastern Slavonia and Western Syrmia show that most of the animal remains belong to domestic cattle (*Bos taurus*) which makes it the most common animal at analysed settlements and it is not surprising given that the animal husbandry is considered one of the bases of Copper Age economy (Jurišić 1988a; Jurišić 1988b: 24-25; Kosanović 1998: 18; Miloglav 2018: 120-121, 128). Large quantities of deer remains were found at two Vučedol settlements from Vinkovci. At Vinkovci - Tržnica approximately 33% of all animal remains belong to red deer (*Cervus elaphus*) and at Ervenica - M. Gupca 14 approximately 22 % (Jurišić 1988b: 24-25; Miloglav 2016: 130, Fig. 67). On the other hand, at Vinograd Streim red deer composes only approximately 9% of all animal remains (Jurišić 1988b: 24-25). Results from Tržnica are very interesting because wild animals remains compose half of all osseous remains (Jurišić 1988b: 24-25) which can be attributed to large areas of oak forests around Vinkovci region (Durman 2013a: 7-8, 10; 2013b: 17). However, remains of roe deer (*Capreolus capreolus*) from all three sites, were found in small percentages, ranging from 2.9 % found at Ervenica, 1.6 % at Vinkovci to 0.6 % at Vučedol - Vineyard Streim (Jurišić 188b: 25-26; Kučera 1999: 11; Miloglav 2016: 130, Fig. 67). Unfortunately, we don't have such information for Vučedol culture site Sarvaš whose name comes from the Hungarian word *szarvas* that means: the one who has antlers – deer (Choyke 2010: 24).

Mechanical and physical properties of osseous raw material

Horn and antler are significantly different. Horns are permanent paired hollow sheaths of keratin that arise from a spongy bony core anchored to the skull. They are usually present in both sexes of cattle and their various relatives (Cornwall 1964: 71-73; Kitchener 1987: 622; A. B. Bubenik 1990: 5). On the other hand, antlers are paired solid bony processes that arise from the frontal bone on the head of an animal of the deer family. They are usually borne exclusively by males with an exception of reindeers where both sexes have them. They are deciduous which means they are re-grown and shed each year and have a growth cycle that is closely associated with the reproductive cycle, hormonal processes and photoperiodism (Cornwall 1964: 67; G. B. Bubenik and Hundertmark 2002). During the first year of male cervids life permanent bony protuberances of frontal bones called "pedicles" are formed. From those two grown pedicels, antlers are later symmetrically formed and then shed (Cornwall 1964: 67; A. B. Bubenik 1990: 5). Antlers of different species slightly differ but are roughly the same in their anatomy (Cornwall 1964: 69-71, Fig. 10). Immediately above the pedicle is a bony rim of the antler base called "coronet" or "burr". When being shed antler detaches where the pedicle meets the burr. "Seal" is the base of a cast antler which plugs the dead antler from the core of the living pedicle. Above it, there is not yet ramified main stem of the antler called "shaft". The shaft continues into a "beam" which has potential to develop two types of branches: "sprouts" (pseudotines) or "tines" (points) (Cornwall 1964; Bačkalov 1979; A. B. Bubenik 1990, Fig. 3). Anatomy of antler becomes more complex with the age of the animal (Christensen 2004: 18). While an antler is growing, it is covered with highly vascular skin called "velvet" which supplies oxygen and nutrients to the growing bone. Growth occurs at the tip and is initially cartilage but later, after antler achieves its full size, it's replaced by bone tissue. At the end of the mineralization process, velvet is lost as the antler core dies. This dead bone structure is a mature antler that soon after falls off (A. B. Bubenik 1990). Antlers have outer compact tissue called the cortex and a spongy core which varies in thickness depending on many factors: part of antler in question, age and species of animal, size of an antler, etc. (O'Connor 1987; Vitezović 2010: 30). Despite having similar microstructure and chemical composition to bones, antlers are considerably different in structure; they are less mineralized than bones and have a higher proportion of collagen. There is also a difference between them in mechanical performance. Therefore, the antler is preferred for its elasticity and toughness for producing objects that will be subjected to particular stress (O'Connor 1987: 4; MacGregor 1991: 29-30; Christensen 2004: 20-21) while more brittle bones are better for making objects requiring sharp points and hard edges (Choyke 2013: 4).

Technology of processing osseous material

Antler objects can have a complex chain of operations because they can require multiple steps of reduction before an object can be shaped. Different techniques could have been used for prepping antler, such as soaking it in water or different solutions before it was sectioned into usable elements (Osipowicz 2007; Nicodemus and Lemke 2016: 113). There are up to four levels of manufacture involved in bone toolmaking: raw material selection, selection of the section of the bone that will be utilised, how was material treated to make it more suitable for rendering and how was it finally shaped. As mentioned, the first step in the chain of operations is raw material selection. That choice is conditioned by availability and physical suitability as much as it is conditioned by culturally ascribed tradition (Choyke 1984; 2013: 1-3). Both shed antlers and those from killed animals can be used as raw material (Choyke 1984: 27; Vitezović 2014: 154). The antler is consciously selected, searched for and gathered material. Individual stags tend to drop their antlers after the breeding period is over, which can be found at the same locations which makes it easy to gather them (Choyke 2010, 23; 2013, 3).

An important part of osseous material research is studying of traces left on the artefacts by manufacture techniques and by use. Traces of various techniques are usually well preserved but traces of wear are much more problematic. They are made last and are first to perish in the unfavourable and inadequate conditions. One tool can be used for more than one action, which makes a determination of its function more difficult. The bases of the traseological analysis are experimental reconstructions and analysis of traces under different magnifications (Vitezović 2010).

Process of transforming raw osseous material into objects can be divided into two basic steps: dividing the raw material into series of usable segments and shaping blanks into the desired object (Sztancs et al. 2010: 40; Vitezović 2010: 49).

1. The first step (*débitage*) is the intentional action of splitting a block of raw material into blanks for the purposes of further processing (Provenzano 2004a: 29; Vitezović 2016: 49).

2. Shaping (*façonnage*) refers to the intentional action of shaping a blank, regardless of the processing method that includes making a general layout of an object and adding specific attributes such as perforations, barbs, etc. (Provenzano 2004a: 29-30; Vitezović 2010: 49).

3. The third step is finishing work (*finition*) and elements added in this step no longer modify the general shape of an object. It includes, among other things, polishing and decorating activities that are not essential for the object to be functional and is done for an aesthetic reason (Provenzano 2004a: 29-30; Vitezović 2010: 49-50).

4. There could also be a fourth step that would account for repairing used or damaged object (Provenzano 2004a: 30; Sztancs et al. 2010: 40).

Chosen techniques, much like the choice of raw material, is culturally ascribed and greatly depends on tradition (Choyke 2013: 1). Dividing antler material into smaller segments (*débitage*) can be done using different techniques that were implemented in two principal ways: by breaking or by wearing away the raw material. Breaking can be implemented by two actions: fracturing and notching. Fracturing would mean violently breaking an element, which can be achieved by direct percussion with or without a hammer or indirect percussion. Notching is a form of percussion which can be implemented in three ways: by launched percussion or by indirect percussion with or without the hammer. Grooving is implemented by a repeated unidirectional movement that is parallel with the longitudinal axis of bone or antler and can be done by sharp flint or bronze point (Provenzano 2001; Vitezović 2016). On the other hand, sawing is a back and forth motion which is perpendicular to the longitudinal axis of the object and can be carried out with lithic edge or a metal blade (Provenzano 2001: 97; 2004a: 32). These techniques can be successful when applied to the thinner antler beams or tines that were usually separated first (Rigaud 2004: 79; Vitezović 2014:

157-58). Scraping consists of using a cutting edge on the surface of the material to reduce, regularise or sharpen objects. Edge is held vertically and scraping takes place in one direction along the longitudinal axis. Abrasion and polishing belong to the same set of technical gestures where the surface is worn by friction using a revolving or back and forth movement. Those terms are often not clearly defined and are variously employed through literature. Difference between them can be distinguished by determining the purpose for which they are used, by their place in the operational chain. Abrasion is a technique which removes a larger quantity of raw material and is employed either in débitage or more commonly in shaping. However, polishing is a technique which removes a small amount of material and usually takes place during the completion phase (Provenzano 2001).

Because of their properties, antlers usually had to be separated with a combination of techniques. There are two basic modes of exploiting antler: "débitage by segmentation", also known as "cut and break technique" and "débitage by extraction" also known as "groove and splinter technique" (Averbouh and Pétillon 2011: 41, Fig. 1). Most commonly used method is cut and break technique which means thinning of the outer layer and then separating, breaking off the remaining tissue (Rigaud 2004: 79; Vitezović 2016: 67, Slika VII/6, VII/7). Thinning of the outer layer can be done by various techniques; the goal is to remove enough of the outer layer until spongy tissue is reached. This can be done by cutting in a slit using stone or metal tool, by using abrasive agent and rope or by adzing or whittling – removing small portions of the material. The remaining tissue is then broken off by flexion or split using an axe or some other tool (Vitezović 2016: 67). Another method is groove and splinter technique that involves extracting longitudinal pieces from the external part of the antler via grooving procedure (Averbouh and Pétillon 2011: 41, Fig. 1:2; Vitezović 2016: 68, Slika VII/10).

Stone and metal tools leave characteristic imprints on osseous material, which can often remain recognizable even after the bone surface is damaged (Greenfield 1999). Metal knives produce sharp V-shaped or hard cornered |_|-shaped cuts (Fig. 2 a, b) and they either leave no striations or leave striations that are more uniformed depth and spacing than when done by stone tools. Generally, metal knives produce a cleaner and even cut with sharp parallel edges, with an exception of serrated-edge blades (saw-like) that leave very distinctive marks (Fig. 2 c) (Greenfield 1999; 2005; Christidou 2008). Stone tools produce a shallower, less even cut mark that in cross-section has two distinctly different sides: a smooth and a rough side. The smooth side rises steeply and smoothly, the rough side rises more gradually with multiple striations left over from production (Fig. 2 d, e). Retouched tools may leave lateral striations on both sides of the apex, depending on whether they are unifacially or bifacially retouched (Fig. 2 f, g) (Greenfield 1999: 804).

CODE	CUT MARK	DESCRIPTION
A		Profile of metal blade - sharp flat edge
B		Profile of metal blade - dulled flat edge
C		Serrated edge (saw - like)
D		Profile of a chipped stone scraper
E		Profile of a chipped stone blade - unrethouched
F		Profile of a chipped stone blade - unifacial rethouch
G		Profile of a chipped stone blade - bifacial rethouch

FIGURE 2. Templates for distinguishing metal and stone tool cut marks (after: Greenfield 1999: Fig. 1)

Preliminary data from Kukuruzište Streim (2012-2015)

Most of the studied material in this paper comes from unpublished findings from Vučedol – Kukuruzište Streim, combined and compared with limitedly available material from Vučedol – Vinograd Streim. Because of the unfortunate circumstances, a lot of osseous material excavated at Vinograd Streim before the war (excavations campaigns 1984-1991) has been lost. Part of surviving material included in this research is a box of mostly osse-

	BONE	ANTLER	HORN	TEETH/TUSK	MOLLUSC SHELL	TOTAL
V-12	2	12	0	0	0	14
V-13	10	25	2	9	1	47
V-14	27	28	2	2	2	61
V-15	69	27	10	3	0	109
V-16	112	22	0	1	2	137
V-17	82	48	0	2	1	133
TOTAL	302	162	14	17	6	501

TABLE 1. Total number of artefacts made out of different raw material present at Kukuruzište Streim (2012- 2017)

ous finds belonging to the 1984 excavations.[1] That material was deposited at Department of Archaeology, Faculty of Humanities and Social Sciences in Zagreb. Thirteen of the finds are osseous artefacts (3 bone and 10 antlers) that originate from the pit named Pit 8 in field documentation. Those osseous finds consist of 2 rib spatulas and bone fragment with traces of manufacture and use. Antler artefacts include a perforated hammer and perforated axe made of antler bases, an axe or adze made from antler beam with only partly preserved perforation, a harpoon, four antler tines with traces of manufacture and use, an antler tine that had been segmented using cut and break technique and a shed antler whose beam and tine were cut off.

Osseous remains found at Kukuruzište Streim during excavations campaigns 2012-2017, include 1403 samples of animal remains, 247 samples of mollusc shells, 49 samples of fish bones and scales and two fragments of *Testudo* (turtle) plastron. This material is yet to be analysed. Furthermore, during the same excavation campaigns, 501 artefacts were found that are complete antlers or horns, finished tools, half-products and objects with traces of manufacture or use (Table 1). So far, this

	UNSHED ANTLER	SHED ANTLER	UNDETERMINED	TOTAL
V-12	1	0	11	12
V-13	0	2	23	25
V-14	2	3	23	28
V-15	0	4	23	27
TOTAL	3	9	80	92

TABLE 2. Total number of shed and unshed antler present at Kukuruzište Streim (2012- 2015)

[1] We express gratitude to the head researcher, prof. dr. sc. Aleksandar Durman, who provided us with this material and complete documentation from the Vinograd Streim excavation. Material in question was part of an exhibition that was held in Zagreb in 1988 (Durman 1988).

FIGURE 3. a) Shed antler with preserved base (Kukuruzište Streim) b) Roe deer antler still attached to the skull of the animal (Kukuruzište Streim). (Vučedol Culture Museum photo archive)

FIGURE 4. Complete antler that had its base and tip of the tines deliberately removed found in a pit (Kukuruzište Streim). (Vučedol Culture Museum photo archive)

data suggests that during manufacturing process bone as a raw material was used in 60 % of cases, antler and horn were used in 35 % of cases while remaining 5 % can be attributed to mollusc shells, tusks and teeth. Completely analysed were 231 osseous artefacts from 2012-2015 excavation campaigns including 108 osseous, 92 antlers, 14 horn, 14 tusk/teeth and 3 mollusc shell artefacts (Table 1).

At Vinograd Streim, red deer antler was preferred over roe deer antler, probably because of its size (Jurišić 1988b: 25-26; Kučera 1999: 11; Vitezović 2018: 180). The same can be assumed for Kukuruzište Streim, but the zooarchaeological analysis is required. Although uncertain, there is a possibility of fallow deer (*Dama dama*) antler tool originating from Vinkovci - Tržnica (Dimitrijević 1956: 412, T. XVII, 2). The number of shed antler with preserved bases (Table 2, Fig. 3 a) at Kukuruzište Streim suggests that gathering antlers was an important task that required people well familiar with the surrounding environment of the settlement (Choyke 2010: 23). Shed antlers are more solid and therefore more suitable for processing then the ones gained through hunting (Choyke 1984: 34; Toškan 2009: 300). However, examples from the same site that are still attached to the skull of the animal (Table 2, Fig. 3 b) indicate hunting. So far, data from Kukuruzište Streim indicate that 3 % of antlers are unshed while 10 % are shed antler bases and remaining 87 % are parts of antler beams and tines which, therefore can't be determined as a shed or unshed (Table 2). Although gathering antler seems to be a primary method of obtaining it as raw material, it is important to note that deer hunting was significant to the Vučedol community. For them, the motivation behind hunting seems to be more than simply obtaining raw material because it possibly had a religious and or social component to it (Milićević Bradač 2002). Importance of deer

	FINISHED OBJECTS	BLANK / PREFORM	BLOCK / RAW MATERIAL	WASTE	UNDETERMINED TECHNICAL PIECES	TOTAL
V-12	6	1	3	1	1	12
V-13	7	2	5	3	8	25
V-14	10	2	2	2	12	28
V-15	7	1	6	4	9	27
TOTAL	30	6	16	10	30	92

TABLE 3. Total number of artefacts representing different manufacturing stages of antler from Kukuruzište Streim (2012- 2015)

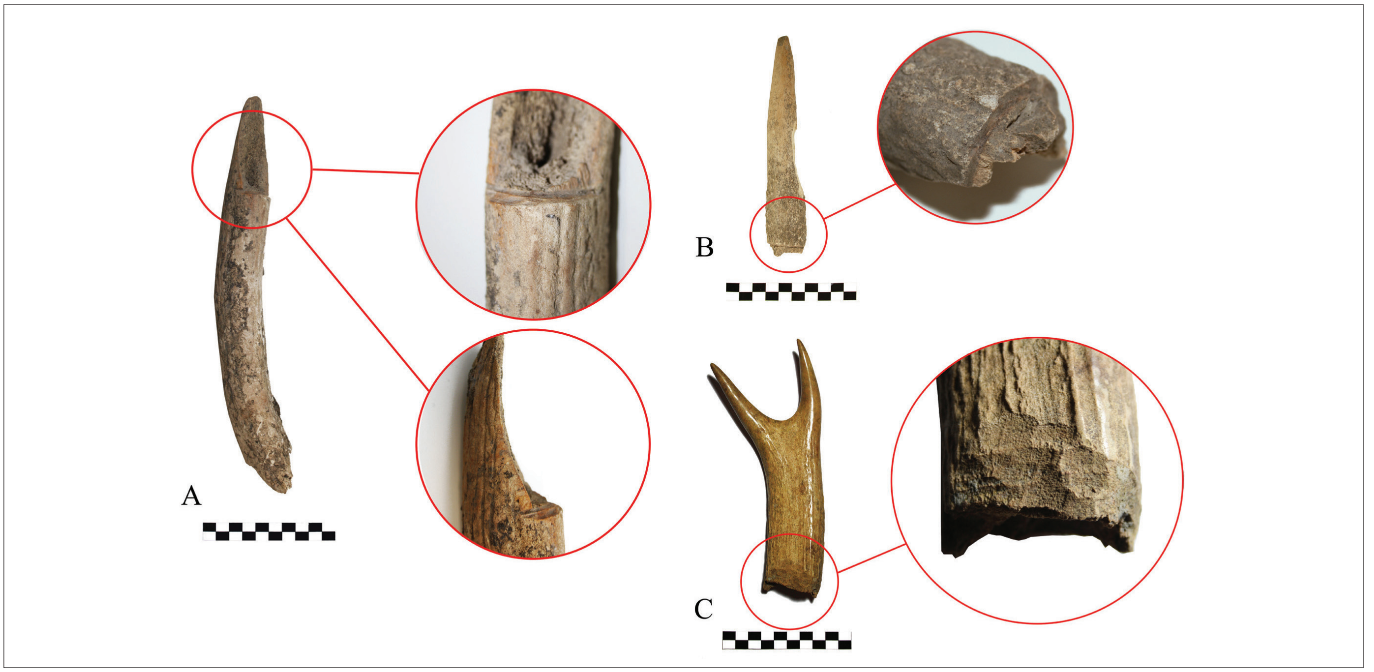

FIGURE 5. a) Example of transversal sawing, unfinished cut and break technique (Vinograd Streim) b) Example of cut and break technique (Kukuruzište Streim) c) Example of thinning the cortex by cutting off small portions of material (Kukuruzište Streim). (Vučedol Culture Museum photo archive)

and deer hunting is emphasized by the ritual burial of a deer on Vučedol – Gradac (Schmidt 1945: 28, T.16: 3; Milićević Bradač 2002: 9, Fig.1). Some authors suggest that during the Copper Age, deer hunting was also motivated by the need for the raw material not only meat and fat (Choyke 1984: 34-35; Toškan 2009: 300).

Examples of all antler manufacturing stages are recorded at the location of Kukuruzište Streim stored raw material, worked and abandoned pieces, waste, half-products and finished products (Table 3). After being collected, antlers can be stored for later use. They can be stored in cool and damp places for future use (Choyke 2010: 23; 2013: 3). During excavations of Kukuruzište Streim complete antlers and horn cores have been found in pits (Fig. 4). Ethnoarchaeological research shows that large waste fills were usually positioned at the edges of the settlement, while small household waste was disposed in the proximity of the house, in the pits that are considered part of household (Hayden and Cannon 1983). Pits could

	BREAKING (FRACTURING/ NOTCHING)	SAWING	CUT AND BREAK TECHNIQUE	UNDETERMINED	TOTAL
V-12	1	1	6	4	12
V-13	1	2	7	15	25
V-14	1	1	5	21	28
V-15	2	0	6	19	27
TOTAL	5	4	24	59	92

TABLE 4. Techniques of antler débitage from Kukuruzište Streim (2012-2015)

have had many different, even multiple functions but, in the end, most of them were filled with waste (Schiffer 1983: 691-92; Durman 1988: 16; Wilson 1994). Pits with more uniform content indicate activities and crafts that took place at the settlement (Hayden and Cannon 1983). Complete antlers found in pits at Kukuruzište Streim had their bases and sometimes tines deliberately removed. Some have traces of initial cuts that show antler was worked on and then abandoned for some reason. Pieces of un-worked or segmented antlers that are found in pits are likely to represent forgotten, stored antlers (Choyke 2010: 23; 2013: 3). We should also note that there is an instance of the whole antler found on the floor of the house, possibly abandoned during a fire which had left it burned and badly preserved (cf. Hayden and Cannon 1983: 159-60).

The methods used at Kukuruzište Streim and Vinograd Streim involve three basic techniques: sawing, notching and fracturing. Cut and break technique is most commonly used (Table 4): after sawing in a deep cut (Fig. 5 a), the object was rotated to make another cut, process which was repeated multiple times until outer cortex was removed and the spongy core was reached. The rest was then chopped off or, more commonly, broken by flexion (Fig. 5 b). Thinning of cortex by cutting off small portions of the material, presumably by using indirect percussion via chisel or another similar tool is also a commonly used technique (Fig. 5 c). Chop marks caused by direct percussion can be observed on some of the artefacts. Most of manufacturing techniques and methods were observed on abandoned pieces, waste and half-products, while finished objects have neatly abraded or polished ends which make determining such techniques more difficult.

Interestingly, specific manufacturing marks were noticed on the osseous material from Kukuruzište Streim, that hadn't been observed on limited material from Vinograd Streim. Striations marks are even in their width and spacing, cut marks have sharp parallel edges, they are uniform in width and depth and tend to get shallower towards the ends (Fig. 6 a, b), and therefore they indicate that metal tool was used in the exploitation of antler. Applied methods and techniques appear to be the same as previously noted, but the tool used in segmenting process is different. Interesting finds from the site are horn cores that have traces of human activates, they aren't cut all the way, but rather have incision marks. Incision marks are very even and uniform in their depth and width, and get shallower at the ends, what implies that they were done by metal tools (Fig. 7) (cf. example from Iron Age in Baron et al. 2016: 31, Plate 5).

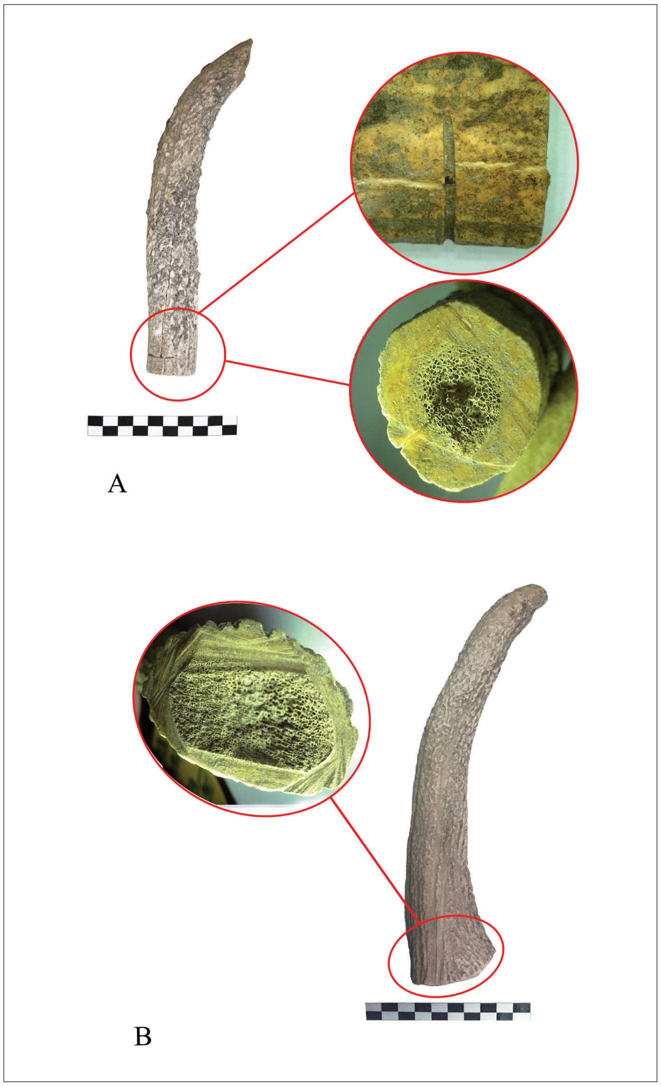

FIGURE 6. a) Example of an antler sawed with metal tool and traces of incision (Kukuruzište Streim) b) Example of cut and break technique implemented by sawing in a cut using metal tool (Kukuruzište Streim). (Vučedol Culture Museum photo archive)

Problem of using metal tools in the Late Copper Age

The idea that metal production resulted in the abandonment of other raw materials (flint, bone, deer antler) is now widely rejected (Choyke 1987; Provenzano 2001: 99). Nevertheless, not enough attention is provided to metal tools used in the manufacturing of osseous tools. One of the first researches to acknowledge using metal tools in bone working was Sergei A. Semenov, whose work was ground-breaking by using experiments and microscopic research in studying the stone and osseous remains (Semenov 1976: 165-67). Nowadays there is a growing interest in researches that deal with this problem, mostly using archaeological experiments (Olsen

FIGURE 7. Incision marks on the base of the horn that was made with metal tool (Kukuruzište Streim). (Vučedol Culture Museum photo archive)

1988; Greenfield 1999; 2005; Provenzano 2004b; Cristiani and Alhaique 2005; Christidou 2008; Jones 2011).

Studding usage of metal tools is very important in transitional contexts such as the Copper Age and adds to the existing debate. Metal tools are rare finds during Neolithic, Copper and Early Bronze Age but do not reflect the full range of artefacts available (Olsen 1988: 337; Greenfield 1999: 797). One explanation is that it reflects the actual prehistoric rarity of metal tools. Another possibility is that it was such a precious commodity that it was frequently recycled. The third possible reason for the rarity of archaeological metal finds is that early metals were chemically unstable and decomposed relatively rapidly under most conditions (Greenfield 1999; Christidou 2008: 734). A study conducted by H. J. Greenfield, on two sites in central Serbia (Petnica and Ljuljaci) with sequences that range from Neolithic to the Bronze Age, states that metal cut marks appear already during the late Neolithic - Vinča culture despite their inefficiency, and percentage of metal cut marks gradually increase with time (cf. Greenfield 1999: 804-808).

A. Durman was the first one to connect precise markings visible on Vučedol – Vinograd Streim osseous material with a metal tool. His conclusion was prompted by the bronze saw found on Vinograd Streim. Saw which has traces of tin (2.2%) and arsen (1.1 %) in its composition (Durman 2006: 60-61) does not belong to Late Copper Age Vučedol culture, but rather to the Early Bronze Age period. It was first published by S. Forenbaher (1990) who dates it in the middle and late Bronze Age – Belegiš culture and it was later mentioned by A. Durman (2006) who ascribed it to the Early Bronze Age Somagyvar – Vinkovci culture. Recently, traces of metal tools in antler manufacture were noticed on osseous material from Vučedol culture sites Sarvaš and Zók (Mitrović and Vitezović 2017: 187-88; Vitezović 2018: 180).

Difference between the sites and periods in adopting the usage of metal tools collaborate conclusion made by Rozalia Christidou (2008: 733-734):*" The frequency, type, raw material, and technique of manufacture of the bone objects made using metal tools vary between sites and chronological phases, suggesting different patterns of adoption of the functional metallurgy, possibly related to the availability of metallic substances and local social and economic factors".* Considering all this, it is not surprising that Vučedol site, as one of the metallurgical centres of the region (Schmidt 1945; Durman 1983; 1997; 2006), quickly implemented usage of metal tools in their manufacturing process. That change would be especially visible in working antler, as it was proven to be a more demanding material to process then bones, as those two materials are most commonly used at Kukuruzište Streim.

Conclusion

The great number of artefacts and tools testify that the technology of processing hard animal material was an important part of Vučedol Culture. This paper's focus is on the antler and its role in the osseous industry of Vučedol site. Antler was very desirable material, not only in Vučedol culture but throughout Copper Age of South-Eastern Europe with a distinctive preference for red deer over roe deer (Choyke 1984: 34-35; Toškan 2009: 300). Its properties, elasticity and toughness make it suitable for making a wide range of durable tools and objects. Antler was purposely targeted raw material source that came not only from hunting but from the organized and systematic gathering which requires a great amount of social organization and specialization. At the location of Kukuruzište Streim examples of a whole, probably stored antlers worked and abandoned pieces, waste, half-products and finished products can be found. The raw material was acquired, brought to the settlement where it was worked on until the finished product was made, after which it was used until it was discarded or lost. Various implemented techniques and different stages of osseous tool manufacturing process that are recorded at Kukuruzište Streim, all point to the existence of workshops inside the settlement, as was already suggested and presumed for other Vučedol Culture settlements such as Sarvaš and Zók (Mitrović and Vitezović 2017: 187-88; Vitezović 2018: 182). Methods and techniques used in antler tools manufacture are unified and vary a little. Sawing, notching and fracturing were basic three used techniques, that were commonly combined in cut and break and groove and splinter techniques. The antler is a very difficult material to work with and combination of techniques is necessary to divide it. Therefore, Vučedol communities during manufacturing process introduced metal tools, while continuing to use previously well-established methods and techniques of antler working. It shouldn't be surprising that Vučedol culture, that had developed local production of metal[2], tried very early on, to incorporate metal tools in their everyday tasks.

Although Vučedol osseous material shows very possible indications of common and frequent usage of metal tools in everyday life, much more extensive study is required. That study could account for, not only the problem of earliest metallurgy and technology but the problem of Vučedol culture chronology, dating and its role in the transition to Early Bronze Age. Manufacturing traces on osseous material can greatly add to the understanding of early metallurgy and the role it played in everyday life of Copper Age people. South-eastern Europe is one of the regions that experienced autonomous development of metallurgy and will prove to be very important in understanding the role of metal in the transition period of late Copper Age to early Bronze Age.

[2] Five furnaces excavated at Gradac offer a positive proof of Vučedol site being an existing metallurgical centre. Furthermore, the discovery of several objects such as a bronze axe with corresponding mould, an ingot, a few other bronze artefacts and pieces of slag, support the above mentioned theory (Schmidt 1938; Dimitrijević 1979, T. XLIII:4, Durman 1983; 2006).
During recent excavations of Kukuruzište Streim three furnaces which differ in their structure were found, as well as a dozen bronze tools. Tools are mostly small and precisely made. Therefore, they could point to very skilled metallurgist. Some of those bronze tools share context with at least one furnace, and together with pieces of slag strongly indicate an existence of metallurgical workshop at Kukuruzište Streim (information available in unpublished excavation reports by D. Roksandić, A. Durman and M. Hutinec from 2015, 2017, 2018 and 2019).

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An experimental approach to reconstruction of wool dyeing in archaeology

Franka Ovčarić
Branka Tomić

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Franka Ovčarić
Centre for Scientific Research and
Popularization of Archaeology, ZipArh
Ilica 126
HR – 10000 Zagreb
franka.ovcaric@gmail.com

Branka Tomić
Ivekovićeva 17
HR – 10000 Zagreb
tomic.branka9@gmail.com

Textile in archaeology has long been seen as an unreliable source of data due to the lack of methods that deal with the processing of such findings. Only during the last couple of years, serious analyses have begun to take place. It was often possible to reconstruct the look of fabrics and decorative objects, while searching for color traces in fibers has rarely been done. Since the first traces of dyed textiles were found, the process itself had already been developed, yet the experimental stage of selection and development of the dyeing process stays unknown. In that case, answers to a variety of questions can be offered by experimental archaeology and interdisciplinary approach. As a starting point, some experiments that have already been done involving fabric dyeing will be used and mentioned later in work (Cardon 2007; Vajanto 2011; Grömer 2016). It took several steps, such as collecting and processing wool, selecting natural dye sources, dyeing the wool and analyzing the obtained samples. In collaboration with other branches of natural and human sciences, information about the past becomes more complete, and the interpretation itself more accurate.

Keywords*: natural dye, mordant, experimental archaeology, walnut, elderberry*

Introduction

As an archaeological find, the textile is considered to be highly valuable because specific preservation conditions are required, which are almost never suitable for both plant and animal fibers (Sutlović 2008; Grömer 2016: 23). Research is mostly focused on the finished product itself or fabric production technology after the fiber is already made, most notably weaving. The process of dyeing fabrics and substances needed for it were seldom stressed although over the last decade there have been some significant papers considering the subject (Cardon 2007; Andersson Strand 2010; Vajanto 2011; Grömer 2016). Though most pigments and mordants are defined by ethnoarchaeological and historical sources, the whole palette of colors and mordants used on archaeological textile remains unknown. The most interesting aspect of the process which has not yet been fully discovered is the selection and development of the pigments and mordants. Each mordant is suitable for a particular type of fiber, and the choice and combination of mordant and pigment significantly affect the longevity and durability of the dye (Schoeser 2009: 30; Vajanto 2011; Grömer 2016: 23). In this experiment, green walnut husks were used as a pigment source, since they are known as the source of pigments in the prehistoric times (Grömer 2016: 23). Second pigment source used were black elderberries, whose pigment is sensitive to sun exposure (Bechtold and Mussak 2009). The goal was to confirm the importance of plant selection and the use of mordants. The mordants used in the experiment were mainly produced by using metal residues and slag. The dyeing experiment was mostly based on oral ethnological sources and modern literature, which is another indication of a strong tradition which is universal throughout the whole Europe (Cardon 2007; Schoeser 2009; Dean 2010; Grömer 2016).

Textile in archaeology

Textile in archaeology has long been seen as an unreliable source of data due to the lack of methods that deal with the processing of such findings. Textile is a particularly sensitive archaeological find since it is rarely recovered because of its difficult preservation (Bender Jørgensen and Walton 1986; Grömer 2016). Conditions required for the preservation of textiles at a site include: stable pH, constant temperature, anaerobic or aerobic environment, and the presence or absence of certain bacteria and fungi (Grömer 2016: 25). Because fabrics of plant and animal origin require different preservation conditions, they are rarely preserved in the same context. The degree of preservation may vary from partial to complete and depends on the combination of preservation conditions (Grömer 2016: 25). Since the first traces of dyed textiles date from the period when the process itself had already been developed, the experimental stage of selection and development of the coloring process is still unknown (Grömer 2016: 25). Therefore, answers to a variety of questions can be offered by experimental archaeology guided by archaeological finds and ethnoarchaeology (Bender Jørgensen and Walton 1986; Schoeser 2009).

Methodology

The experiment consisted of several steps, such as collecting and processing the wool, selecting the natural dyes based on ethnological and archaeological sources, dyeing the wool and analyzing the samples (Sutlović 2008; Schoeser 2009; Andersson Strand 2010; Vajanto 2011; Grömer 2016). The aim of experiment was to reconstruct the production process of collecting and treating the raw material and finally dyeing the wool for comparison with the archaeological material and the context in which it can be found (Bender Jørgensen and Walton 1986). Pigments were extracted from the selected plants and mixed with metal or salt and vinegar-based mordants (Dean 2010; Vajanto 2011). Color durability was tested on each sample to better understand the selective phases of the development of pigments and/or mordants. Macroscopic and microscopic analyses were performed on the obtained samples, color-code parameters were determined, and a map of colors was made for the samples dyed with a variety of mordants and dyes. The experiment was done in three phases: preparation, experimentation and analysis and processing of the collected results. During the preparation, the first step was to collect and prepare wool by sorting, washing in pure natural water, and drying. In the experimental phase, the prepared wool was treated with the mixtures which contained naturally obtained dyes and mordants. The first group of samples was treated using metal-based mordants, while the other group was treated with a mixture of salt and vinegar. The third control unit was dyed without presence of mordants for better understanding the importance and reasons for the development and use of mordants (Manlin and Xiaoming 2013: 596; Schoeser 2009: 30). Mordant is a substance that acts as fiber color fixator which in combination with pigments results in better colorfastness and it is used for obtaining different hues in the production of colors. All of the used wool was dipped in plain water before soaking in mordants. Because they required certain preparation time (Bechtold and Mussak 2009), the three used mordants were prepared a few months before the experiment. Two of the mordants used were metal-based and the main components were iron and copper, the recipe that was based on the ethnoarchaeological studies (Manlin and Xiaoming 2013: 594; Grömer 2016). These mordants were obtained by immersing metal waste (old nails or scrap metal) into a mixture of water and vinegar (Dean 2010: 42; Grömer 2016: 154). The third type of mordant was made by adding 5 ml of vinegar and salt mixture per 100 ml of water. To monitor the effect of acidity or alkalinity on the hue and saturation of the color obtained, each pots pH value was measured. Black elderberries and green walnut husks were used as sources of pigments (Bechtold and Mussak 2009: 156). Because of the presence of tannins which may serve as a color fixator, walnut husks were selected as they are a well known natural dye source (Grömer 2016). Because the elderberry dye is sensitive to the external influences (Dean 2010: 130-131), it was possible to record the importance of variables such as choice of mordants and length of dyeing while using elderberries as the source of pigment. The collected data resulted in a better understanding of the selective phase of choice of mordants and plants suitable for pigment extraction.

continued for the 140 minutes with samples taken every 30 minutes. The last samples were taken after cooling. The dyed samples were subsequently rinsed in water and dried (Table 1).

Results

All of the dyed samples were subjected to macroscopic and microscopic analyses (Vanden Berghe 2013: 58). The first and simplest was organoleptic analysis. Samples were examined and the subjective rating of hue/color was made. The biggest change in hue and color

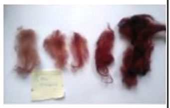
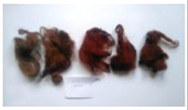
BLACK ELDERBERRIES				
Mordant	Without mordant	Vinegar+salt	Copper mordant	Iron mordant
Samples				
Color	Dark purple-red	Intense pink-red	Dark coppery red-purple	Dark blue, almost black
Fineness	Coarse	Coarse	Coarser	The Coarsest
WALNUT HUSKS				
Mordant	Without mordant	Vinegar+salt	Copper mordant	Iron mordant
Samples				
Color	Brown	Bright brown	Dark brown	Red- brown with purple undertone
Fineness	Coarse	Coarse	Coarser	The Coarsest

TABLE 1. Table of obtained colors and hues considering the use of pigment and mordant (Made by Ovčarić F. and Tomić B.)

Firstly, parts of the selected plants were crushed to form a paste and dipped in water for 24 hours. The next day, the mixture was boiled for 60 minutes and sifted through the cloth after cooling. The resulting color bath was additionally diluted. Next, the wool was soaked in plain water for 60 minutes and then additionally in mordants for another 60 minutes (Vajanto 2014: 65). For each color bath, 10 g of wool and 1000 ml of dye were weighed and measured. They were placed in the pot and gradually heated to the boiling point after which the dyeing

saturation was noticed on samples treated with metal base mordants and on the same samples, change in fineness of fibers occurred. Samples treated with metal-based mordants appeared coarser to touch than samples without mordant and with salt and vinegar as mordant. The colors on the samples were subjectively evaluated. Subsequently, an analysis was performed using a digital loupe with 90X magnification. On fibers soaked in metal base mordants, areas of larger color accumulation and stains of unknown origin were visible and further

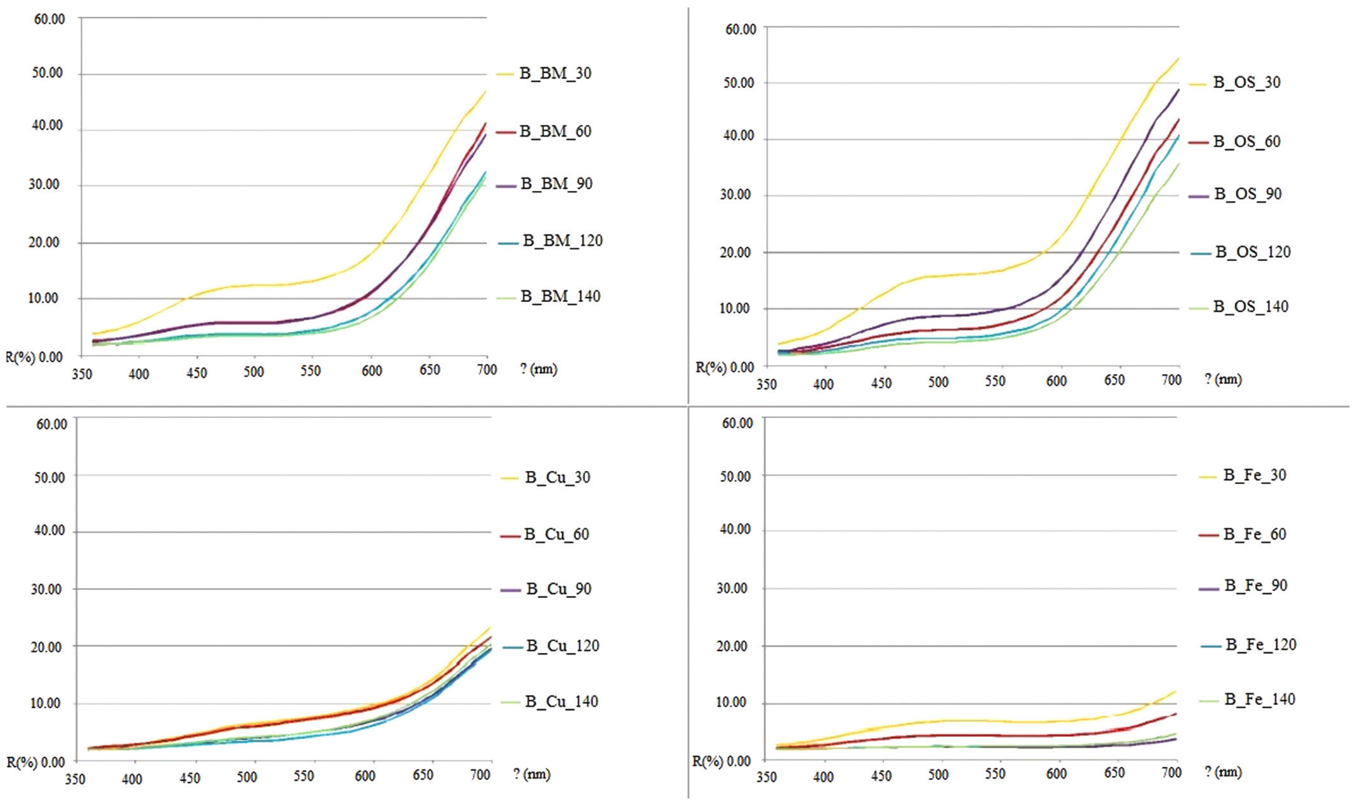


FIGURE 1. Remission curve when dyed with black elderberries (B-elder, BM-without mordant, OS-vinegar+salt, Cu-Copper, Fr-Iron, Number-Duration of dyeing) (Made by Ovčarić F. and Tomić B.)

analysis with electron microscope and energy dispersive spectroscopy analyses were performed. For the electron microscope analysis, a sample of raw wool was taken, as well as samples dyed with elderberries and walnut husks soaked in metal-based mordants. After that, the samples were subjected to analysis through energy dispersive spectroscopy and it confirmed the inorganic nature of the material after treatment with metal salts. Copper presence of 1.58 wt.% and iron presence of 0.22 wt.% was shown in regards to other visible elements that are part of the wool fiber itself. Spectrophotometric analysis showed that the samples dyed with elderberries, both with and without mordant, belong to the orange-red part of the color spectrum. Samples soaked in metal-based mordants had higher hue values and appeared to belong to the orange-yellow part of the color spectrum. A change of hue was not observed, and samples became black, in particular the iron mordanted samples. Samples soaked in vinegar and salt were red-hued, which could be seen organoleptically as these samples had the brightest hue of color. On the remissive spectrophotometer, the coloristic parameters such as brightness, hue and chromaticity/saturation and the value of remission in the visible part of the spectrum were determined. On these graphs, we can see the remission curves which show that:

· On the samples dyed with elderberries and walnut husks but without mordants it can be seen that color depth is the largest on the sample that was thermally treated the longest (140 minutes).

· On the elderberry sample with the addition of salt and vinegar, highest color saturation is achieved at the 140th minute and on the walnut husk sample at the 120th minute.

· All the samples dyed with the addition of copper gained the highest coloration at the 120th minute.

· Iron-treated samples have the highest color saturation in comparison to all others, maximum remission is seen after 90 minutes on the elder sample and after 120 minutes on the walnut sample.

To determine the stability of wool coloration, samples were exposed to sunlight and washed in order to determine if the fabric could have been worn in everyday life. (Vajanto 2014: 62-70). Previously prepared lye was obtained by boiling wood ash in water to achieve a slightly alkaline pH. Using laboratory appliances adjusted to certain parameters, washing was simulated. To analyze the influence of sunlight, samples were put on the window sill for a month and exposed to sunlight. Afterwards, everything was subjected to spectrophotometric analysis. The obtained results confirm that the color remains more stable on washed samples than on samples exposed to sunlight. After exposure to sunlight, the coloring fades but the hue does not change and the samples dyed with both plant dyes have very poor stability without the addition of metals(Vajanto 2014: 62-70).

Discussion

In the samples dyed with elderberries, it was observed that the coloration shows the highest value in the sample which has been thermally treated the longest (140 minutes). Samples dyed with elderberries and bathed in a solution of vinegar and salt also showed the highest coloring depth value after 140 minutes. Wool dyed with elderberries and a copper-based mordant solution resulted in a deeper color tone than wool dyed without mordant and with the addition of vinegar and salt, which, according to previous sources, could have been expected (Bechtold and Mussak 2009). In this case, the highest color depth value was achieved after 120 minutes, while the sample dyed for 140 minutes has a lower coloring depth value than the sample dyed for 90 minutes. Samples dyed with elderberries and dyed in the iron-based mordant exhibited an even greater coloring depth value than those in the copper-based mordant solution since the iron-based mordant was the strongest and the most aggressive mordant used in the experiment (Bechtold and Mussak 2009). The remission maximum for this case was achieved after the 90th minute of dyeing and further thermal treatment of the sample lowered the color depth value (Fig.1).

Samples dyed with walnut husks without the addition of mordants showed the same results as the samples dyed with elderberries. In both cases, the color depth value was increased by prolonging the dyeing process. For samples dyed in vinegar and salt-based mordant, the highest coloring depth value was recorded in the 120th minute of the dyeing process and the coloring depth value decreased with the prolonged dyeing. Samples dyed in a copper-based mordant solution showed the

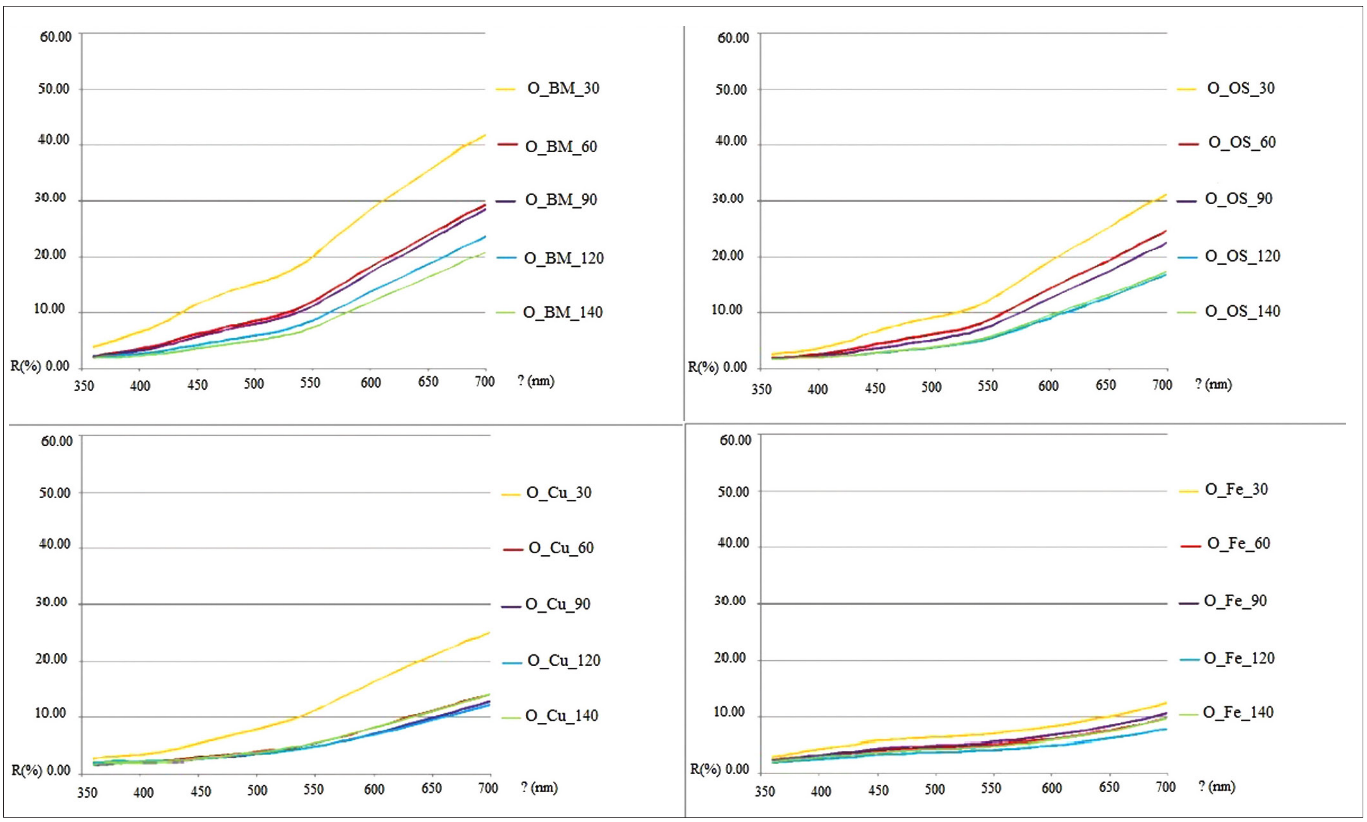


FIGURE 2. Remission curve when dyed with green walnut husks (O-walnut, BM-without mordant, OS-vinegar+salt, Cu-Copper, Fr-Iron, Number-Duration of dyeing) (Made by Ovčarić F. and Tomić B.)

highest coloring depth value after 120 minutes of dyeing and further dyeing decreased this value. In this case, the coloring depth value of the sample dyed for 140 minutes was similar to the color of the sample dyed for 60 minutes. For samples dyed in a strong iron-based mordant solution, the greatest coloring depth value was achieved after 120 minutes of dyeing and the sample that had been dyed the longest exhibited a lesser color depth value, similar to the sample dyed for 60 minutes (Fig. 2).

According to the results obtained, it can be concluded that when dyeing fibers without mordants and with the vinegar and salt-based mordants, greater duration of the dyeing process results in a greater coloring depth value. Also, the samples dyed in elderberry water extract have a pronounced peak between 470 and 500 nm, consistent with the obtained red tones of wool. Wool samples dyed with green walnut husks extract were dark brown, and the remission curves had no pronounced peak. Patterns dyed with elderberries, with and without mordants, belonged to the orange-red part of the color spectrum. Differences were observed between samples dyed with the metal-based mordant, and samples dyed without mordants and in the vinegar and salt-based mordant solution. Samples dyed with a metal-based mordant showed a higher hue which approaches towards the orange-yellow area of the color spectrum. However, due to the lower value of the chromaticity and the brightness, the change in the tones could not be observed, or rather, it was perceived as “black” in particular samples dyed in iron-based mordants. Samples dyed with vinegar and salt mordant solution showed a value of $h^* < 45$ which confirmed their red tone as it was seen organoleptically. These samples have the “brightest” color tones. The sample dyed for 90 minutes was perceived as darker. Samples dyed with walnut husks also belonged to the orange part of the color spectrum, with slightly yellower hue than samples dyed with elderberries. It was noted that samples dyed without mordants and samples dyed with vinegar and salt mordant solution exhibited similar chromaticity. Samples dyed in a copper-based mordant were more chromatic, whereas the samples dyed in an iron-based mordant were most saturated. When the samples dyed with plant-based dyes were compared, it is seen that a similar reaction occurred. Various sources (Dean 2010; Grömer 2016) mention that tannins in combination with iron give dark, almost black tones. In this experiment, samples dyed with elderberries and the iron-based mordant resulted in a noticeably darker coloration than samples dyed with walnut husks in the same iron-based mordant. Samples dyed with elderberries in an iron-based mordant resulted in a very dark, almost black color, which was expected, but not achieved in samples dyed with walnut husks (Grömer 2016).

Conclusion

Some plants are more and some less suitable for dyeing, so there was a selection phase of suitable dyes. Due to the coloring and mordant conditions, a wide range of hues were obtained. The choice of mordant significantly affects the hue and colorfastness. Green walnut husks produce a more stable color due to the presence of tannins. It has been confirmed that using metal salts as mordants can achieve significant coloration with shorter dyeing time. Instrumental methods in fiber analysis and metal presence can be made successful and determine the degree of damage and also indicate the traces of metals in fiber that can affect human health as well as the dyeing process. The development of the use of metals and the availability of metal ore may have been the key moments not only in metallurgy but also in textile production. Since archaeological research into prehistoric color remains is still developing, this experiment is intended to be repeated with other dyes with the goal of better future understanding and comparing the results within the archaeological context.

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Bone dating at the Zagreb Radiocarbon Laboratory, Croatia

Andreja Sironić
Jadranka Barešić
Ines Krajcar Bronić

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Andreja Sironić
Jadranka Barešić
Ines Krajcar Bronić
Ruđer Bošković Institute
Bijenička cesta 54
HR – 10000 Zagreb
asironic@irb.hr
jbaresic@irb.hr
krajcar@irb.hr

Bone remains can contain information of date of death, disease, nutrition habits and diet, location/movement, genealogy etc. of an individual and therefore bones represent a very interesting material for archaeological studies. Bones are composed of soft organic (collagen) and a mineral (bioapatite) tissue. Both tissues can be used for radiocarbon dating when certain conditions are satisfied. At the Zagreb Radiocarbon Laboratory, there are two techniques for radiocarbon dating: by liquid scintillation counting (LSC) and by accelerator mass spectrometry (AMS). The AMS technique enables dating of collagen from quite small bone fragments and also dating of bone apatite from cremated bones. Here we present our results of bone radiocarbon dating within the international radiocarbon intercomparison exercises and two case studies of ^{14}C-AMS bone dating from two archaeological sites in Croatia: the Sokol fortress from Konavle and the St. Stephen church in Pustijerna, Dubrovnik.

Keywords: radiocarbon dating, AMS, bones, cremated bones, collagen, apatite, radiocarbon intercomparison

Introduction

Bone can contain information about histology, paleobiology and paleoecology of fossil vertebrates, diet, date, contemporaneous climate, body temperature, provenance, mobility, conditions after the death (diagenesis), etc., obtained by analyzing its morphology, diagenesis rate, rare earth elements composition, stable and radioactive isotopes (Tütken and Vennemann 2011).

^{14}C radioactive decay used for dating (Arnold and Libby 1949; Libby et al. 1949; Libby 1955) revolutionized archaeology and paleontology. In archaeology, wood and bone remains are materials mostly used for dating. However, unlike wood, bones are much more prone to contamination with exogenous carbon. This feature has to be overcome by a series of cleaning and extraction steps.

In the Laboratory for low-level radioactivities of the Ruđer Bošković Institute (also known as the Zagreb Radiocarbon Laboratory) bone dating has been conducted since the early 1970s (Srdoč et al. 1973; Horvatinčić et al. 1983) by the gas proportional counting technique (GPC). Liquid scintillation counting (LSC) technique was implemented in 2004, with two sample preparation techniques: CO_2 absorption or benzene synthesis (Horvatinčić et al. 2004; Krajcar Bronić et al. 2009). Sample preparation for accelerator mass spectrometry (AMS) was established in 2007 (Krajcar Bronić et al. 2010; Sironić et al. 2013). It enabled dating of milligram size samples, thus fairly broadening the application of the ^{14}C method. By this point, only the collagen extracted from bones was applied in ^{14}C dating, while by introducing the AMS technique, apatite from cremated bones became eligible for dating.

Here we present the bone dating procedure at the Zagreb Radiocarbon Laboratory, focusing on the AMS technique. We also present two case studies of bone dating from two archaeological sites, St Stephen in Pustijerna, Dubrovnik and Sokol fortress in Konavle.

^{14}C bone dating principle and problems associated

^{14}C is produced from the interaction of nitrogen with cosmic rays in the upper atmosphere, forms CO_2 molecule and enters the biosphere through photosynthesis, primary and secondary consumers. In this way, the ^{14}C activity of the terrestrial biosphere generally reflects the ^{14}C activity of the atmosphere, while aquatic biospheres (marine and freshwater) reflect their own initial carbon source, which will be discussed later within reservoir effect. After the death of an organism, ^{14}C is no longer replenished, and its activity decreases in accordance with the ^{14}C radioactive decay. By measuring the remaining ^{14}C activity in the organism's remains, the time passed from death to the moment of measurement can be calculated. The ^{14}C half-life of 5730 years makes the method suitable for dating of up to 60,000 years old materials. Since the concentration of ^{14}C in atmospheric CO_2 is very low, only 10^{-10} %, special techniques needed to be developed in order to isolate carbon from the analysed material and prepare it in a form of matrix suitable for physical measurement (gas CH_4, benzene, graphite, Srdoč et al. 1971; Horvatinčić et al. 2004; Sironić et al. 2013). Therefore the radiocarbon method is destructive for the material.

In nature, stable ^{12}C (98.9 %) and ^{13}C (1.1 %) carbon isotopes also exist. The ratio of $^{13}C/^{12}C$ varies for different materials. During chemical or physical reactions of the transformation of one material (compound) to an other, isotope fractionation occurs, meaning that the ^{13}C and ^{12}C composition in the product is different than that in the source material. Composition of ^{13}C is expressed as a $\delta^{13}C$ value, which is the relative deviation of a $^{13}C/^{12}C$ ratio in a material compared to that in a standard (PDB, Pee Dee Belemnite; Mook 2000). Values of $\delta^{13}C$ can be used for controlling the purity of the samples, or for gaining information of the samples' origin.

Bone consists of mineral (apatite) and organic components (collagen). Collagen (~23 wt%, Wopenka and Pasteris 2005; Glimcher 2006) is built of long protein fibers, with a molecular weight ~300,000 (i.e. 300 kDa), mostly composed of amino-acids as glycine (Gly), proline (Pro) and hydroxyproline (Hyp), Hyp being typical for collagen. Collagen fibers are inter grown by nm-size bioapatite crystals of a general chemical formula $Ca_{10}(PO_4)_6OH_2$, constructing the hard tissue. The phosphate in apatite is substituted by carbonate ions 0.5 – 1 wt%. Both components contain carbon from the atmosphere making them both potentially suitable for ^{14}C dating. The same structure can be found in antler, bony part of horn and tooth dentine or ivory. Enamel part of a tooth is similar, with the exception that organic content is up to 1 wt% and the bioapatite crystals are the order of magnitude larger and with negligible porosity which makes enamel bioapatite not prone to diagenetic alteration.

Radiocarbon dating of collagen

The first attempts to date bones considered using the carbon from apatite (e.g. Haynes 1968) or collagen (Berger et al. 1964). However, due to bone diagenesis (adsorption of ions, diffusion, ion exchange in the apatite lattice or precipitation of secondary minerals in pore spaces) carbon from apatite can also contain exogenous carbon. The very high porosity of the bone apatite makes the environmental carbonate difficult to be selectively removed, so the extraction of collagen was developed by gelatinization of collagen (Longin 1971). After mechanical cleaning, bone is decalcified by treatment in acid followed by gelatinization step. Bone remains can be treated with the base before gelatinization to remove humic substances (e.g. DeNiro and Epstein 1981). Further on, ultrafiltration can be applied after the gelatinization step. In general, laboratories use ultrafilters that concentrate molecules larger than 30 kDa, which are likely to be long protein chains of collagen so that the smaller organic molecules that could be part of contaminants from the soil are removed (e.g. Brown et al. 1988; Bronk Ramsey et al. 2004; Higham et al. 2006). However, it is important that the ultrafilters go through a pre-cleaning step since they can be a source of contamination (Hüls et al. 2007). Amino-acid extraction could be used to further eliminate contaminants (Yuan et al. 2000). During bone diagenesis a substantial part of collagen could be lost, making it not suitable for dating, so pre-screening techniques, such as percent of nitrogen (%N) in whole bone powder, should be considered (Brock et al. 2010a) for the bones with <1% of collagen yield. In general, bones with C/N ratio between 2.9 – 3.5 (van Klinken 1999) and with collagen yield higher than 1 wt% can be pre-cleaned using the Longin method with base step pre-cleaning. For poorly preserved bones, with low collagen yield or elevated C/N ratio, the extraction of the Hyp amino acid can be used. Marom et al. (2013) showed that, in poorly preserved bones, collagen could be contaminated with exogenous organic molecules chemically bonded to amino acids, in which case selectively extracted Hyp molecules could be used for dating.

For collagen, $\delta^{13}C$ values vary regarding the diet of an animal/human. Collagen $\delta^{13}C$ value increases with the degree of a trophy (Schoeninger et al. 1983) meaning that herbivore bones collagen has lower $\delta^{13}C$ values than omnivore or carnivore collagen. $\delta^{13}C$ value is also different for plants: C_3 photosynthetic cycle plants (most plants) have $\delta^{13}C$ value around -27 ‰, while C_4 photosynthetic cycle plants (e.g. maize, sugar beet, millet) have it around -12 ‰ (Waller and Mewis 1979; Hoefs 1997). This also has an influence on the net $\delta^{13}C$ value of collagen. For example, herbivore feeding on C_3 plants would have $\delta^{13}C$ value around -26 ‰ (compensation due to the higher trophy level from plants to animal), while those feeding on C_4 around -11 ‰. If the diet is mixed $\delta^{13}C$ value would lie in-between (Fischer et al. 2007; Lamb et al. 2012; Salazar-Garcia et al. 2014).

Marine diet can have a strong impact on ^{14}C dating, due to the marine reservoir effect. Surface marine waters contain carbon depleted of ^{14}C resulting in higher apparent age of marine biota (~400 years, Hughen et al. 2004). Marine biota also has higher $\delta^{13}C$ values comparing to terrestrial animals. Terrestrial animals (including humans) consuming marine biota can have $\delta^{13}C$ of collagen as high as -16 ‰ (Johansen et al. 1986; Ascough et al. 2007, 2012). In order to compensate for the marine reservoir effect when radiocarbon dating, paleo/archaeodiet can be determined by combining $\delta^{13}C$ with $\delta^{15}N$ and $\delta^{34}S$ values, and radiocarbon date can be corrected accordingly (Lightfoot et al. 2014; Sayle et al. 2014; Dury et al. 2018).

Radiocarbon dating - bioapatite

When there is enough collagen to perform dating, bioapatite is usually not considered. Structural carbonate in bioapatite originates from blood bicarbonate and is in close relationship with the food intake of the human/animal. Skeletal remains from humid climate regions, such as Europe or America, show a large difference between ^{14}C dates of bioapatite and collagen, due to bone diagenesis. However, calcined bones (should not be confused here with cremated calcinated bone, which are discussed later) from arid regions like Africa or Arabia can be reliably ^{14}C dated from a bioapatite carbonate (Zazzo and Saliège 2011).

Bioapatite can also be used for dating in case of cremated bones, i.e., bone remains that underwent burning on temperatures higher than 600 °C. The high temperature transforms highly porous crystal lattice of bioapatite to much denser lattice with higher crystallinity, making it resistible to diagenesis and suitable for radiocarbon dating (Lanting et al. 2001; van Strydonck et al. 2005; Naysmith et al. 2007; Hüls et al. 2010). It was believed that the structural carbonate survives such high temperatures, while all collagen carbon is lost. However, later studies showed that cremated bones exhibit the “old wood” effect (Olsen et al. 2013) and that the major part of structural carbonate in the cremated bones (can be up to 86 %) comes from fuel used for burning of the bones (Hüls et al. 2010). Nevertheless, in most cases, it could be expected that the difference between the ^{14}C activity of the wooden fuel and the cremated bones is probably minimal and dating should always be considered within the broader context of the findings.

Cremated bones are suitable for dating if the crystal lattice underwent a complete transformation to high crystallinity lattice, i.e., that the cremation temperature was high enough. If the lattice is not thick enough, exogenous carbon from the environment can enter crystal lattice resulting in higher carbon content (comparing to phosphorus), lower $\delta^{13}C$ values and eventually younger radiocarbon dates (van Strydonck et al. 2009). A sample should be checked for its color (pure white are better than yellowish or charred), crystallinity (checked with infra-red spectra), carbon to phosphorus ratio (C/P should be lower than ~0.12), and $\delta^{13}C$ value (lower than -19 ‰) (Olsen et al. 2008). Generally, carbon percentage should be lower than ~0.25 wt%, however, Major et al. (2019) showed that carbon percentage up to 0.56 wt% also gives a satisfactory radiocarbon age.

Marine diet, i.e., marine reservoir effect should not have a significant influence on the dating of cremated bones, if the most structural carbon comes from burning fuel (Hüls et al. 2010), however, further studies need to be undertaken in this direction (Olsen et al. 2008).

Bone dating at the Zagreb Radiocarbon Laboratory

During 50 years of existence of the Zagreb Radiocarbon Laboratory about 7000 samples have been processed by GPC, LSC and AMS techniques. About 3.5 % are bone samples, and 40 % of bones have been analyzed by AMS alone, introduced to the Laboratory about a decade ago. AMS enabled analyses of much smaller bone fragments and teeth and also of the cremated bones (about 10 % of bones). Currently, at the Laboratory two radiocarbon techniques are available, the LSC and AMS. For the LSC technique, carbon from bone is extracted by the Longin method (Longin 1971), and carbon is converted to benzene through a series of chemical reactions (collagen - CO_2 - Li_2C_2 – C_2H_2 - C_6H_6, benzene, Horvatinčić et al. 2004; Krajcar Bronić et al. 2009). The activity of ^{14}C is measured in benzene by radioactive decay in a liquid scintillation counter. For LSC 2-4 g of carbon is required (80 - 400 g of bones). The AMS technique of graphite synthesis requires 1.5 mg of carbon (1-5 g of bones).

Experimental procedures for AMS and data reporting

For collagen extraction, bone samples (1-5 g) are mechanically cleaned, rinsed in ultrapure water (UPW) in the ultrasonic bath, then in acetone, then again in UPW. This step removes a smaller amount of grease. In case bones have been treated with resins, for restoration/preservation purposes, 'soxhlet' method is applied (Bruhn et al. 2001), which implies rinsing the sample in series of solvents with increasing polarity, from the most hydrophobic to water (tetrahydrofuran, chloroform, n-hexane, acetone, methanol, water). After these precleaning steps, bone is demineralized at the room temperature by 1M HCl until the completely gelatinous/soft bone texture is reached. This step removes carbonates from bones and fulvic acids, organic molecules present in soil derived from biota decomposition. Next, the sample is treated by 0.25M NaOH solution (the base step) in order to remove the humic acids, also molecules derived from the organic part of the soil, that are soluble in bases. This is followed by treatment again in acidic solution (1M HCl) to remove atmospheric CO_2 adsorbed in bases. This part is known as the A-B-A procedure (acid-base-acid, Goh and Molloy 1972; Gupta and Polach 1985; Brock et al. 2010b; Sironić et al. 2013; Dunbar et al. 2016). However, if it is estimated that in the base wash would result in considerable sample loss and that the sample is not likely to be contaminated with humic acids, this step can be omitted. The gelatinous rest is treated in UPW acidified with HCl to pH 2-3 and 80 °C for 12 hours, dissolving the collagen. The solution is hot-filtered, through a glass fibre filters, removing the insoluble parts (e.g. roots, sediment, wood fragments, etc.). The filtrate is freeze-dried resulting in sponge-like collagen. Collagen is loaded in quartz tubes, sealed in the vacuum with CuO and Ag-wool and put in the oven at 850 °C to oxidize collagen to CO_2.

Cremated bones are treated according to Lanting et al. (2001) and Olsen et al. (2008). 1-5 g of bones is precleaned with UPW. The bone is grinded and treated with 1.5 % of NaClO (48 hours) to remove the remaining organics in order to free the bone surface for the next step. The carbonates from the surface, possibly containing exogenous carbon, are dissolved by 1M acetic acid (24 hours). After rinsing and drying, the sample is finely crushed, placed in a vessel with phosphoric acid (85 %) in a separate vessel portion and evacuated. The beaker is tilted, so the acid is poured into the portion with the crushed bone and left over night for the reaction of apatite carbonate hydrolysis to CO_2 to take place.

A portion of CO_2 obtained by either collagen combustion or apatite hydrolysis is separated for $\delta^{13}C$ analyses on Isotope Ratio Mass Spectrometer (IRMS), while another portion is turned to graphite by zinc reduction with iron catalyst, pressed in aluminum targets for $^{14}C/^{13}C$ analyses on accelerator mass spectrometer (AMS, Krajcar Bronić et al. 2010; Sironić et al. 2013). The CO_2 gas and the graphite from the samples are produced at the Zagreb Radiocarbon Laboratory, while both IRMS and AMS analyses are done at the Center for Applied Isotope Studies (CAIS), the University of Georgia, Athens, USA, or at the Scottish University Research Centre, (SUERC) Glasgow, UK.

Conventional radiocarbon age of the sample is calculated from $^{14}C/^{13}C$ values normalized to -25 ‰, using Libby's half-life (5568 years). It is expressed as years BP ("Before Present" with "present" being the calendar year 1950) (Mook and van der Plicht 1999). Since the activity of ^{14}C in the atmospheric CO_2 is time-variable due to changes in cosmic/solar radiation, the Earth magnetic field, climate, etc., the calculated ages have to be corrected, i.e., calibrated. The radiocarbon calibration curves are con-

Sample name	Age (known)	Consensus age age_{cncs} (BP)	Z	A	Measured age age_{lab}(BP)	u-value
VIRI Sample E - mammoth	~30000 BP	38772 ± 2532	4013	269	36834 ± 473	0.75
VIRI Sample F - horse	<5000 BP	2525 ± 69	4014	239	2510 ± 25	0.20
VIRI Sample H - whale	~10000 BP	9510 ± 158	4015	247	9452 ± 26	0.36
VIRI Sample I - whale	~10000 BP	8328 ± 176	4016	244	8298 ± 27	0.17
SIRI Sample B - marine mammal	~40000 BP Pleistocene	38727 ± 284	5284	767	38758 ± 200	0.09
SIRI Sample C - mammoth	^{14}C background, MIS 7	0.00895*	5315	789	0.00497* 0.0012 ± 0.0005[1] 54025 ± 3563[2]	

MIS 7 - Marine Isotope Stage (240-190 thousand years), *LOD-limit of detection expressed as fraction modern, [1]fraction modern corrected for the laboratory background, [2]age calculated from background corrected fraction.

TABLE 1. Bone samples from VIRI and SIRI exercises, their consensus ages and ages measured at the Zagreb Radiocarbon Laboratory. Z is code for laboratory number, A is a code number of graphite, u is a statistical test u-score, defined in Eq1.

structed by measuring ^{14}C activity/conventional date in samples of known calendar dates (dendrochronologically dated tree rings, laminated sediment layers, speleothems dated by U-Th method, etc.). The calibration of conventional age results in the date range(s) of calendar years expressed as cal AD or cal BC (calibrated Anno Domini or calibrated Before Christ calendar years) with probability density function. The curve for calibration used in this report is IntCal13 (Reimer et al. 2013), and the computer program is OxCal v.4.3.2 (Bronk Ramsey 2017).

International Radiocarbon Intercomparison exercises

After the introduction of AMS to the Laboratory, there had been two international radiocarbon laboratory intercomparison exercises conducted: the Fifth International Radiocarbon Intercomparison (VIRI) and the Sixth International Radiocarbon Intercomparison (SIRI) exercises (Scott et al. 2007; 2010a; 2010b; 2017). Both exercises involved about 50 radiocarbon laboratories around the globe.

VIRI was a four-year project with three stages, comprised of grain, bone, wood, charcoal, shells and humic acids (total of 22 samples). SIRI was focused on natural samples, of wood, bone charcoal, barley mash and humic acids, a total of 12 samples. The results of dating the samples from VIRI and SIRI are published in Sironić et al. (2013) and Krajcar Bronić et al. (2015a). Here we compare the results of collagen bone dating from VIRI and SIRI in the Zagreb Radiocarbon Laboratory.

The description of samples, their consensus values and values measured at the Laboratory is presented in Table 1. A statistical test, u-score, defined as:

$$u = |age_{lab} - age_{cncs}| / \sqrt{(\sigma^2_{lab} + \sigma^2_{cncs})} \quad \text{Eq1}$$

age_{lab} and age_{cncs} are conventional ages calculated by the Laboratory and consensus intercomparison age, and σ_{lab} and σ_{cncs} are their uncertainties, respectively. If the u-score value is lower than 2, the result is acceptable. Known age of the SIRI sample C-mammoth was >60000 BP, making this sample material for testing the limit of detection (LOD) for the collagen radiocarbon measurement. For that reason, the resulted value is reported not as age, but as fraction modern, i.e., as the activity of ^{14}C measured in the sample expressed as a fraction of activity in a modern sample, modern sample activity is defined as 226 Bq/kgC.

All the calculated u-scores have the value below 1, meaning that the values measured at the Laboratory for collagen bone samples are acceptable. The consensus LOD value for the background sample SIRI-C is actually about two times higher than the LOD values for the other background samples in SIRI (Scott et al. 2017) which means that in general radiocarbon laboratories have difficult

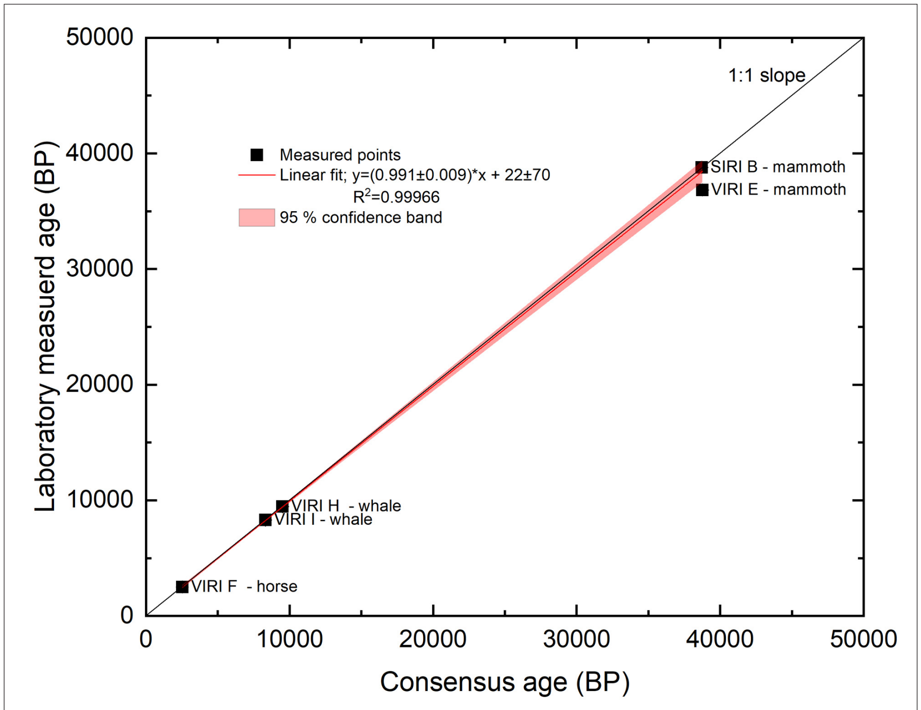

FIGURE 1. Correlation of Laboratory measured ages and the consensus ages for samples of bone collagen from VIRI and SIRI exercises.

times removing the contaminants from bones older than 55000 years. The Laboratory's LOD value is below the consensus value, although higher than LOD for standard background samples, yielding age of 54000 ± 3600 years. Therefore, the lowest age for bone collagen that can be reported by the Laboratory is about 50000 years.

The conventional ages for the bone samples measured at the Laboratory are correlated to the consensus ages from the VIRI and SIRI exercises in Figure 1. The correlation slope is close to 1 (0.991 ± 0.009) and R^2= 0.99966, showing an excellent agreement between the two sets of data. The SIRI sample C is not shown since it should be below the detection limit.

Cases of dating with AMS at the Zagreb Radiocarbon Laboratory

Dating of bones from Sokol fortress in Konavle near Dubrovnik

The Sokol fortress in Konavle was built on a huge rock formation and used as a control point in the Roman times and in the Justinian times. It was under several patrons in medieval times and under the Dubrovnik Republic until the Big Earthquake in AD 1667, after which it was abandoned in AD 1672.

In 2012 and 2013 an extensive archaeological excavation took place at the site. Among other investigations, skeletal remains of 27 individuals were examined anthropologically and radiocarbon dated (Krajcar Bronić et al. 2015b; Topić et al. In press). From the bones the collagen

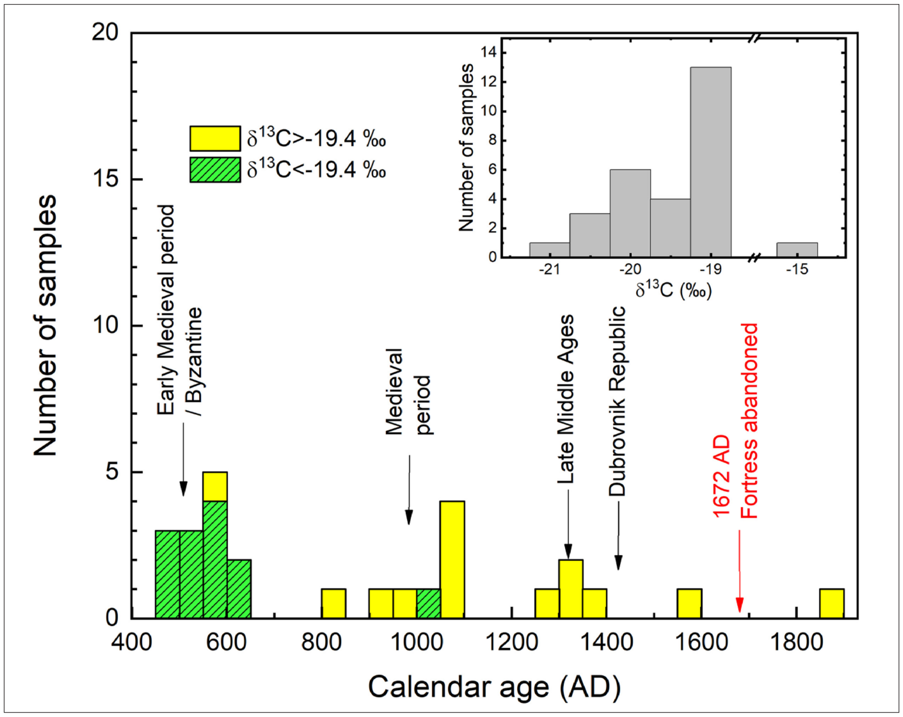

FIGURE 2. Frequency distribution of calendar ages for bones from the Sokol fortress, recalibrated by OxCal v.4.3.2 (Bronk Ramsey 2017). The number of samples for each date is presented as a number of samples with $\delta^{13}C$ collagen higher and lower than -19.4 ‰. The inner figure presents the frequency distribution of $\delta^{13}C$ values for the same bone collagen samples.

was extracted, CO_2 and graphite were prepared at the Zagreb Radiocarbon Laboratory and analyzed on IRMS and AMS at SUERC and CAIS. The collagen dates ranged from the 6th to 16th century, with one collagen dated to the 19th century (Fig. 2). Majority of samples were dated to the 6th century. The dated bone remains were of men, women and children, showing the continuation of settlement not only as a military character but also as a residential area around the fortress. $\delta^{13}C$ values of the bones ranged from -18.7 ‰ to -20.8 ‰, typical for the bone human collagen omnivore of predominant C_3 plant diet (Fig. 2, inner graph,). A shift from lower $\delta^{13}C$ values (< -19.4 ‰) in the Byzantine times to higher values in later periods (> -19.4 ‰) implies a change in dietary habits of the Sokol fortress habitants.

Dating of bones from St Stephen in Pustijerna church, Dubrovnik

The St. Stephen in Pustijerna church is one of the most well-known and one of the 24 oldest churches in the historical core of the city of Dubrovnik (Peković 1998; 2010). The historical findings place it to a period between the 6th century and the Big Earthquake in AD 1667 (Peković 1998; Regan and Nadilo 2006). During the archaeological excavations in 2011/2012, all cultural layers inside the church and church cemetery were included. Five human bone samples from the graveyard were radiocarbon dated (Krajcar Bronić et al. 2012; Topić et al. 2012). Samples were processed by collagen extraction and CO_2 and graphite preparation for IRMS and AMS analyses at CAIS. In Figure 3 and Table 2 the re-calibrated (by OxCal v.4.3.2) radiocarbon ages of the bone collagen samples are presented. $\delta^{13}C$ values range from -20 ‰ to -18 ‰ which could be attributed to the mixed diet, similar as the findings for the Sokol fortress Medieval period. The oldest bone (Z-4787) was dated to cal AD 778 – 880 (median cal AD 832), while the youngest (Z-4792) to cal AD 1262 – 1285 (median cal AD 1273) showing the continuous use of the graveyard from 8th to 13th century.

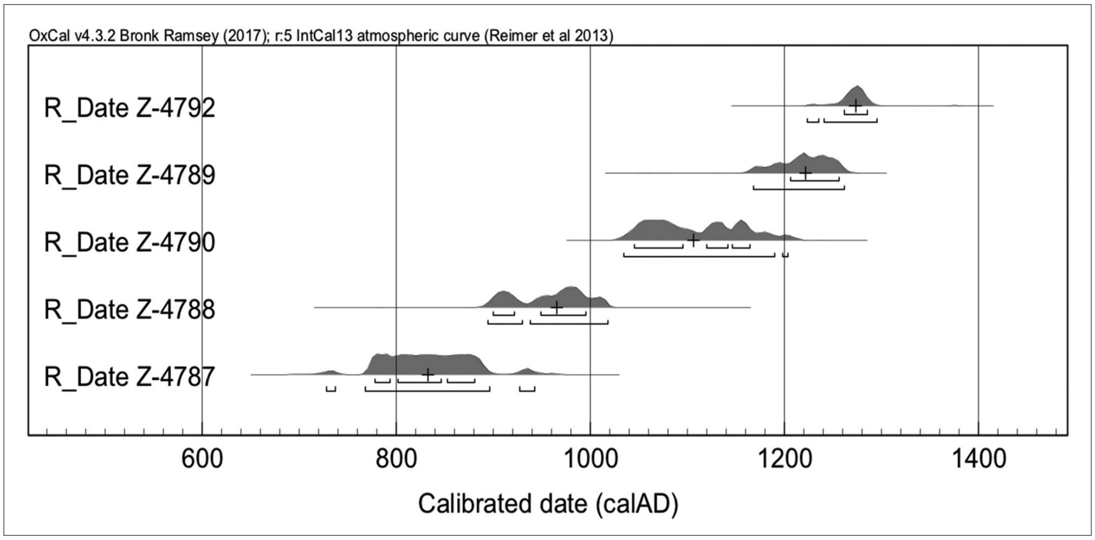

FIGURE 3. Multiplot of re-calibrated ranges by OxCal v.4.3.2 (Bronk Ramsey 2017) from Krajcar Bronić et al. (2012) for the bone collagen samples from the graveyard of the St. Stephen in Pustijerna church. "+" mark the median. Z is the Laboratory identification number. Horizontal brackets mark 1σ (upper level) and 2σ (lower level), i.e., 68.2 % and 95.5 % probability density range(s).

Sample name	Z	A	Conventional age (BP)	Calibrated period	Median (cal AD)	$\delta^{13}C$ (‰)
Human bone, trench 2, grave 7 –upper graveyard level	4792	386	735 ± 30	Cal AD 1262 – 1285 (68.2%)	1273	-19.5
Human bone, trench 2, grave 13 – upper graveyard level	4789	385	825 ± 25	Cal AD 1206 – 1256 (68.2%)	1222	-19.8
Human bone, original burial, trench 2, grave 8 –synchronous with construction of chapel floor	4790	394	910 ± 30	Cal AD 1045 - 1095 (39.6%) Cal AD 1120 - 1142 (15.6%) Cal AD 1146 - 1164 (13.0%)	1106	-18.0
Human bone, trench 2, grave 22 – bottom of older graveyard level – with construction	4788	381	1080 ± 30	Cal AD 900 - 922 (20.5%) Cal AD 949 - 995 (47.7%)	965	-20.0
Human bone – forearm, trench 2, grave 33 – the oldest grave	4787	393	1190 ± 30	Cal AD 778 - 793 (11.7%) Cal AD 801 - 846 (34.5%) Cal AD 852 - 880 (21.9%)	832	-20.0

Table 2. List of human bone samples excavated from St. Stephen in Pustijerna church during 2011/2012 excavations, their conventional ages, calibrated periods with median and $\delta^{13}C$ values for the bone collagen. Conventional age is rounded according to the Radiocarbon journal recommendations; the calibrated period is within 68.2 % (1σ) probability of result, numbers in brackets are probabilities for discontinued periods; 1σ for $\delta^{13}C$ is ± 0.1 ‰. Z is a laboratory identification number; A is the number of graphite target. Re-calibrated by OxCal v.4.3.2 (Bronk Ramsey 2017) from Krajcar Bronić et al. (2012)

Conclusion

In the Zagreb Radiocarbon Laboratory, radiocarbon dating by the AMS technique was introduced a decade ago enabling dating of milligram size samples, which resulted in an increase in the dating of collagen from archaeological bone remains. AMS also opened a possibility for the dating of apatite from cremated bones. International intercomparison exercises (VIRI and SIRI) among other types of samples contained bone samples for collagen extraction which was analyzed in the Laboratory. The date values from the Laboratory showed very good matching with the consensus values.

Two case studies of the archaeological dating of the bone collagen from the Sokol fortress in Konavle and the graveyard of the St. Stephen in Pustijerna church, Dubrovnik, were conducted. The measured dates proved the existence of the settlement/graveyard in the continuation, for the Sokol fortress, from 6th to 16th century and for the St. Stephen church graveyard from 9th until the 13th century.

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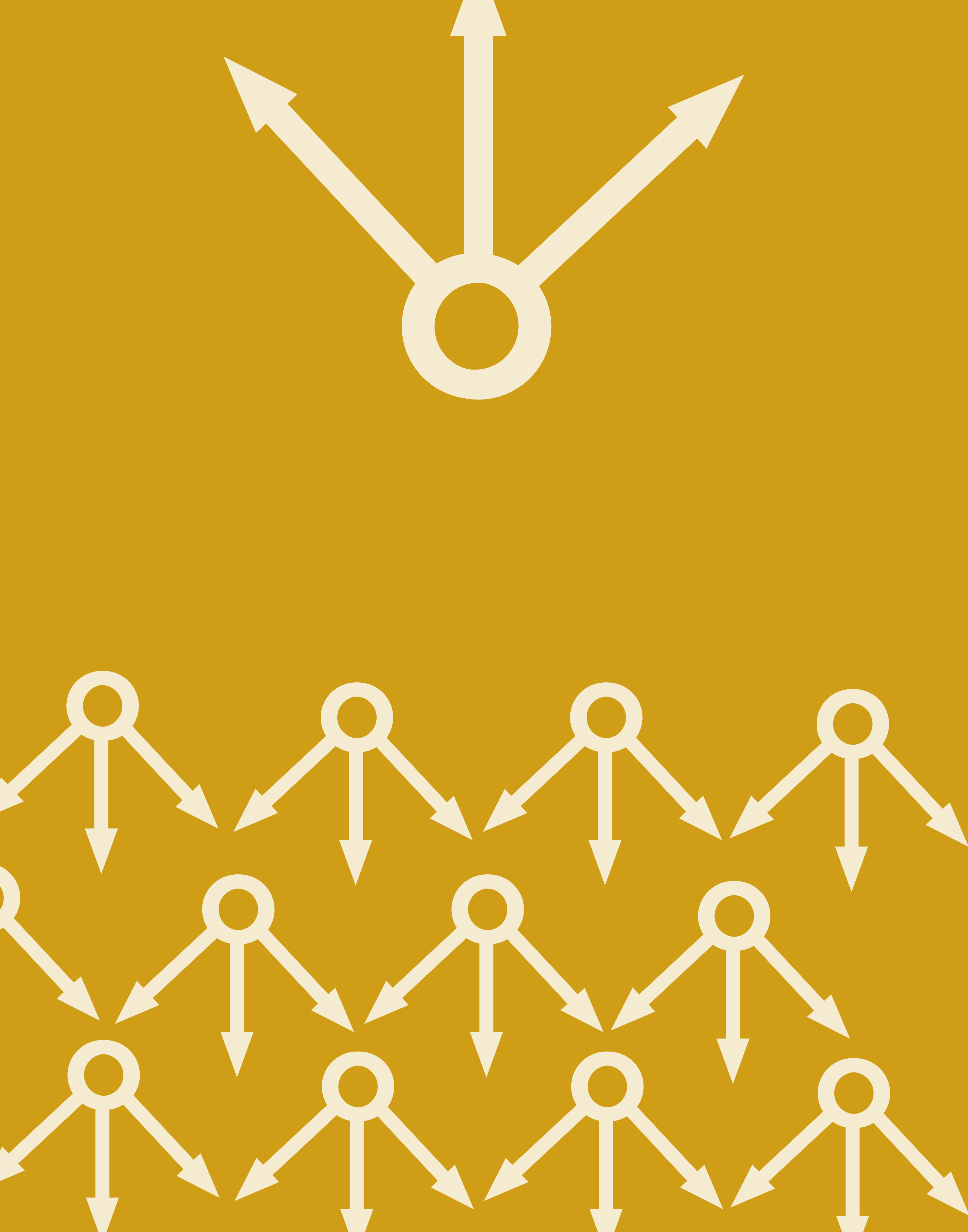

Storytelling. Is there a better method of archaeological site interpretation?

Milica Tapavički-Ilić
Jelena Anđelković Grašar

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Milica Tapavički-Ilić
Jelena Anđelković Grašar

Institute of Archaeology
Kneza Mihaila 35/IV
RS – 11000 Belgrade

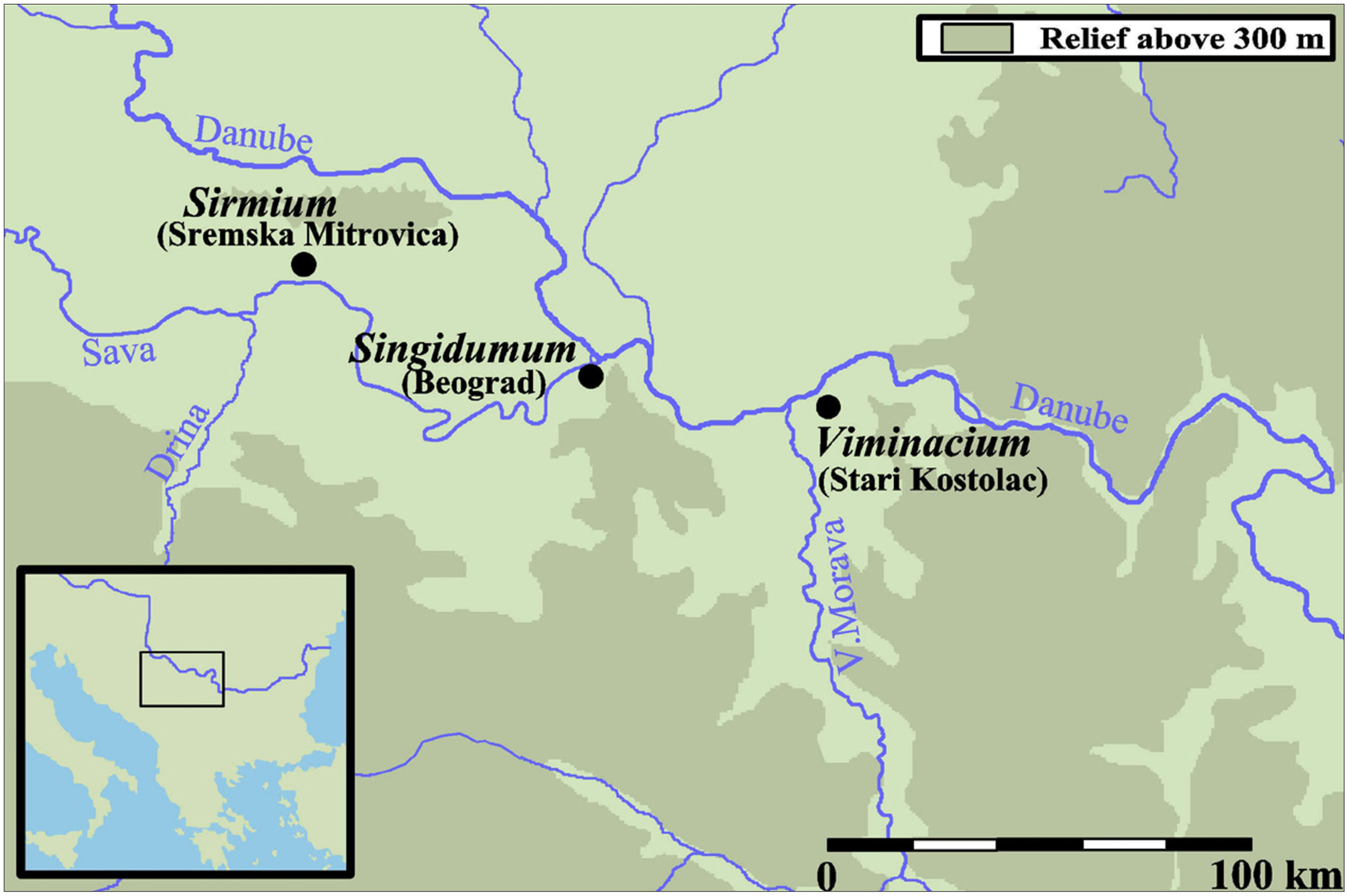
mtapavic@sbb.rs
jelenandjelkovic@gmail.com

In this paper, the authors present Viminacium, an archaeological site from the Roman Era that was turned into an archaeological open-air museum. Ever since it was opened in 2006, this open-air museum was visited by an always increasing number of guests. Expert guides offer a unique experience of storytelling directly on the site, that contributes to the visitors' overall experience.

Keywords: *storytelling, Viminacium, archaeological open-air museum, visitor, guide*

Viminacium is a well-known Roman site in eastern Serbia, positioned on the right Danube bank. (Map 1) During Roman times, it was the capital of the Roman province Moesia Superior. Its wider area includes almost 450 hectares and it has been excavated for more than a century. The latest excavation phase was initiated at the beginning of the 21st century. Several archaeological complexes were unearthed and also covered with protective constructions. (Fig. 1) They include remains of a Roman bath (*thermae*), an amphitheater, parts of city walls with towers, the northern gate of the legionary fort, the Roman mausoleum and several dozens of graves in the eastern Viminacium cemetery, three fresco painted tombs beneath the mausoleum, several Roman tombs (*memoriae*) in the southern Viminacium cemetery and some other structures. All of them are designed to host large numbers of visitors at any time of the year.

However, for a long time, the site was systematically destroyed. It was a victim of looting done by professional treasure-hunters who looked for gold and other precious items. (Fig. 2) On the other hand, it was a victim of local farmers, who systematically destroyed architectural remains and tombstones, taking useful materials home and re-using them. Finally, on the eastern end of the site, there is a strip mine that represented a permanent threat to the site. (Fig. 3)



MAP 1. Position of the site Viminacium (map by V. Ilić)

At this crucial point, an idea was born to establish an archaeological park, actually an open-air museum that would bring visitors to the site. It took several years and finally, in 2006, it was officially opened.

Interpretations of archaeological finds and structures were offered to the public. In order to make these easily understandable, a narrative based on storytelling was designed. The authentic location surely offered a good basis that could easily help the narrative develop and grow. Eventually, the always growing number of visitors and their presence at the site lead to a reduction of looters and treasure hunters. Soon enough, they stopped looting. And soon enough, it was possible to evaluate the results of storytelling and visitors' impressions.

According to research in 2006, the profile of Viminacium visitors was one-third children's excursions, followed by different group visitors (one-quarter of the total number of 50.000), individual visitors and approximately the same number of visitors coming on cruises (about 20% each). The study was based not on questionnaires (like those conducted in 2012 and 2013), but on data from the accounting, indicating to whom the tickets were sold. In other words, in 2006, one-third of the total number of tickets was sold to school children (from both primary and high schools).

Five years later, in 2011, Viminacium was visited by 75.000 tourists and one-fifth of them (15.000) were those arriving on cruise ships (Maksin et al. 2009: 144). Due to this rather big number of visitors from cruisers, there was an initiative to design questionnaires aiming to reveal what were the most impressive parts of their visit to Viminacium. This research was conducted mainly during 2012 and 2013. The main helping factor was that all of the cruisers stop at the port in Novi Kostolac, some 5 km from the site itself, thus requiring a twenty-minute bus drive to the site. The same route was taken during return and enough time was left for visitors to fill in the questionnaires. This kind of research would not have been possible among other Viminacium visitors since e.g. children or adults on an excursion (group visitors) leave directly from the site.

FIGURE 1. Aerial view of the site Viminacium and its tents (Documentation of the Institute of Archaeology)

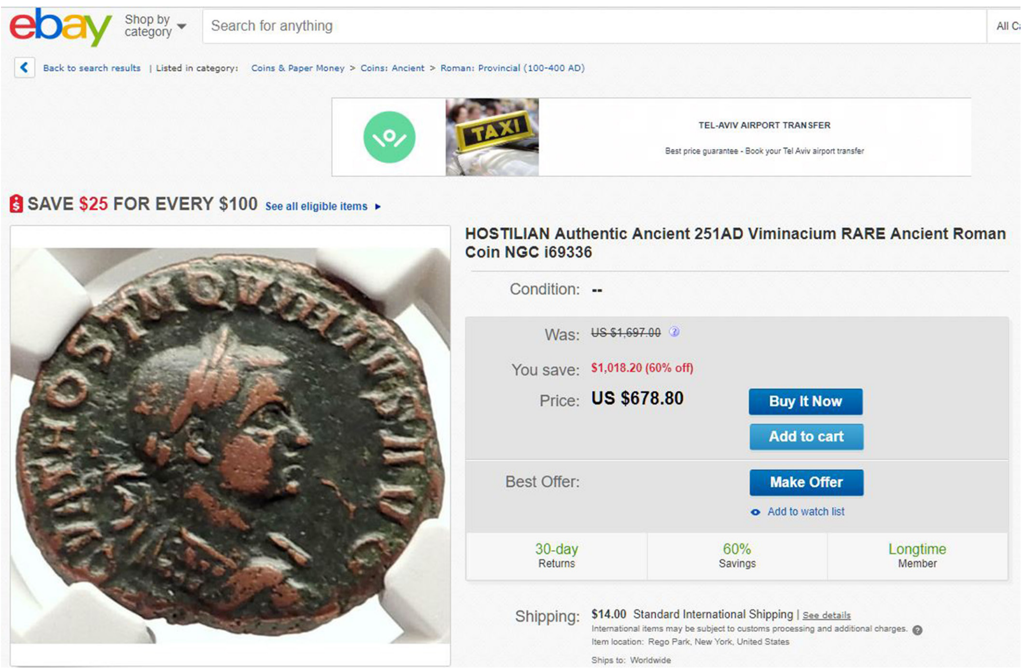


FIGURE 2. Screenshot of an ebay offer from Viminacium (accessed Feb. 26th 2019).

FIGURE 3. Aerial view of the strip mine close to Viminacium (Documentation of the Institute of Archaeology)

The data given below and illustrated in the charts were gained exclusively from the questionnaires and research conducted during 2012 and 2013 among Viminacium visitors arriving to the site on cruisers. These visitors were mostly foreign.

The first part of the questionnaire was optional and it aimed to provide basic information about the visitors. There were an almost equal number of men and women in the tours, over 80% were retired and older than the age of 60, while more than 85% held a university or a college degree. (Fig. 4, after Tapavički-Ilić and Anđelković Grašar 2014: 192, Charts 1-4). Almost all of them have been to Europe before and have visited ancient sites. Among the most commonly mentioned ones were Pompeii, Ephesus and Hadrian's Wall. This indicated that they had something to compare Viminacium to.

The second part addressed specific parts of the site, like the Roman baths, the Mausoleum and the so-called Underworld, positioned under the Mausoleum. In all of the cases, visitors claimed that they have understood the concept of these specific site parts (Fig. 5, after Tapavički-Ilić and Anđelković Grašar 2014: Charts 10, 12 and 14). and even more important, they claimed that this was due to expert guides' explanations (Fig. 6, after Tapavički-Ilić and Anđelković Grašar 2014: 195-198, Charts 11, 13 and 15).

Finally, an overall impression of the site and the guided tours reflected pretty much the same impression as those stated about each specific part of the site (Fig. 7, after Tapavički-Ilić and Anđelković Grašar 2014: 202, Chart 25). Two basic motivators were the site itself and the expert guides, showing that they are equally important for a good site interpretation.

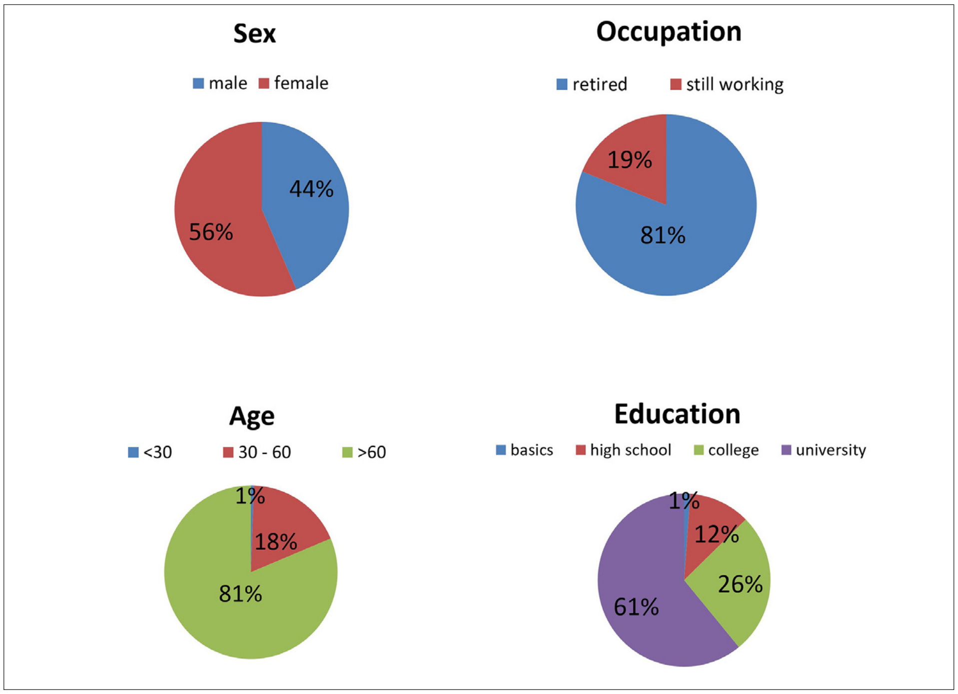


FIGURE 4. Basic information about Viminacium visitors: sex, occupation, age and education (after Tapavički-Ilić and Anđelković Grašar 2014, Diagrams 1-4)

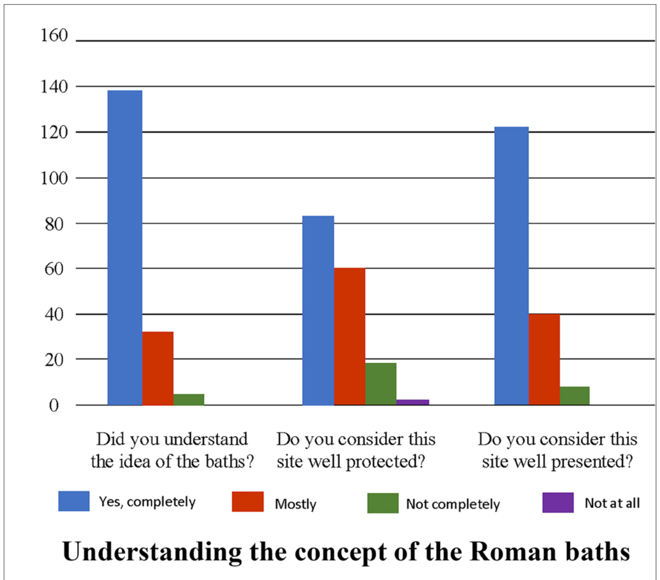
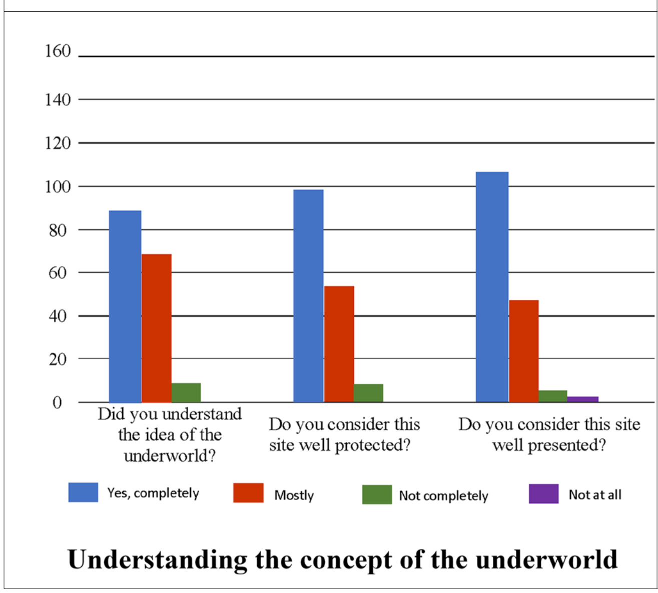
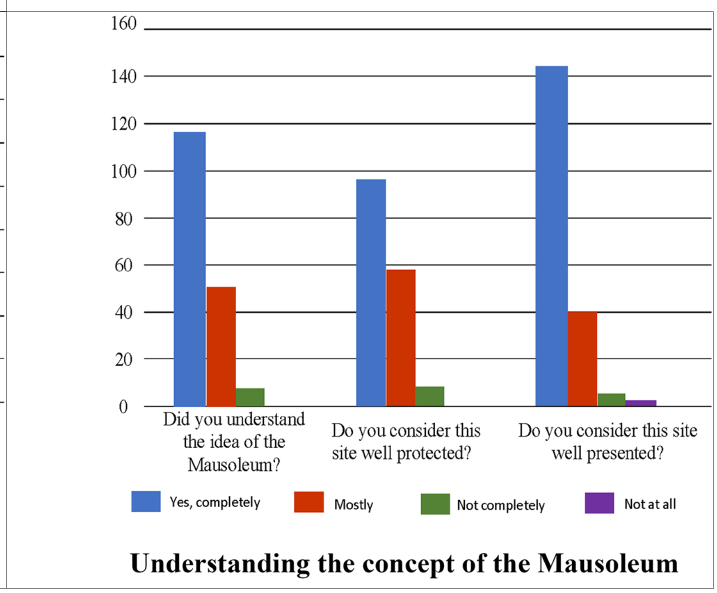
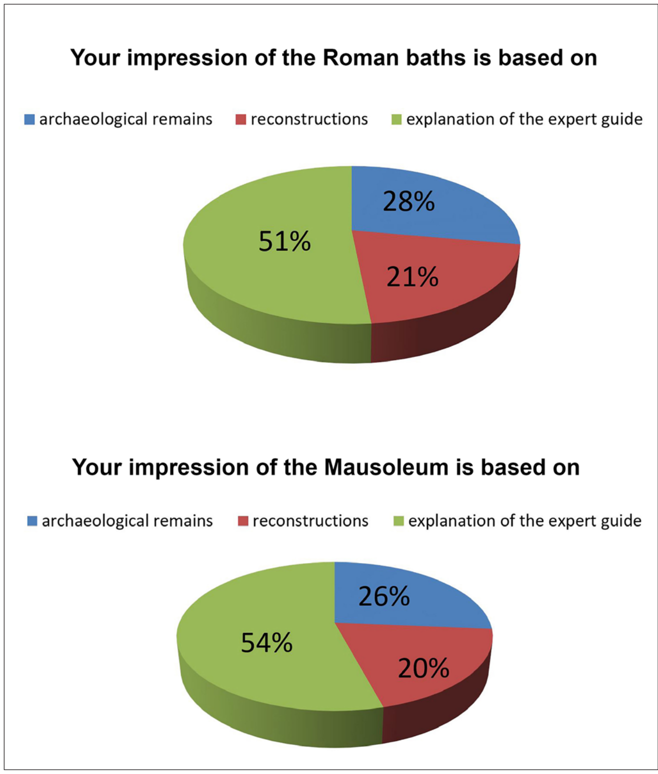


FIGURE 5. Understanding the concept of specific site parts: the Roman baths, the Mausoleum and the Underworld (after Tapavički-Ilić and Anđelković Grašar 2014, Charts 10, 12 and 14)







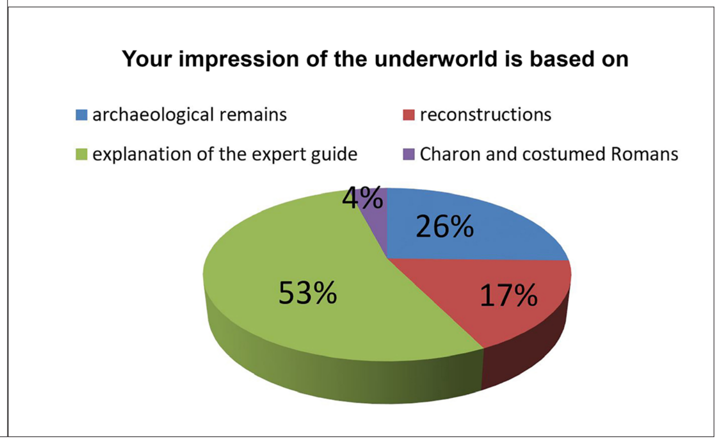


FIGURE 6. Influence of expert guides' explanations on visitors regarding the Roman baths, the Mausoleum and the underworld (after Tapavički-Ilić and Anđelković Grašar 2014, Charts 11, 13 and 15)

By looking at the charts shown before, it can be concluded that explanations of expert guides, or shortly - storytelling, was the greatest factor which influenced visitors' good impression and acceptance of the Archaeological Park of Viminacium. It seems that guides were ambassadors or direct reflections of the Archaeological Park. A site might speak for itself, but it is a language not many people would be able to understand. If one is just a curious or interested layman, the message might flow just past him.

In Viminacium, a concept was designed that includes main features of the site, fascinations and narratives (Đošević 2009: 23). The concept was designed primarily by archaeologists but in close cooperation with guides. Sometimes, archaeologists themselves acted as guides.

Main features of the site describe the time and place in which the legionary fort and the city of Viminacium were established. They also include basic facts about the imperial city (from which emperor Hostilian reigned) and the imperial mausoleum (in which emperor Hostilian was buried). Further on, it always needs to be mentioned that Viminacium is among the very rare archaeological sites with no modern settlement upon it (Fig. 8, after Đošević 2009: 23, Table 1).

The imperial mausoleum also belongs to the main fascinations of Viminacium. Within the same structure, another fascination includes fresco painted tombs from the 3rd century A.D. The frescos belong to the most beautiful pieces of Roman art throughout the Empire. However, they do not impress visitors only with their beauty and uniqueness, but also with their specific position within the structure, since they are displayed in the so-called Underworld, several meters below the ground. Visitors need to descend do the Underworld and enter each of the three tombs from below, observing the frescos from the perspective of the deceased.

Finally, Viminacium narratives include stories of emperor Hostilian's death, of the Mona Lisa from Vimiancium and of the transition of the Roman Empire towards the east. Since it was not yet determined what emperor Hostilian died of, there are several possibilities, all wrapped up in an exciting and tempting narrative. Further on, political and military turbulences of the late 3rd and early 4th century caused the Roman Empire to incline towards the east, adding more excitement to Hostilian's story.

Despite all the turmoil, Viminacium artist created fascinating frescos and among them, there is the beautiful "Viminacium Mona Lisa". Her story, sad, yet eternal in its inspiration, is always very well accepted by visitors.

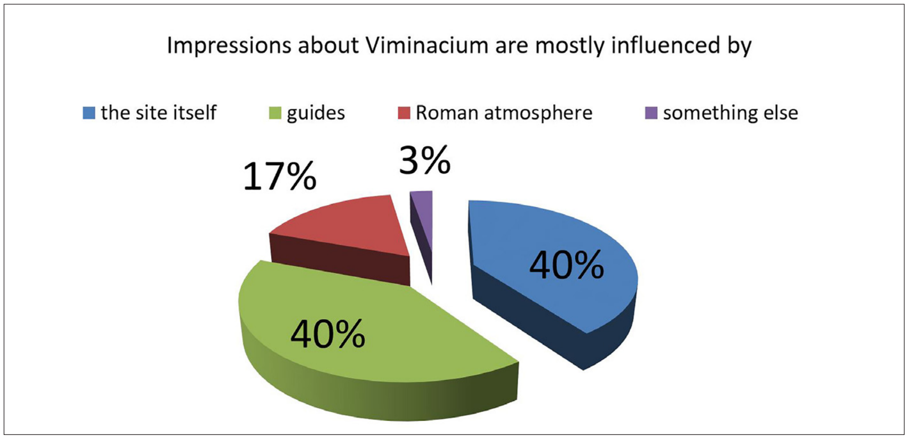


FIGURE 7. Overall impression of the site and the guided tours (after Tapavički-Ilić and Anđelković Grašar 2014, Chart 25)

Lokalitet	Viminacium
Ključne karakteristike	• Početak I veka n.e. • Glavni grad Gornje Mezije • Carski grad (Hostilian) • Carski mauzolej • Uz Carnuntum, jedini veliki rimski logor/naselje nad kojim nije niklo novo - olakšana istraživanja
Fascinacije	• Carski mauzolej • Najlepše freske kasne antike na celoj teritoriji Rimskog carstva • Prvom polovinom IV veka tačka seljenja (i zadržavanja) Rima u Konstantinopolj
Naralivna tema	• Tajna imperatorove smrti • Mona Liza kasne antike • Tranzicija carstva • Viminacium, lumen meum

Izvor: www.merr.sr.gov.yu/dokumenti

Site Viminacium

Main features
- Beginning of the 1st century AD
- The capital of Moesia Superior
- Imperial city (Hostilian)
- Imperial Mausoleum
- Besides Carnuntum, the only big Roman legionary fort/settlement without any modern structures upon it. Easily accessible for research.

Fascinations
- Imperial Mausoleum
- The most beautiful frescos of Late Antiquity in the whole of the Roman Empire
- During the first half of the 4th century, the capital of the Empire was moved from Rome to Constantinople

Narratives
- The secret of emperor's death
- Mona Lisa of Late Antiquity
- Transition of the Empire
- Viminacium, lumen meum

Source: *www.merr.sr.gov.yu/dokumenti*

FIGURE 8. Main features, fascinations and interpretative themes or narratives of Viminacium (with translation, after Đošević 2009, Table 1)

Why is storytelling important?

At first glance, archaeology and storytelling seem worlds apart. The first is an academic discipline, concerned with hard fact, rational argument and identifiable sources, while the second is 'mere' fiction and entertainment.

However, storytelling can be a powerful means of communicating all sorts of human truths, social values and community traditions. Archaeology is at its most relevant and interesting when it transcends factual description and engages with the people of the past. Both, after all, are ways of making sense of the world around us. By combining archaeology and storytelling, a new form of communication can be created which brings together academics and audiences in a shared experience of human past (Given 2009: 33).

Storytelling is one tool to make the past accessible to the present. It combines fictional stories with factual archaeological research. Although storytelling involves creating narratives using archaeological information, it is not merely inventing fanciful stories. It is also not a one-way process or something professionals (producers) do for the edification of the public (consumers) (Praetzellis 2014) since e.g. Viminacium guides always expect their public to react and comment. As long as one recognizes what is fact from what is fiction, stories could push archaeologists to ask new questions – questions about the heritage that are important to current residents and not just the researchers (Janesko 2018).

Further on, during storytelling, filtering is necessary for meaning to be possible. It is also part of archaeological conditions. Not only it is not possible to record *everything*, but many things are simply also not recordable, not preserved.

Although many visitors think that a great job is being done at the Viminacium, the work is not yet finished. By spreading the story, this archaeological park would potentially gain more and more visitors, both foreign and domestic. Statistics already show that their number has grown to over 120.000 per year. Analyses based on questionnaires showed that visitors' emotions are one of the most important elements in developing Viminacium as an archaeological park. Its insufficient number of remains is supplemented by successful presentations, lectures and the overall atmosphere. The feeling of having learned something new in such an easy and interesting way is surely nice, as well as the feeling of being ready to share your new knowledge with others. So, storytelling would lead to the spreading of the story, this again leading to making others willing to visit the site.

In addition to that, the more visitors, the less looting can be performed on the site. If there are visitors permanently walking around the archaeological park, it is unlikely for treasure hunters to act.

In 2018, a so-called "Adventure park" was opened in Viminacium, targeting mostly young people, their number as visitors would surely grow. Thus, there will be an opportunity to repeat the study and focus it more on children and adolescents. Hopefully, after a sufficient number of interviews, the authors would be able to compare the impact of storytelling to the older and the younger population.

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