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# Prehistoric ornaments in a changing environment. An integrated approach to the Late Upper Palaeolithic and Mesolithic *Columbella rustica* shells from the Vlakno cave, Croatia

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A R T I C L E  I N F O

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A B S T R A C T

This paper advances knowledge of human behavioural and adaptational strategies in coastal areas related to acquiring, producing and distributing ornaments, specifically, the omnipresent marine gastropod *Columbella rustica.* By applying quantitative and qualitative approaches to the most extensive collection of *Columbella rustica* shells in the Eastern Adriatic region discovered in the Late Upper Palaeolithic and Mesolithic levels of Vlakno cave in Croatia, we have determined the complete step-by-step life cycle of this bead type, in particular, where and how shells were collected, produced, used, distributed and discarded. By integrating different methodologies, our data revealed changes in the collection strategies, reduction of the shell size during the Mesolithic period, and standardisation and continuity in production techniques. Detailed analyses of broken shells in the archaeological assemblage identified the presence of technological traces resulting from processing mistakes, supporting our hypothesis of on-site production. A significant share of used and unused standardised beads points that bead production at this site was for personal use but also likely for the exchange and distribution systems. Standardised, systematic and long-lasting activity related to the ornaments places Vlakno cave as one of the leading centres for maintaining regional exchange and communication networks in the Eastern Adriatic region during significant climatic and environmental changes happening in this region in the Late Pleniglacial and the early Holocene. Detecting on-site activities related to the ornaments in Vlakno cave has extended our understanding of how symbolic motives influenced the settlement model of the Late Pleniglacial and Early Holocene hunter-gatherers in Eastern Adriatic region and overall contributed to fundamental questions about the complexity of ancient human societies' adaptation strategies.

## 1. Introduction

Pigments and ornaments have attracted humans since the early phases of the Palaeolithic and, from then, remained a part of human material culture in almost all human societies (Sehasseh et al., 2021; Radovčić et al., 2015). Ornaments and pigments testify that our ancestors could not only "recognise" the potential to use and modify raw material, e.g., ocher or animal tooth or shell, in bead but, consequently, to create and share symbols and their meanings. Subsequently, these specific archaeological remains point out how the prehistoric mind was aware of aesthetics and, more importantly, the symbolic dimension originating from wearing and exposing these creations to be visible to others. Accordingly, prehistoric beads, the fundamental units of prehistoric ornamental sets, are, together with pigments, one of the earliest material proxies proving our ancestors' ability to operate symbolically, marked as a critical development point in human cognition (Álvarez-Fernández and Jöris, 2007; Bednarik, 2008; White, 1992). In 1992, R. White introduced the social and symbolic roots of the origin of prehistoric body adornments in the anthropological debate. Since then, they have played an essential role in our endeavours to understand our cultural evolution better.

Displayed in their multiformity and worn in varied ways, personal ornaments have become polysemic objects carrying diverse denotations through their evolutionary history. In prehistoric contexts, beads are

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only rarely found *in situ* as part of a completely preserved individual ornamental composition, i.e., in burials (Alarashi et al., 2023; Gravel--Miguel et al., 2022; Orschiedt, 2016; Vanhaeren and d'Errico, 2001; White, 1999). Beads are found scattered throughout the deposits or recovered during the subsequent sieving of the sediment. Despite the challenging circumstances of their recovery, analysis of these small-sized artefacts can still provide important information about prehistoric choices, lifestyles and symbolic behaviour. Preserved materials purposefully collected and used for bead production in early prehistory include, amongst others, various types of mollusc shells, bones of different animal species, stones (clay and soft ones), and wood (e.g., Taborin, 2004; White, 2007; Werker, 1988; Vanhaeren and d'Errico, 2006). We can only use our imagination while referring to ethnographical records to conditionally complement our ancestors' list of other potentially perishable raw materials used for ornamentation. Until now, prehistoric ornaments' role was attributed to the aesthetic, protection, and construction of personhood (e.g., Borić and Cristiani, 2019) or as a marker of age, gender, power, or marital status (e.g., Bar-Yosef Mayer; 2015; Kuhn and Stiner; 2007). Also, throughout varied qualitative and quantitative analyses supported by ethnographical records of modern forager populations, ancient personal ornaments are commonly interpreted as indicators of social status and identity (Stiner, 2014; Vanhaeren and d'Errico, 2011; Rigaud, 2011). Accordingly, ornaments were essential "technology" for transmitting messages characterised by the standardisation of beads' form and formal redundancy, fundamental features of any communicational system (Kuhn and Stiner, 2007). Standardisation, necessary for the consistency of symbolic meaning, can be observed in the prehistoric beads' shapes, i.e., in the selectivity of certain natural forms (shells, teeth) and production technology. The small size and durability of the beads favour the redundancy supporting the successful transmission of messages/information. In that regard, beads have been one of the most significant objects in studying acculturation or diffusion systems (Bourdieu, 1977) and are commonly part of hunter-gatherers exchanging systems aiming at building and maintaining social networks (Wiessner, 1982; Rigaud et al., 2019; Cvitkušić, 2015). Still, we do not have enough knowledge and insights about the acquisition and distribution routes of raw materials used for ornaments. Ethnographically, connections and networks can be traced amongst ethnographic groups if this information is available, such as in North America (Dubin, 1999).

Despite the wealthy opus on the ornamental research in prehistory, to date, we still miss more information on the human activities related to the complete process of marine shell ornaments' life cycle, i.e. where shells were collected and selected, where and how they were produced, used, distributed and finally discarded (Baysal and Yelözer, 2023; Rigaud et al., 2019; White et al., 2007; Cristiani et al., 2014).

This paper aims to complement our knowledge of activities related to acquiring, producing, using, and discarding ornaments in prehistoric hunter-gatherer societies by integrating quantitative and qualitative analysis and experimental activity by exploring the most extensive collection of *Columbella rustica* shells in the Eastern Adriatic region discovered in the Late Upper Palaeolithic and Mesolithic deposits of Vlakno cave, characterised by multiform states of integrity and use. During the Late Pleniglacial and early Holocene, the distribution of ornaments is well documented in the Eastern Adriatic region and its hinterland (Cristiani et al., 2014; Cvitkušić and Komšo, 2015; Cvitkušić, 2017; Cvitkušić and Vujević, 2021; Komšo, 2007; Komšo and Vukosavljević, 2011). The rich ornamental assemblage from the Late Upper Paleolithic (LUP) and the Mesolithic deposits of Vlakno cave, characterised by continuity in the representation throughout the sequences, variety of the bead types, the multiform outcome of production activity (i.e. technological mistakes, perforated beads) and modalities of use (i.e., used, unused) (Cvitkušić et al., 2018), point that this site likely served as a specialised workshop for the ornaments in the broader region during indicated periods. The dynamic and activity of ornament production at the site stayed undisturbed even with the profound Holocene change of Vlakno becoming part of the island. The rich assemblage of *Columbella rustica* in Vlakno cave allowed us to study and gain better insight into behavioural and adaptational strategies in coastal and inland areas and the connectivity of our ancestors related to symbolic behaviour and mobility patterns associated with raw materials collection and *chaîne opératoire* for ornaments.

## 2. *Columbella rustica* shells

Two species of Columbella (Lamarck, 1799) inhabit the Mediterranean Sea and nearest parts of the Atlantic Ocean: (1) *Columbella rustica* (Linné, 1758) present in the entire Mediterranean Sea and extending into the neighbouring Atlantic southward to Senegal and northward to Portugal, and (2) *Columbella adansoni* (Menke, 1853) recorded in Cape Verde islands, and assumed to occur across Macaronesia, from the Azores to the Canary Islands, and along the West African coasts from Ghana to Angola (Russini et al., 2017). *Columbella rustica* is a small marine gastropod inhabiting warm waters' rocky or sandy bottoms (Poppe and Goto, 1991). It is well-adjusted to external environmental alterations, such as temperature and pH changes (Wahl et al., 2016). The natural colour varies from white to red and brown with irregularly speckled patterns. The compact solid shell is oval-shaped, with the spire not too high. The thickest parts of the *C. rustica* shell are (i) the area along the top of the body whorl attaching to the spire, (ii) the siphonal canal, and (iii) the outer lip of the aperture, while the thinnest part is the apex, followed by the periphery part of the body whorl (Bosch et al., 2023). This shell taxon is considered non-edible (Syrides, 2019).

Since the Upper Palaeolithic, *C.rustica* was collected and used exclusively for ornamental purposes in European hunter-gatherers' societies. The oldest *C. rustica* beads are discovered in Bizmoune Cave in southwest Morocco in deposits dated ≥142 thousand years (Sehasseh et al., 2021*)*. With the beginning of the Mesolithic, *C. rustica* became omnipresent in the archaeological record (Álvarez Fernández, 2008) as a unique element of a shared symbolic vocabulary of forager groups. In later periods, it was not exclusively related to hunter-gatherer populations (Álvarez Fernández, 2003, 2008; Karali, 1999). *C. rustica* has a wide spatiotemporal distribution in the Mediterranean area (Álvarez Fernández, 2003, 2008; Mussi, 2002; Stiner, 1999; Benghiat et al., 2009; Cristiani, 2012; Kuhn et al., 2001; Bar-Yosef Mayer, 2005). It is present in the continental part of Europe as well (e.g., Eriksen, 2002; Álvarez Fernández, 2003; Álvarez Fernández, 2008) and is one of the few bead types distributed over more extensive distances (Cucart-Mora et al., 2022).

## 3. Regional and site background

Vlakno cave is located on the inner side of Dugi otok island, centrally positioned within the Eastern Adriatic area (Fig. 1, nr. 9). The cave is a simple speleological object with a small inner space of ~40 m$^2$ and a wide opening facing southeast. There is a source of fresh water in the vicinity, less than 150 m away (Brusić, 2005:198; Vujević, 2021:35). With these characteristics, it was almost ideal for a campsite and shelter for small groups of foragers since prehistoric times (Vujević and Parica, 2011; Vujević and Bodružić, 2014; Cvitkušić et al., 2018; Vukosavljević et al., 2014). At the beginning of the Holocene, a profound environmental change encompassed the Adriatic region, with a rapid sea level rise (Surić, 2006:182). Nine thousand years ago, the Adriatic plain amounted to only 17% of its former area and was reduced to a narrow strip around the Gulf of Trieste (Miracle 1995:117–118). The Adriatic area's geography was fundamentally reshaped and transformed from the Adriatic Plain into the Adriatic Sea as we know it today (Peresani et al., 2021; Sikora et al., 2014). During lower sea level, the cave was located far from the sea, and the entire island was part of the mainland and formed a 100–400 m high ridge rising above the valleys (Vujević and Parica, 2011:23).

Due to sea level rise and flooding of the Adriatic Plain, Dugi otok and


**Fig. 1.** Central position of Vlakno cave site (9) in the Eastern Adriatic region with the indicated coastline from Late Pleistocene to Holocene. Sites with ornaments: 1. Nugljanska cave, 2.Abri Šebrn, 3. Pupićina cave, 4. Lim 001, 5. Romualdova cave, 6. Šandalja II, 7. Ljubićeva cave, 8. Zala cave, 9. Vlakno cave, 10. Vela spila.

the surrounding islands got separated from the mainland, forming one much larger island, and Vlakno became a coastal site (Brusić, 2005:198). According to some studies (Miracle, 2007; Boschian 2003:99), hunter-gatherer groups from the central and southern parts of the Eastern Adriatic region were forced to settle in the hilly hinterland and change their subsistence strategies. Reduced territory decreased connections with the western Adriatic coast and directed groups to more intensive use of local resources and movements towards the eastern Adriatic hinterland. Nevertheless, many cave sites at the Adriatic Plain's edge attest to the landscape's viability during that period (Pilaar Birch and Miracle, 2017:87), and the rich archaeological assemblage from the Vlakno cave further supports that notion (Vujević, 2016; Vujević and Bodružić, 2021).

The Vlakno deposits yielded rich evidence of the LUP and Mesolithic occupation without a visible hiatus in the stratigraphy, making Vlakno an ideal place for studying the transition from the Pleistocene to the Holocene and the adaptations of the Epigravettian communities to significant climatic and environmental changes happening in this region. Despite this profound change, the dynamic and activity traced in the site's entire sequence stayed consistent. Archaeological investigations in the Vlakno cave started in 2004 (Brusić, 2005), while systematic excavations have been ongoing since 2011 (Vujević, 2011; Vujević and Parica, 2011). In the test trench, a depth of almost 5 m was reached, with cultural layers that can be traced back to the last 19.5 kya (Beta302247, 16330 ± 70 BP, 17600-17450 cal BC (19550-19400 cal BP), taken from Stratum 10). Systematic research is currently stopped at a depth of 3.7 m, i.e. Stratum 8 (Beta607870, 13640 ± 40 BP, 14685 - 14372 cal BC (16634 - 16321 cal BP). The stratigraphic sequence of Vlakno is well documented in the test trench and confirmed with absolute dates, representing a long-lasting occupation dated from early Epigravettian throughout late Epigravettian and early Mesolithic in cultural terms—absolute dates acquired from the site range from c. 19.5 ky cal BP to c. 8.6 ky cal BP (Fig. 2.). The excavated area of a test trench is divided into ten primary cultural strata with subdivisions, with many layers without a visible hiatus separated only by thin layers of ash and burnt soil representing occupation surfaces of the cave use (Vujević and Bodružić, 2014; Cvitkušić et al., 2018). At 2 m depth from the surface, cultural layers are interrupted by a 10 cm thick layer of tephra, the Neapolitan yellow tuff (dated to c. 14.9 ± 0.4 ka cal BP; Deino et al., 2004; Radić et al., 2008). Stratum 1 represents the surface layer. It displayed evidence of disturbance in stratigraphy and small finds (several pieces of Neolithic and Roman-age pottery, along with some recent archaeological material). Undisturbed Mesolithic layers below the surface are phased in two: Stratum 2 and Stratum 3, corresponding roughly to the Early Holocene. These upper strata consist of loose and dusty sediments with high quantities of land snails and marine molluscs in deposit. Preliminary sedimentology results indicate that most sediments are deposited through anthropogenic activities (G. Boschian, pers.

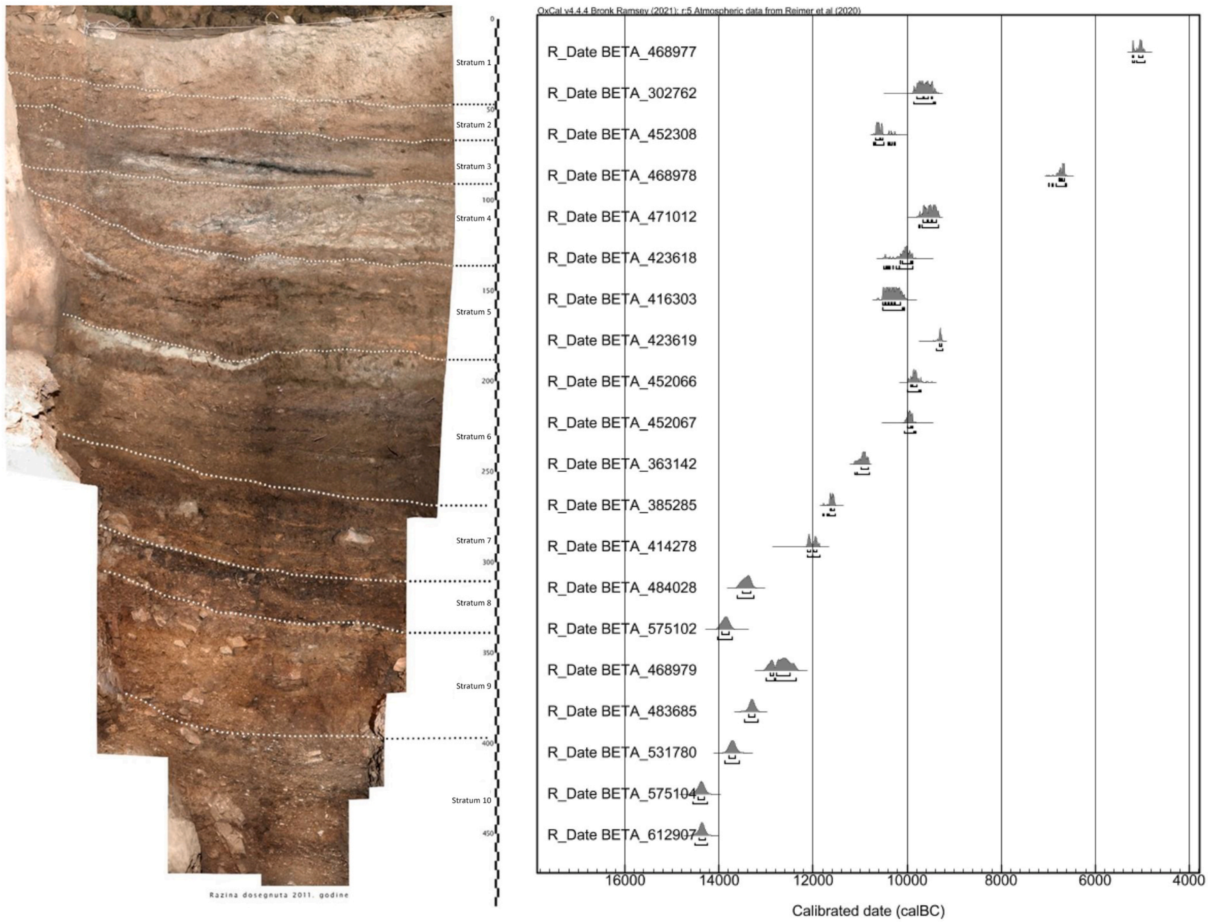


**Fig. 2.** The stratigraphic sequence of Vlakno cave.

comm). The division is based primarily on 14C dating, although there is also evidence of temporal changes in the faunal and lithic assemblages from these two strata (Vujević and Bodružić, 2021; Radović et al., 2021). Chronologically, the Mesolithic occupation started ca. 8000 cal BC (Beta-677951, 9300 ± 30 BP). The archaeological assemblage of Mesolithic Strata 2 and 3 are typical Mesolithic but with pronounced Epigravettian tradition, which can especially be observed in ornaments, lithics, and subsistence strategies (Cvitkušić et al., 2018). Stratum 4 marks the end of the LUP, while Stratum 5 represents the first cave settlement phase after the eruption in the Phlegraean fields. The tephra layer, Neapolitan yellow tuff from the mentioned eruption, served as a stratigraphic boundary between Stratum 5 and Stratum 6 (Vujević and Parica, 2011:26; Vujević and Bodružić, 2021).

Strata 6 to 10 are located below the tephra layer and represent various chronological sections of life in the cave during the chronological period from about 15 to 19.5 ky cal. BP. Stratum 10 includes the lowest layers from the test trench, although since systematic excavations have not yet reached these layers, the phasing could be somewhat different in the future. Lithics, especially endscrapers, back bladelets, and backed points, show that all strata can culturally be designated to the Epigravetien, although characteristics of the lithic assemblage from Stratum 10 point to its early phase.

Preliminary analysis of faunal remains from Mesolithic Strata 2 and 3 shows a predominance of mammals. However, there are also remains of fish and birds, which are extremely rare in the strata below (Radović et al., 2021). Within the taxonomically identified mammalian assemblage in Stratum 3, red deer (*Cervus elaphus*) was the most common mammalian taxon, followed by a red fox (*Vulpes vulpes*). In contrast, in the chronologically later Stratum 2, the red fox is the predominant taxon, followed by red deer. Marine fish remains are present in the faunal assemblage from the beginning of the Mesolithic layers, with a significant increase in Stratum 2 (Radović et al., 2021). A combination of dental calculus and stable isotope analyses from a well-preserved buried skeleton of a male aged between 35 and 40 from Stratum 2 also showed that the individual regularly consumed marine resources with various plant foods (Cristiani et al., 2018).

The ornamental assemblage (N = 692) from Vlakno cave is comprised of nine different taxa discovered throughout LUP (Stratum 4 to 8) and Mesolithic (Stratum 2&3) deposits (Table 1). The most represented ornaments are from marine species, i.e. gastropods *Columbella rustica* and *Tritia neritea* and scaphopods *Antalis* sp. (Table 1). Besides modified, many whole unmodified specimens have been discovered (Table 1, number in the brackets), particularly 105 *C. rustica* shells in Stratum 2 and 3.

## 4. Material and methods

We have analysed 379 *C. rustica* shells discovered in the LUP (N = 23) and Mesolithic (N = 356) deposits of Vlakno cave (Fig. 3) aiming to reconstruct the *chaîne opératoire,* i.e., the sequence of actions related to their production, such as modalities of collection, production, use, and discard by performing technological, use-wear, and residue analyses supported by experimental activity. The experimental activity was carried out on a modern sample of 160 *C. rustica* collected along the Adriatic coast, aiming to reconstruct the specific technique applied to perforate the archaeological shells from Vlakno cave.

Taxonomical determination of archaeological *C. rustica* shells from the Vlakno cave is based on the previous taxonomical identification (Cvitkušić, 2015) and strict geographic separation of two species inhabiting the Mediterranean Sea.

**Table 1**
Ornamental assemblage from Stratum 2 to Stratum 8, Vlakno cave. Numbers in the brackets indicate whole, unmodified specimens.

| Stratum | Marine gastropods, bivalve and scaphopods | | | | | | Freshwater gastropods | | Mammal teeth |
|---|---|---|---|---|---|---|---|---|---|
| | *Columbella rustica* | *Tritia neritea* | *Tritia nitida* | *Glycymeris* sp. | *Acanthocardia tuberculata* | *Antalis* sp. | *Theodoxus danubialis* | *Lythoglyphus naticoides* | *Cervus elaphus* |
| **2** | 222 (81) | 3 | 2 (1) | | | | | 1 | 2 (1) |
| **3** | 29 (24) | 22 (1) | (3) | | | | 1 | 1 | 1 (1) |
| **4** | 9 (1) | 42 (1) | 4 (5) | 2 (1) | 1 | 2 | 2 | | 3 |
| **5** | 13 | 37 | 2 (6) | 19 (2) | (1) | 7 | 1 | 1 | 2 (3) |
| | | | | **TEPHRA ~ 14.9 ± 0.4 ka cal BP** | | | | | |
| **6** | | 45 (1) | 1 | 7 | | 174 | 2 | 1 | 18 (14) |
| **7** | | 7 | | | | | 1 | | 4 (3) |
| **8** | | 1 | | | | | | | 2 |

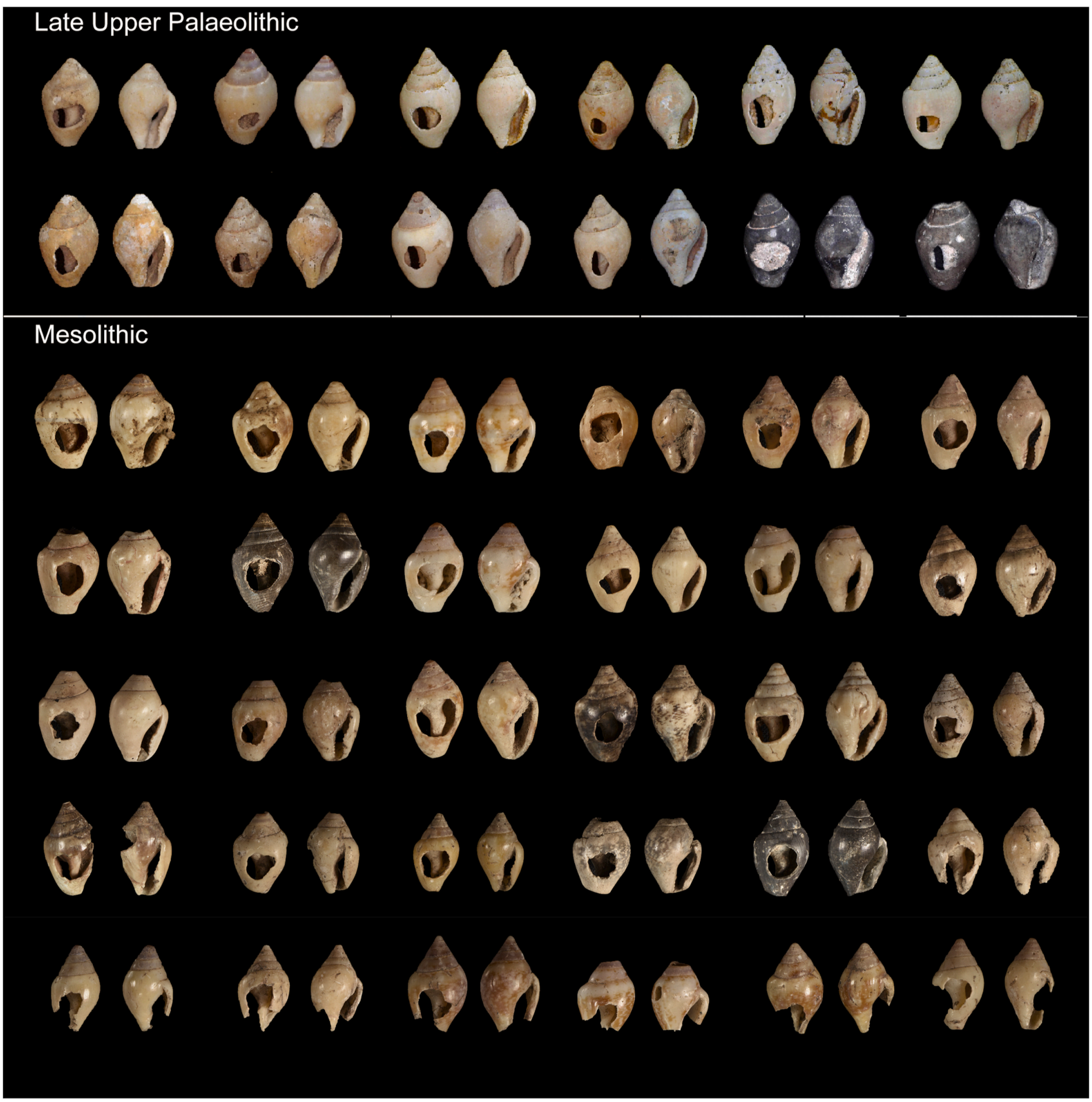


**Fig. 3.** Selection of LUP and Mesolithic *Columbella rustica* shells from Vlakno cave.

The good state of preservation and the abundance of *C.rustica* shells in the deposits above the tephra (from Stratum 5 to 2) allowed us to apply a methodological approach of quantitative and qualitative analysis based on integrated metrical, technological, and use-wear studies, aided by taphonomical analysis. Furthermore, aiming to detect specific production techniques, we have compared the archaeological *C. rustica* with an experimental collection using Geometric Morphometrics (Cristiani et al., 2020). All the analyses have been performed at the DANTE—Diet and ANcient TEchnology laboratory (Sapienza University of Rome, Italy).

### 4.1. Morphological and morphometric analyses

Before performing detailed analysis, LUP and Mesolithic *C. rustica* shells were divided into three groups according to integrity: Group 1 – whole specimens with perforation; Group 2 – whole specimens without perforation; and Group 3 – damaged/broken specimens. Group 1 (G1) is comprised of entire, undamaged perforated beads and beads with missing small parts, i.e., the apex or small fragments of the outer lip (N = 223). Group 2 (G2) includes whole shells without modifications (N = 106). Group 3 (G3) includes incomplete and/or damaged specimens, i.e., shells with missing significant parts of the body whorl or the entire lip area with or without signs of perforation hole (N = 50).

For all G1, G2, and experimental specimens, metric data were recorded with a digital calliper: (1) dimensions of the bead (maximum length and width in mm) and for the G1 (2) dimensions of the perforations (maximum length and width in mm).

The taphonomic study was carried out on all specimens with a focus on pre-depositional alterations (predator drilling, bioerosion), anthropogenic modifications (perforations, ocher residues, thermic alterations), and post-depositional alterations (fragmentations, decalcifications) (Driscoll and Weltin, 1973; Claassen, 1998; Crothers, 2004; d'Errico et al., 2005).

### 4.2. Experimental activity

*C. rustica* shells used in the experimental activity were collected on the shore of Zadar County, Croatia. Experimental shells (N = 160) divided into four groups (N = 40) and perforated by testing two direct and two indirect percussion techniques already documented in the archaeological record (Álvarez Fernández, 2006; Benghiat et al., 2009; Rodríguez-Hidalgo et al., 2010; Cristiani, 2012; Mărgărit, 2016; Mărgărit et al., 2018). Techniques of perforation applied in experimental activities included the production of holes on the central body whorl of the shell with 1. direct percussion using a pebble; 2. direct percussion using a flint core; 3. indirect percussion using flint flake and pebble; 4. indirect percussion using retouched point and pebble (Cristiani et al., 2020). Attempts to perforate *C. rustica* using (1) a bone tool and (2) a wooden stick have been unsuccessful, resulting in damaged and broken points of tools made of this compared to shell, softer, organic material.

Described and recorded criteria on the experimental *C. rustica* shells comprehend perforation shape, section morphology of the walls, percussion flake, micro-flaking, compressions, crushing and notching marks, striations, and cracks. In particular, the outline of the perforation (circular, oval, sub-regular, and irregular), the section morphology of the perforation walls (straight, internally bevelled or jagged), the presence/absence of the percussion flake, the position (internal or external) and the invasiveness of the micro-flaking, the presence/absence and the organisation (isolated or bands) of striations, the invasiveness of compressions marks, as well as the presence/absence of crushing and notching, were recorded together with the presence/absence of cracks starting from the perforation rim for each perforated shell.

### 4.3. Microscopic analysis

Specimens from G1 and G3 were analysed by low and high magnification by using a Zeiss Axio Zoom V16 binocular stereo microscope with progressive magnifications ranging between × 10 and × 112 and equipped with a Zeiss Axiocam 305/506 colour camera. For the G1 specimens, the use-wear and technological analysis aimed to identify functional modifications such as rounding of the perforation, faceting of the profile, changes of colour, striations, and residues in order to discern patterns of acquisition, manufacturing, wear, use, and finally, deposition/discard. The type and distribution of use-wear traces and residues related to the perforation hole, the lip, and dorsal and ventral surfaces have been recorded. For the G3, the use-wear and technological analysis aimed to identify specimens that were discarded as a mistake during perforation activity, i.e., technological accidents based on technological marks such as striations together with flattening or compression from counterblows, crushing and notching marks, percussion flake in the perforation area, and to detect possible used shells among broken specimens. All technological traces on the archaeological specimens were observed according to the traces recorded on the experimental sample.

### 4.4. Geometric morphometric

A 2D geometric morphometric approach was applied to test whether it could distinguish between perforation holes on *C. rustica* shells on the base of the perforation shape. Zenithal pictures of experimental and archaeological shells were taken using a Canon EOS 100D with a fixed 50 mm macro lens.

Thirty-six (36) landmarks were manually positioned at every 10° along the perforation in a clockwise direction using the open-source software tpsDIG2 (v.2.32). To facilitate this process, a digital protractor was placed on the specimen picture at the centre of the perforation, vertically aligned with the siphon. The analysis of the perforation holes was carried out in RStudio (v. 2023.06.1 + 524) using the packages Momocs (1.4.0), tidyverse (v.2) and kableExtra (1.3.4). Elliptic Fourier analysis of the perforation shapes was performed in Momocs, where the TPS data for each perforation was imported as coordinates and scaled to centroid size. Following Bonhomme et al. (2014), Fourier transforms were computed for each perforation hole. Twelve harmonics were retained, allowing to gather 99% of the harmonic power. Results were obtained by applying Principal Component Analysis to assess shape variation and potential clustering based on the shape of the perforation hole. Raw data and R code can be found in https://zenodo.org/records/10786315.

## 5. Results

The Mesolithic specimens (N = 356) are better preserved than the LUP (N = 23). Visual inspection of *C. rustica* shells revealed that a significant share of Mesolithic shells display the characteristic alterations of shells collected in thanatocenoses, such as bioerosion marks, sponge marks, and/or breakage of the spire, compared to LUP specimens where most of the shells have the appearance of freshly collected shells with preserved apex. The whole sample has a significant share of specimens characterised by multiform outcomes, such as entirely perforated and intact shells, whole perforated and intact shells with changed natural colour to black, broken specimens, shells with the marks of the initial but unfinished perforation process, and manufacturing discard. We hypothesise that the heterogeneous sample of *C. rustica* shells is related to the on-site production activity of the ornaments, in particular, that broken specimens are likely discarded as technological mistakes, intact shells are a raw material supply, and that among perforated beads, there are a significant share of used but also unused ones.

The distribution of *C. rustica* according to the state of integrity is

**Table 2**
Distribution of *C. rustica* according to the state of integrity: G1 – whole specimens with perforation; G2 – whole specimens without perforation; G3 – damaged/broken specimens.

| *Columbella rustica* | G1 | G2 | G3 |
|---|---|---|---|
| Late Upper Palaeolithic | 21 | 1 | 1 |
| Mesolithic | 202 | 105 | 49 |

presented in Table 2. An increased number of specimens in divided groups (G1, G2 and G3) characterise the Mesolithic sample.

Results of morphometric analyses revealed differences between the size of Mesolithic and LUP *C. rustica*. The average length and width of the *C. rustica* with intact apex from LUP deposits is 14.62 × 8.85 mm, and from Mesolithic, 13.49 × 8.69 mm (Table 3; Fig. 4). The average dimension of the experimental sample is 13.62 × 8.39 mm (Table 3).

The naturally present pattern on the shell's surface is invisible in most archaeological *C. rustica*. Loss of the natural pattern results from the various chemical and mineralogical changes that occur due to long-term residence in the sediment (Claassen, 1998). Sponge marks and pitting forms are detected in almost half of the Mesolithic sample, indicating that shells were likely collected on the beach. Calcification and root damage are present in 12% of Mesolithic specimens. Pitting forms and root damage are observed on two LUP specimens.

Almost 20% of perforated LUP and ~20% of G1, G2, and G3 Mesolithic *C. rustica* shells are black, characterised by the even dark colour of the surface and core of the shell, likely resulting from controlled exposition to the fire (Perlès and Vanhaeren, 2010). In the Mesolithic sample, the share of perforated (used ~36%, unused ~28%) and whole unmodified black shells (~36%) is represented almost equally. LUP and Mesolithic C. rustica shells in Vlakno cave appear as (1) non-burnt, i.e. with the natural colour of the surface, or (2) burnt, i.e. black or very dark grey colouring of the surface and core of the shell (Claassen, 1998). In the Vlakno sample, we have not detected heated but not burnt shells with light grey colour or surface patches (Claassen, 1998).

The use-wear analysis of G1 showed that ~60% of the LUP and Mesolithic *C. rustica* beads were used (Fig. 5).

The analysis revealed that ~40% of G3 specimens were broken during the perforation process. They all have one or a combination of more common features visible in a perforation area on the body whorl in the form of percussion flaking and/or flint striations marks (Fig. 6; e, f, h, k, s) and very sharp perforation edges with a characteristic pattern of missing outer lip area (Fig. 6; e, s). Hence, they were marked as technological mistakes. A small share of broken beads in G3 have use-wear traces, but it cannot be distinguished if the fractures result from the use or post-depositional factors. Moreover, the cause of shell damage of G3 specimens without technological traces conditionally can be attributed to natural factors (predators, post-depositional) or anthropic factors (trampling, gathering debris) (e.g. Bosch et al., 2023; Stiner, 1999; Perlès, 2016; Stafford et al., 2015).

Moreover, during analyses, ocher residues, in the form of small steins or spots, have been detected in one-fourth of the Mesolithic beads, localised along the edge of the perforation for the most (Fig. 7; a, b, c, e), across the columella (Fig. 7; a, d, g), on the surface of the body whorl (Fig. 7; a, d, e) and along the lip (Fig. 7; f, h). Spots of red residues have been identified inside one LUP specimen. The type of ochre distribution could be associated with using coloured threads to retain the ornaments (Cristiani et al., 2014). On one *C. rustica* (Fig. 7; e), a big part of the shell surface appears covered by a reddish compacted patina that distributes, leaving the surface below the perforation rim clean. This would confirm that the ornaments could have been retained with coloured threads or that the shells had been in contact with an intensely red-coloured surface.

The experimental activity resulted in the biggest share of broken

**Table 3**
Descriptive statistics for Late Upper Palaeolithic, Mesolithic and experimental *C. rustica* with preserved apex.

| | N | Minimum (mm) | Maximum (mm) | Mean (mm) | Std. Deviation |
|---|---|---|---|---|---|
| **Late Upper Palaeolithic** | 18 | 12,37 | 16,09 | 14,6433 | 1,00009 |
| **Mesolithic** | 207 | 10,05 | 16,82 | 13,4109 | 1,31726 |
| **Experimental sample** | 136 | 11,00 | 17,00 | 13,6213 | 1,10094 |

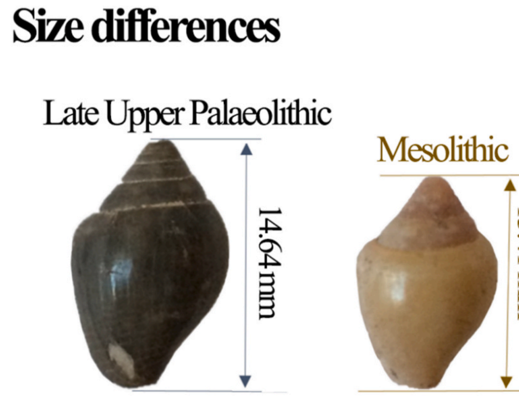


**Fig. 4.** The difference in the size between Late Upper Palaeolithic and Mesolithic *C. rustica* from Vlakno cave.

specimens in the experimental samples perforated by indirect percussion using flint flake and pebble and retouched point and pebble. Technological mistakes are present, but less, in the experimental samples perforated by direct percussion using a pebble and a flint core. Also, we have noted that production mistakes depend on the expertise of the person performing the experimental activity, mainly that a person with more experience had fewer mistakes.

When analysing the shapes of the experimental perforation holes, it is possible to differentiate between perforations produced by the different tested techniques. As seen in Fig. 8 the perforation holes made through various techniques and tools form three distinct clusters. In particular, the PCA results highlight the apparent difference in the shape of holes produced through direct percussion using a pebble and the ones made through indirect percussion using a flake edge. The former are circular, while the latter are thinner and more elliptical; finally, the perforation holes produced using a flint point through indirect percussion result in a more oval shape (Fig. 8).

Furthermore, the results of LDA on the PCA scores show that in 70% of the cases, it is possible to discriminate between the tested perforation techniques appropriately. In 90% of the cases, holes produced using a pebble through direct percussion are correctly identified. A similar high successful discrimination rate (80%) is also achieved for perforation holes made using a flake edge adopting an indirect percussion. A much lower correct identification rate (40%) characterised the holes produced using a flint point through indirect percussion.

Finally, the results of MANOVA performed on the PCA scores show a significant difference between the perforation produced by indirect percussion with a pebble and indirect percussion with a flake edge ($p = <0.001$) as well as in the case when the perforation produced by direct percussion with a pebble and indirect percussion with a point are compared ($p = 0.0165$) (Table 4). On the other hand, no significant difference is recorded when the perforations produced through indirect percussion using a flake and a point are compared ($p = 0.078$) (Table 4).

Several points can be raised by comparing the perforation holes of *C. rustica* shells from Vlakno with the experimental ones (Fig. 9).

First, no difference in shape is observed between the LUP and the Mesolithic *C. rustica* from the Vlakno assemblage. As shown in Fig. 9, the PCA shows that the shape of the archaeological perforations falls towards the more circular ones experimentally produced by direct percussion using a pebble. These results are confirmed when a MANOVA Pairwise is run to compare the perforation shapes of the *C. rustica* from Vlakno with the ones produced experimentally (Table 5).

No significant differences are recorded in perforation shapes among the archaeological specimens, suggesting that a similar technique was employed to perforate *C. rustica* shells during both periods. In this sense, using a pebble through direct percussion was the technique most likely employed, given the significant differences in shape between the archaeological specimens and the holes produced through indirect

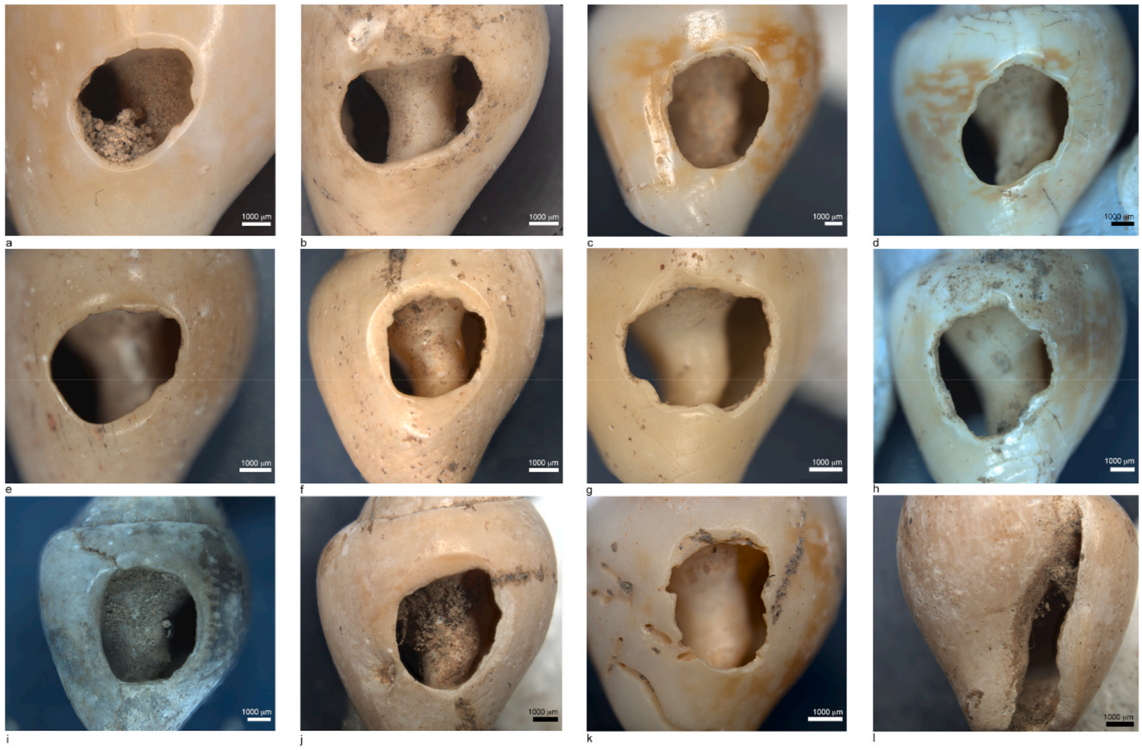


**Fig. 5.** Selection of used LUP (a, b) and Mesolithic (c – l) *C.rustica* from Vlakno cave presented by sample number: a) 78.4; b) 56.6; c) 14.96; d) 14.206; e) 24.7; f) 14.76; g) 14.98; h) 14.4; i) 24.6; j) 14.78; k) 14.32; l) 14.78.

percussion using a flint point.

## 6. Discussion

By integrating quantitative and qualitative analyses of *C. rustica* shells from LUP and Mesolithic deposits of Vlakno cave, we have determined its anthropogenic collection, production, and use, indicating that Vlakno cave was a specialised workshop for ornaments. Furthermore, the conducted study allowed us to elaborate on the on-site activities related to ornaments, including complete *chaîne opératoire* for this widespread taxon for shell ornaments omnipresent in the Mediterranean region (Álvarez Fernández, 2008, 2010; Cristiani et al., 2014; Cvitkušić, 2017). Moreover, we have detected a reduction in the size of the Mesolithic specimens. A significant difference in size, i.e., length (Perlès, 2016), of Vlakno's Late Pleistocene and Holocene *C. rustica* shells can be interpreted in favour of three possible intertwined factors: (1) environmental changes; (2) human pressure on coastal resources; and (3) changes in collection strategies. The environmental change in the central Eastern Adriatic caused by the rise of the sea level, separating Dugi otok and Vlakno cave from the mainland, has consequently directed inhabitants to exploit mainly local coastal resources. Studies have shown that these two factors can impact the decrease in shell size (García-Escárzaga et al., 2022; Klein and Steele, 2013). The decrease of the shell size and significant increase in the Mesolithic sample perfectly fit in the period of Dugi otok becoming an island induced by sea level rise, where changes in the surface temperature of the Adriatic Sea were undoubtedly present. However, research showed that this small-sized gastropod is well-adjusted to environmental changes, i.e., temperature and pH alterations (Wahl et al., 2016), an occurrence common in the eastern Adriatic area (Milišić, 2007). The increasing prominence of fishing activities during the Early Mesolithic period is likely connected with an environmental change and rising sea levels, with Dugi otok becoming separated from the mainland already before ca. 10,194–8351 cal BC at 95% confidence (Z-3660: 9760 ± 280 BP) (Surić, 2006) and Vlakno cave becoming a coastal site. Dental calculus and stable isotope analyses (human burial, Stratum 2) showed that the inhabitants regularly consumed marine resources (Cristiani et al., 2018), and the same is recorded for early Holocene layers of the nearest site of Vela Spila (Rainsford et al., 2014). Likely, environmental changes directed the human population inhabiting Vlakno cave to the intensive exploitation of coastal resources, a behaviour that consequently impacted the *C. rustica* shell size.

Besides the intensive exploitation of coastal resources caused by changed geography, the reduction in the size of the Holocene shell can also point to modifications in collection strategies. The exact size difference of *C. rustica* from the Late Upper Palaeolithic and Mesolithic periods is recorded in Franchti cave (Perlès, 2016). Perlès' experimental activity (2016) revealed that the mode of collection (thanatocoenoses *vs*. underwater) could be a significant factor in size variation. *C. rustica* collected underwater, on average, was bigger. Compared to the one collected from the beach, the only recorded lack was the dull colour of the shell. The significant share of black shells, with the shell's integrity and significant height of the LUP *C. rustica*, can indicate that shells were collected alive from the sea during this period. It is rather challenging to prove if hunter-gatherers collected them in the shallow waters or on rocky shores since the only indicators are significant mean height and integrity of the shell with preserved apex, but it is something that should be considered. ~30% of the Mesolithic sample is characterised by sponge marks, pitting, and missing apex, indicating that shells were at least partially gathered on the nearby coast. Interestingly, more than 80% of Mesolithic black *C. rustica* have an intact apex. By all means, a two-mode gathering - thanatocoenoses and underwater - can explain characteristics present in the Vlakno Mesolithic sample. On the contrary, in the LUP sample, we found only two shells collected in thanatocenoses. Hence, we can consider that the beginning of the Holocene brought modifications in gathering modes in the Vlakno cave.

Regarding black *C. rustica* shells, our hypothesis on the deliberate burning, especially in Holocene layers, is supported by the following facts: (1) Among nine different taxa used for beads, changes in natural colour due to thermic alteration are limited exclusively to *C. rustica* and

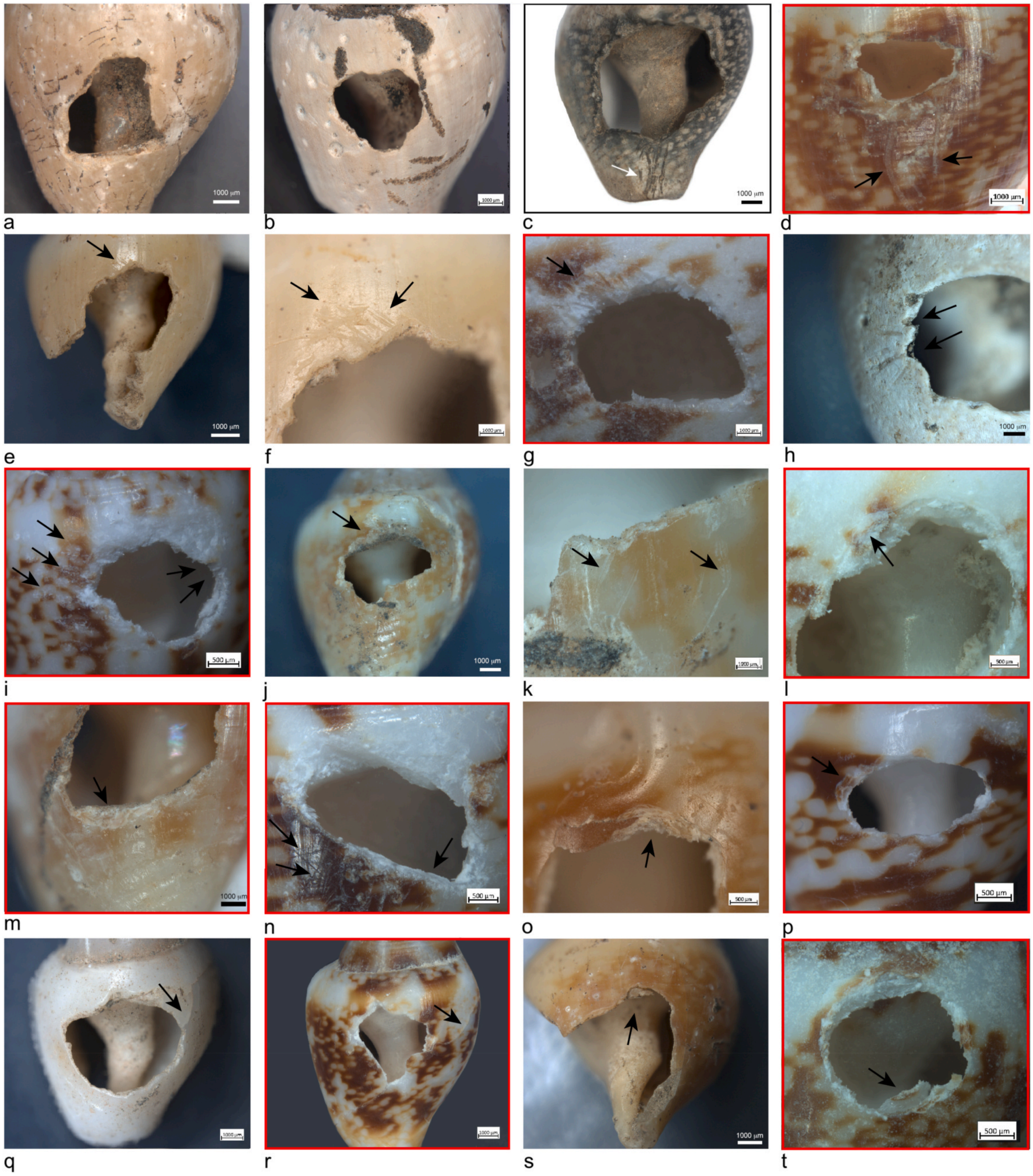


**Fig. 6.** Selection of LUP (a, b), Mesolithic (c, e, f, h, j, k, m, o, q, s) and experimental (d, g, I, n, p, r, t) *C. rustica* (framed in red) showing unused specimens, technological mistakes and technological traces. Unused - a, b, c, e, h, j, m, q, s; Flint striations - c, d, e, f, g, h, k, n; Compression mark – I, m, n, o; Flake of production – s, t; Fracture of the body whole – q, r; Technological mistakes and perforation flakes– e, s.

*Tritia neritea* taxa; (2) In comparison to the 20% of burnt *C. rustica*, the proportion of burning or heating traces on Mesolithic lithic artefacts is ~3,5% (Z. Perhoč and M. Bodružić; *pers. comm.* 2024); (3) The proportion of intact, used and unused perforated black *C. rustica* is nearly equal in the Mesolithic sample.

Combined analyses of *C. rustica* allowed us to elaborate on step-by-step activities related to the on-site production of ornaments, specifically (i) modes of the acquisition and selection, (ii) colour modification of the selected sample, (iii) perforation activity, and (iv) sorting of the outcome (Fig. 11). With the high percentage of likely deliberately burnt intact black *C. rustica* shells in the overall Mesolithic sample of intact shells (~28%), we can suggest that the change of natural colour in Vlakno cave preceded perforation activity. As for our experimental activity, perforation actions in Vlakno cave resulted in two possible outcomes: (1) successful perforation and (2) unsuccessful perforation, i.e., technological mistake. Moreover, one specimen from Vlakno cave exhibits an unfinished perforation, indicated by a small round hole of flint trace mark characterised by a counterblow mark on the dorsal side of the shell (Fig. 11, 3). Interestingly, the same case is recorded on one *C. rustica* from the Ifri Oudadane site in NW Morocco (Hutterer et al., 2021).

As illustrated in Fig. 10, our analysis revealed that following the perforation activity, beads were sorted as (1) perforated shells (intended for use (used ~60%; Figs. 5 and 7), or as a supply (unused ~40%; Fig. 6), and (2) discard, i.e., technological mistakes (~40%; Fig. 6).

On-site bead production in Vlakno cave is strongly indicated by (i) unused perforated LUP and Mesolithic *C. rustica* (~40%), (ii) unperforated black shells (~20%), and (iii) technological mistakes (~40%).

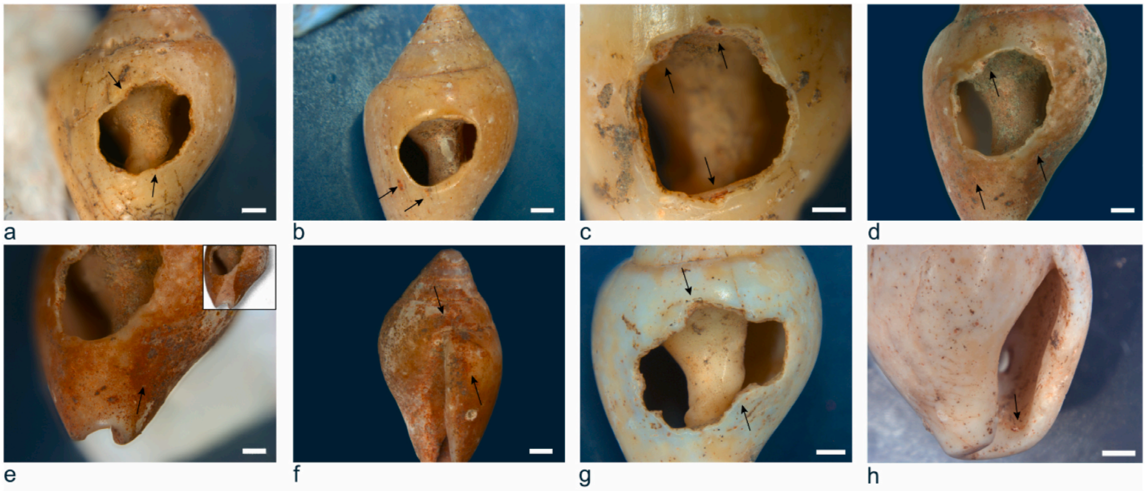


**Fig. 7.** Selection of *C. rustica* with ocher residues presented by sample number: a) 14.102; b) 24.7; c) 14.13; d-f) 14.101; g-h) 14.211. The insert in figure "e" marks the part of the shell surface where residues are less distributed.

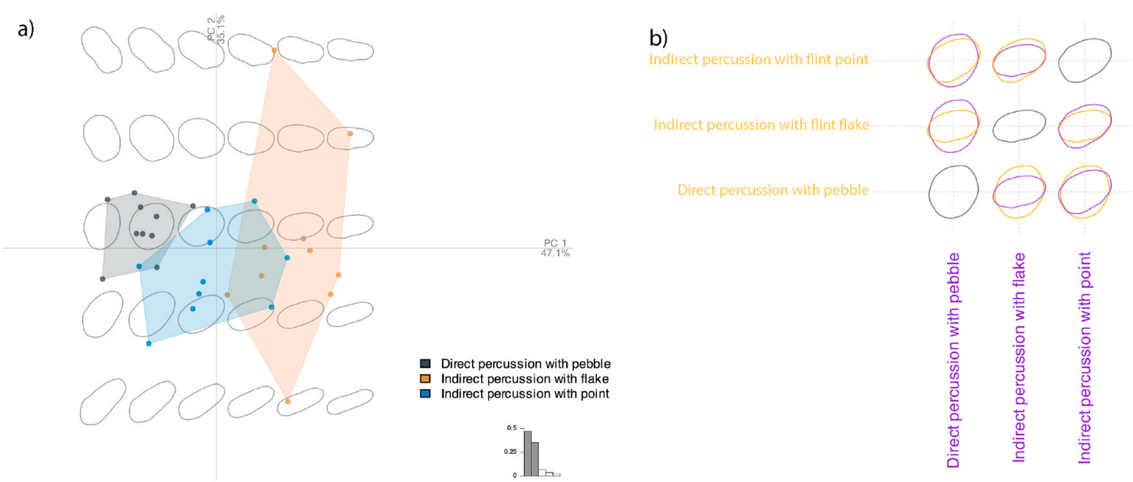


**Fig. 8.** Morphometric analysis of the experimental perforation. a) PCA of the experimental perforation holes; b) perforation shape comparison.

**Table 4**
Results of the MANOVA pairwise performed on PCA scores of experimental perforation holes. Significance codes:'***' = 0.001; '**' = 0.01; '*' = 0.05; '-' = 0.1

| MANOVA Pairwise – Perforation shape *vs.* Perforation technique | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Df** | **Pillai** | **approx F** | **num Df** | **den Df** | **Pr(>F)** | **Significance** |
| Direct percussion with pebble - Indirect percussion with flake edge | 1 | 0.9681009 | 27.313975 | 10 | 9 | 0.0000158 | *** |
| Direct percussion with pebble - Indirect percussion with point | 1 | 0.8338897 | 4.518087 | 10 | 9 | 0.0165126 | * |
| Indirect percussion with flake edge - Indirect percussion with point | 1 | 0.7467457 | 2.653741 | 10 | 9 | 0.0787874 | – |

Broken beads in archaeological contexts were generally not recognised as technological mistakes, while whole and broken specimens were not considered for the use-wear analysis. In the case of Vlakno cave, microscopic analyses of the complete *C. rustica* assemblage, regardless of the integrity state, have revealed important information related to the production activity and the selection process of the finished products. Broken shells with perforation holes could be considered accidently lost or damaged during use. Experimental activity suggested that in Vlakno's case, a significant portion of broken shells without use-wear were likely fractured during production and subsequently discarded as waste. Use-wear is present on only a few fractured specimens. All technologically broken and unused *C. rustica* in Vlakno cave exhibit standardised features, such as percussion flaking in the hole area, flint striations marks on the body whorl, and a missing part of the outer lip of the aperture (see Fig. 6). The last feature strengthens our hypothesis regarding technological mistakes, as this part is one of the thickest areas of *C. rustica* shells and is rarely missing due to post-depositional processes. This is in contrast to, for example, the apex (Bosch et al., 2023), which is missing in 20% of the Vlakno archaeological sample. Moreover, it should be mentioned that the breakage of the shell in gastropods can result from predator attacks, such as crustaceans, which are responsible for much of the apertural lip damage observed in modern systems (Walker and Brett, 2002). While a gastropod that survives an attack can repair its damaged shell, the process will leave visible scars as disruptions in the growth lines, surface ornament, or colour pattern of the shell (Stafford et al., 2015). We have ruled out the possibility of a crustacean attack as the cause of the breakage of *C. rustica* in Vlakno cave due to the presence of technological traces. However, crustacean attack as a cause of breakage

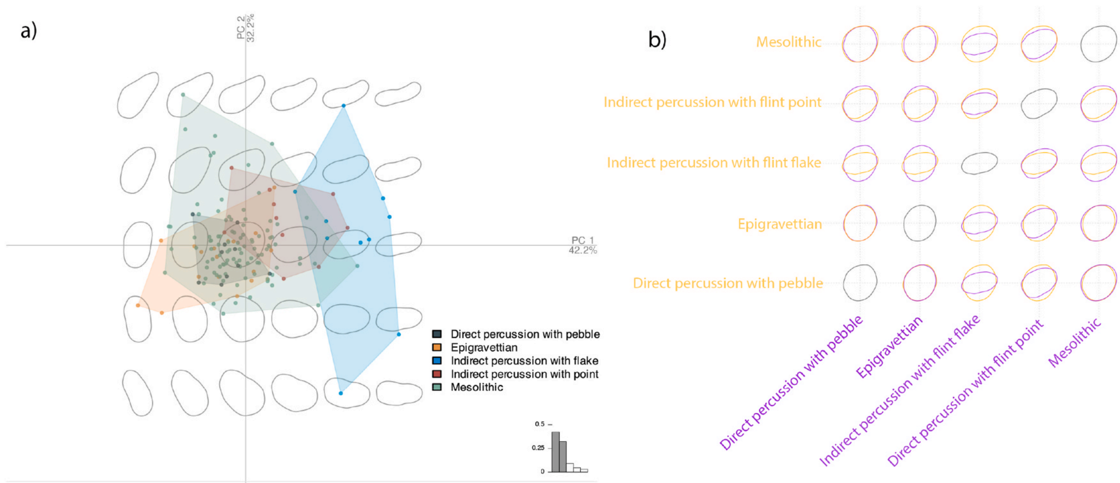


**Fig. 9.** Morphometric analysis of the archaeological and experimental perforation holes. a) PCA combining both archaeological and experimental specimens; b) shape comparison between archaeological and experimental perforation holes.

**Table 5**
Results of the MANOVA pairwise performed on PCA scores of experimental and archaeological perforation holes. Significance codes:'***' = 0.001; '**' = 0.01; '*' = 0.05; '-' = 0.1

| MANOVA Pairwise of Archaeological Perforation *vs.* Experimental Perforation | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Df** | **Pillai** | **approx F** | **num Df** | **den Df** | **Pr(>F)** | **Significance** |
| Late Upper Palaeolithic - Mesolithic | 1 | 0.0838367 | 0.9791407 | 10 | 107 | 0.4659763 | – |
| Late Upper Palaeolithic - Direct percussion with pebble | 1 | 0.1889574 | 0.3960673 | 10 | 17 | 0.9305411 | – |
| Late Upper Palaeolithic - Indirect percussion with flake | 1 | 0.8261988 | 8.0812895 | 10 | 17 | 0.0001057 | *** |
| Late Upper Palaeolithic - Indirect percussion with point | 1 | 0.6402423 | 3.0254024 | 10 | 17 | 0.0216002 | * |
| Mesolithic - Direct percussion with pebble | 1 | 0.1040516 | 1.1497436 | 10 | 99 | 0.3339882 | – |
| Mesolithic - Indirect percussion with flake | 1 | 0.5726424 | 13.2656139 | 10 | 99 | <0.001 | *** |
| Mesolithic - Indirect percussion with point | 1 | 0.2774711 | 3.8018733 | 10 | 99 | 0.0002308 | *** |

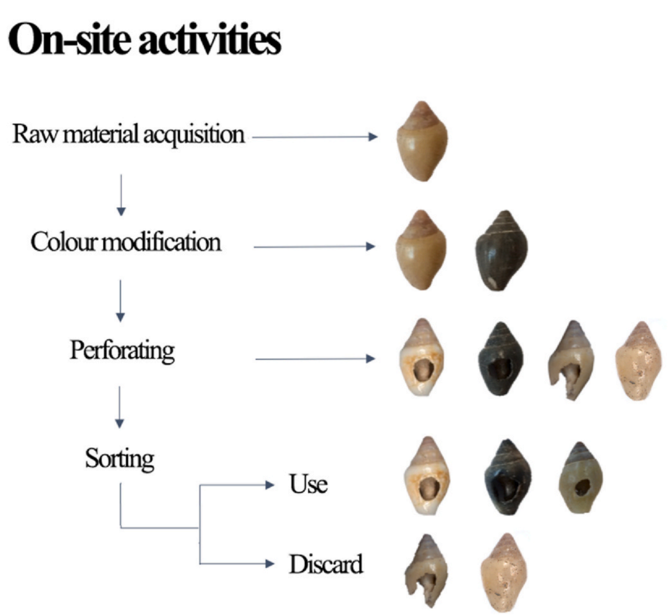


**Fig. 10.** Illustration of the step-by-step on-site activities related to the production of *C. rustica* beads.

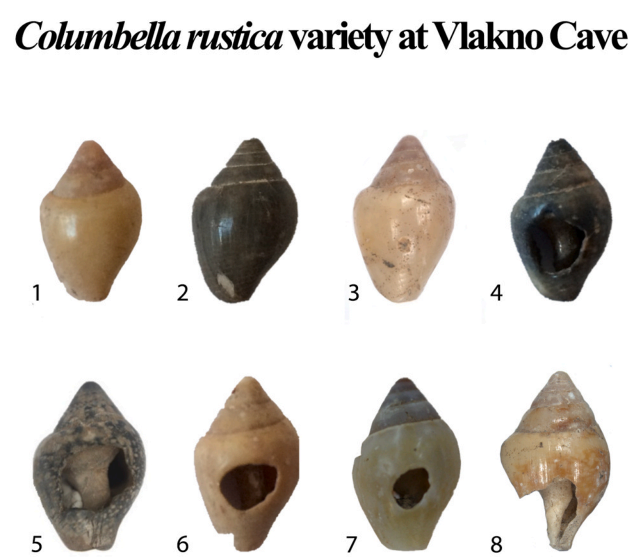


**Fig. 11.** On-site bead production in Vlakno cave is strongly indicated by: 1. Intact shells with natural colour; 2. Intact shells with changed color; 3. Shell with the mark of perforation punch; 4. Used black shells; 5. Unused black shells; 6. Used with natural color; 7. Unused with natural color; 8. Technological mistakes.

cannot be ruled out for the specimens without technological marks based solely on fracture patterns. Additionally, shells could have been accidently brought to the cave already naturally broken as a part of gathering activities (e.g., Bosch et al., 2023; Perlès, 2016), or broken in the cave, for example, by trampling.

Regarding perforation techniques, they were simple and consistent during both periods, most likely involving direct percussion with a pebble. In general, the perforation of prehistoric beads involved simple techniques (e.g. Cristiani et al., 2014; Perlès and Vanhaeren, 2010;

Vanhaeren and d'Errico, 2001; White, 2007), although few complex and time-consuming processes have been detected in Palaeolithic assemblage (Heckle, 2018; Wei et al., 2017; White, 1989). Standardisation in Vlakno cave is evident in both production technology and the preference for raw material in favour of *C. rustica* shells during the Mesolithic. The small size and durability of the *C. rustica* shell support the redundancy, which is essential for successfully transmitting messages/information ((Kuhn and Stiner, 2007). Hence, standardisation and redundancy as fundamental features of the communication system further support the role of Vlakno cave as a relevant *taskscape* (Ingold, 1993), i.e., a specialised workshop for producing and distributing ornaments in the Eastern Adriatic region, and likely further. The presence of *C. rustica* beads at the contemporaneous sites in the region (Fig. 1, sites 2–4, 7–10) supports the notion of the shared symbolic vocabulary and aesthetic standards of the foragers' groups inhabiting the Eastern Adriatic region (Cvitkušić and Vujević, 2021; Cristiani et al., 2014; Cvitkušić, 2017; Komšo and Vukosavljević, 2011). Conducted studies on the ornaments from this area revealed no evidence of bead production (Cvitkušić, 2017; Cvitkušić and Komšo, 2015; Komšo and Vukosavljević, 2011), except for the Vela Spila site (Cristiani et al., 2014). In general, ornaments are found in low numbers, with anthropogenic modifications suggesting they were most likely introduced, already used, and accidently lost at those sites. A slightly different situation is recorded in the Holocene levels of the Vela spila site, with the ornament assemblage comprised exclusively of *C. rustica* characterised by mainly used beads and with a small share of unused beads together with ~13% unperforated specimens, pointing to on-site production (Cristiani et al., 2014). Compared to Vela Spila, the Holocene ornamental assemblage from Vlakno cave is more diverse concerning the type of raw materials and the state of the beads' integrity, with *C. rustica* as the dominant bead type. Furthermore, the selection and use of *C. rustica* shells in Vlakno cave more straightforwardly reflect modes of collection strategies and reveal stages of production activity to the specific details (Fig. 11). Accordingly, the Vlakno cave, with its central position in the Eastern Adriatic region, seems to have represented a central point for the acquisition, production, and distribution of the ornaments in the region. Extensive spatial distribution of *C. rustica* from the Italian peninsula along the Adriatic area to the south in Montenegro and Greece (e.g., Borić et al., 2023; Álvarez Fernández, 2008; Mussi, 2002; Taborin, 1993; Cvitkušić, 2017; Cristiani et al., 2014; Cristiani and Borić, 2017; Perlès, 2018), suggest the existence of wide-ranging networks and communication paths in this northern corner of Mediterranean. Shell ornaments are suitable for tracking our ancestors' symbolic behaviour and ideas (e.g. Cucart Mora et al., 2022; Rigaud et al., 2022), and several studies have shown the potential of isotope analysis of shells for tracing the movements (Colonese et al., 2009; Milano et al., 2022). In future, this approach could contribute to a more profound understanding of the role of the Vlakno cave in the settlement patterns and mobility of prehistoric populations in this region.

## 7. Conclusion

This paper has complemented our knowledge related to the symbolic behaviour of our ancestors, how ornaments influenced movements, and how they contributed to the creation of 'the pattern of dwelling activities' (Ingold, 1993: 153) and opened new directions for studying ornaments. Since the Middle Palaeolithic, shells have been intentionally collected and used as ornaments. Our results confirmed that the Vlakno cave was no exception, with continuity of purposeful shell gathering during the Late Upper Palaeolithic and Mesolithic and solid arguments that it was used as a specialised workshop for ornaments where on-site production was taking place. Furthermore, *C. rustica* from Vlakno cave allowed us to perceive ornaments in a different light and better understand our ancestors' symbolic behaviour and mobility patterns related to the collection of raw materials and *chaîne opératoire* that can be applied to the ornaments. Standardisation of production technology and a significant share of used and unused standardised beads of *C. rustica* shells indicate that bead production in Vlakno cave was for personal use and the exchange and distribution systems in the broader region. During the environmental Pleistocene - Holocene and techno-cultural Palaeolithic-Mesolithic transitions, the Vlakno cave kept a significant role in the Eastern Adriatic and most likely operated as one of the leading *taskscape* locations for maintaining regional exchange and communication networks. Overall, identification of the raw material preferences, technological choices, modes of use, and ornamental production standardisations allowed us to understand better the symbolic behaviour of prehistoric hunter-gatherers hidden behind the scattered beads throughout the Vlakno deposits. Finally, the Vlakno cave, as a significant location for activities related to ornaments, broadens our knowledge of how symbolic motives influenced the settlement model of Late Upper Palaeolithic and Mesolithic foragers of the Eastern Adriatic area.

## CRediT authorship contribution statement

**Barbara Cvitkušić:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Emanuela Cristiani:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Andrea Zupancich:** Investigation, Formal analysis, Data curation, Methodology, Writing – original draft, Writing – review & editing. **Dario Vujević:** Data curation, Funding acquisition, Investigation, Writing – review & editing.

## Declaration of competing interest

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

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## References

Alarashi, H., Benz, M., Gresky, J., Burkhardt, A., Fischer, A., Gourichon, L., et al., 2023. Threads of memory: reviving the ornament of a dead child at the Neolithic village of Ba'ja (Jordan). PLoS One 18 (8), e0288075. https://doi.org/10.1371/journal.pone.0288075.

Álvarez Fernández, E., 2003. Die Reise der Schnecke Columbella rustica während des Mesolithikums und zu Beginn des Neolithikums in Europa. Archäeologisches Korrespondenzblatt 33 (2), 157–166.

Álvarez Fernández, E., 2006. Historia de las investigaciones sobre los objetos de adornocolgantes en el territorio europeo durante el Paleolítico Superior y el Mesolítico (con especial referencia a la cornisa cantábrica y al valle del Ebro). Sautuola XII, 89–116.

Álvarez Fernández, E., 2008. The use of Columbella rustica (clase: gastropoda) in the iberian peninsula and Europe during the mesolithic and early neolithic. In: Hernández Pérez, M., Soler García, J.A., López Padilla, J.A. (Eds.), V Congreso del Neolítico Peninsular (Alicante, 27–30 noviembre 2006), Museo Arqueológico de Alicante, Diputación Provincial de Alicante, Alicante, pp. 103–111.

Álvarez Fernández, E., 2010. Shell beads of the last hunter-gatherers and earliest farmers in south-western Europe. Munibe - Antropol.-Arkeol. 61, 129–138.

Álvarez Fernández, E., Jöris, O., 2007. Personal ornaments in the early upper palaeolithic of western eurasia. An evaluation of the record. Eurasian Prehistory 5 (2), 29–42.
Baysal, L.E., Yelözer, S., 2023. Searching for the individual: characterising knowledge transfer and skill in prehistoric personal ornament making. J. Archaeol. Method Theor 30, 172–202. https://doi.org/10.1007/s10816-022-09589-z.
Bar-Yosef Mayer, D.E., 2005. The exploitation of shells as beads in the Paleolithic and Neolithic of the Levant. Paleorient 31 (1), 176–185.
Bar-Yosef Mayer, D.E., 2015. Nassarius shells: preferred beads of the Palaeolithic. Quat. Int. 390 (12), 79–84.
Bednarik, R.G., 2008. Beads and cognitive evolution. Time Mind: The Journal of Archaeology, Consciousness and Culture I (III), 285–318. https://doi.org/10.2752/175169708X329354.
Benghiat, S., Komšo, D., Miracle, P.T., 2009. An experimental analysis of perforated shells from the site of Sebrn Abri (Istria), Croatia. In: McCartan, S.B., Schulting, R., Warren, G., Woodman, P. (Eds.), Mesolithic Horizons,Volume II. Oxbow Books, Oxford and Oakville, pp. 730–736.
Bonhomme, V., Picq, S., Gaucherel, C., Claude, J., 2014. Momocs: outline analysis using R. J. Stat. Softw. 56 (13), 1–24. https://doi.org/10.18637/jss.v056.i13.
Borić, D., Cristiani, E., 2019. Taking beads seriously: prehistoric forager ornamental traditions in southeastern Europe. PaleoAnthropology 208–239.
Borić, D., Cristiani, E., Pravidur, A., Marić, A., Whallon, R., 2023. Osseous tools and personal ornaments from the Epigravettian sequence at Badanj. GLASNIK Zemaljskog muzeja Bosne i Hercegovine u Sarajevu 55, 7–72.
Bosch, M.D., Buck, L.T., Strauss, A., 2023. Perforations in Columbellidae shells: using 3D models to differentiate anthropogenic piercing from natural perforations. J. Archaeol. Sci.: Report 49. https://doi.org/10.1016/j.jasrep.2023.103937.
Boschian, G., 2003. Environment and hunters-gatherers mobility in the northern adriatic region. Preistoria Alp. 39, 91–102.
Bourdieu, P., 1977. Outline of a Theory of Practice (Trans. R. Nice). Cambridge University Press, Cambridge.
Brusić, Z., 2005. R. br. 98 – pećina Vlakno. Hrvatski arheološki godišnjak 1/2004, 197–199.
Claassen, C., 1998. Shells. Cambridge University Press, Cambridge.
Colonese, A.C., Troelstra, S., Ziveri, P., et al., 2009. Mesolithic shellfish exploitation in SW Italy: seasonal evidence from the oxygen isotopic composition of Osilinus turbinatus shells. J. Archaeol. Sci. 36, 1935–1944.
Cristiani, E., 2012. Ornamental traditions of the late Pleistocene and early holocene foragers in the eastern alps: the case of riparo biarzo. Gortania 34, 89–102.
Cristiani, E., Borić, D., 2017. Personal adornment and personhood among the last mesolithic foragers of the danube gorges in the central balkans and beyond. In: Bar-Yosef Mayer, D.E., Bonsall, C., Choyke, A.M. (Eds.), Not Just for Show. The Archaeology of Beads, Beadwork and Personal Ornaments. Oxbow Books, pp. 39–68.
Cristiani, E., Farbstein, R., Miracle, P., 2014. Ornamental traditions in the eastern adriatic: the upper palaeolithic and mesolithic personal adornments from Vela spila (Croatia). J. Anthropol. Archaeol. 36, 21–31. https://doi.org/10.1016/j.jaa.2014.06.009.
Cristiani, E., Radini, A., Borić, D., Robson, H.K., Caricola, I., et al., 2018. Dental calculus and isotopes provide direct evidence of fish and plant consumption in Mesolithic Mediterranean. Sci. Rep. 8, 8147. https://doi.org/10.1038/s41598-018-26045-9.
Cristiani, E., Zupancich, A., Cvitkušić, B., 2020. Combining microscopic analysis and GIS to analyse experimental perforations on Columbella rustica shells. In: Mărgărit, M., Boroneanț, A. (Eds.), Beauty and the Eye of the Beholder: Personal Adornments across the Millennia. Editura Cetatea de Scaun, pp. 27–40.
Crothers, G., 2004. The foraging mode of production: the case for the Green River Kentucky, archaic shell middens. In: Crothers, G. (Ed.), Hunters and Gatherers in Theory and Archaeology. Center for Archaeological Investigations Occasional Paper, vol. 31. Southern Illinois University, Carbondale, pp. 401–422.
Cucart Mora, C., Gómez-Puche, M., Romano, V., de Pablo, J.F.-L., Lozano, S., 2022. Reconstructing Mesolithic social networks on the Iberian Peninsula using ornaments. Archaeological and Anthropological Sciences 14, 174. https://doi.org/10.1007/s12520-022-01641-z.
Cvitkušić, B., 2015. Osobni Ornamenti Kao Sredstvo Komunikacije U Gornjem Paleolitiku I Mezolitiku Na Istočnom Jadranu/Personal Ornaments as Means of Communication during Upper Paleolithic and Mesolithic on the Eastern Adriatic. University of Zagreb, Zagreb (unpublished PhD).
Cvitkušić, B., 2017. Upper palaeolithic and mesolithic ornamental traditions in the eastern adriatic coast and hinterland. Collegium Anthropologicum 41 (1), 1–16.
Cvitkušić, B., Komšo, D., 2015. Display modes of personal ornaments in the Upper Palaeolithic sites of Istria, Croatia. Coll. Antropol. 39 (2), 481–488.
Cvitkušić, B., Vujević, D., 2021. Role of personal ornaments: Vlakno cave, Croatia. In: Borić, Dušan, Antonović, Dragana, Mihailović, Bojana (Eds.), Foraging Assemblages, vol. 2, pp. 531–537.
Cvitkušić, B., Radović, S., Vujević, D., 2018. Changes in ornamental traditions and subsistence strategies during the Palaeolithic- Mesolithic transition in Vlakno cave. Quat. Int. 494, 180–192. https://doi.org/10.1016/j.quaint.2017.08.053.
d'Errico, F., Henshilwood, C., Vanhaeren, M., van Niekerk, K., 2005. Nassarius kraussianus shell beads from blombos cave: evidence for symbolic behaviour in the Middle stone age. J. Hum. Evol. 48, 3–24.
Deino, A.L., Orsi, G., de Vita, S., Piochi, M., 2004. The age of the Neapolitan Yellow Tuff caldera-forming eruption (Campi Flegrei caldera – Italy) assessed by 40Ar/39Ar dating method. J. Volcanol. Geoth. Res. 133 (1–4), 157–170.
Driscoll, E.G., Weltin, T.P., 1973. Sedimentary parameters as factors in abrasive shell reduction. Palaeogeogr. Palaeoclimatol. Palaeoecol. 13, 275–288.
Dubin, L.S., 1999. North American Indian Jewelry and Adornment: from Prehistory to the Present. Harry N. Abrams, New York.
Eriksen, B.V., 2002. Fossil Mollusks and exotic Raw Materials in Late glacial and early Postglacial find contexts: a Complement to lithic studies. In: Fisher, L.E., Eriksen, B. V. (Eds.), Lithic Raw Material Economies in Late Glacial and Early Postglacial Europe, BAR International Series, vol. 1093. Archaeopress, Oxford, pp. 27–52.
García-Escárzaga, A., Gutiérrez-Zugasti, I., Marín-Arroyo, A.B., Fernandes, R., Núñez de la Fuente, S., Cuenca-Solana, D., Iriarte, E., et al., 2022. Human forager response to abrupt climate change at 8.2 ka on the Atlantic coast of Europe. Scientifc Reports 12, 6481. https://doi.org/10.1038/s41598-022-10135-w.
Gravel Miguel, C., Cristiani, E., Hodgkins, J., Orr, C.M., Strait, D.S., Peresani, M., et al., 2022. The ornaments of the arma veirana early mesolithic infant burial. J. Archaeol. Method Theor. https://doi.org/10.1007/s10816-022-09573-7.
Hutterer, R., Schröder, O., Linstädter, J., 2021. Food and ornament: use of shellfish at Ifri Oudadane, a holocene settlement in NE Morocco. Afr. Archaeol. Rev. 38, 73–94.
Heckle, C.E., 2018. Reconsidering production organisation in the Early Upper Palaeolithic: the case for specialised production of Aurignacian beads. Quat. Int. 491, 11–20.
Ingold, T., 1993. The temporality of the landscape. World Archaeol. 25, 152–174.
Karali, L., 1999. Shells in aegean prehistory. In: BAR International Series, vol. 761. Archaeopress, Oxford.
Klein, R.G., Steele, T.E., 2013. Archaeological shellfish size and later human evolution in Africa. Proc. Natl. Acad. Sci. USA 110, 10910–10915. https://doi.org/10.1073/pnas.1304750110.
Komšo, D., 2007. Nakit na području Istre od paleolitika do neolitika. In: BLEČIĆ, M., ČREŠNAR, M., HÄNSEL, B., HELLMUTH, A., KAISER, E., METZNER-NEBELSICK, C. (Eds.), Scripta Praehistorica in Honorem Biba Teržan, Situla 44, Ljubljana, Narodni Muzej Slovenije.
Komšo, D., Vukosavljević, N., 2011. Connecting coast and inland: perforated marine and freshwater snail shells in the Croatian Mesolithic. Quat. Int. 244 (1), 117–125.
Kuhn, S.L., Stiner, M.C., Reese, D.S., Güleç, E., 2001. Ornaments of the earliest upper paleolithic: new insights from the levant. Proceedings of the National Academy of Sciences USA 98 (13), 7641–7646.
Kuhn, S.L., Stiner, M.C., 2007. Body ornamentation as information technology: towards an understanding of the significance of early beads. In: Mellars, P., Boyle, K., Bar-Yosef, O., Stringer, C. (Eds.), Rethinking the Human Revolution: New Behavioural and Biological and Perspectives on the Origins and Dispersal of Modern Humans. MacDonald Institue of Archaeology, pp. 45–54.
Mărgărit, M., 2016. Testing the endurance of prehistoric adornments: raw materials from the aquatic environment. J. Archaeol. Sci. 70, 66–81.
Mărgărit, M., Radu, V., Boroneanț, A., Bonsall, C., 2018. Experimental studies of personal ornaments from the iron gates mesolithic. Archaeological and Anthropological Sciences 10, 2095–2122.
Milano, S., Schöne, B.R., González-Morales, M.R., et al., 2022. Temporal and spatial variability of prehistoric aquatic resource procurement: a case study from Mesolithic Northern Iberia. Sci. Rep. 12, 3111. https://doi.org/10.1038/s41598-022-07239-8.
Milišić, N., 2007. Glavonošci, Puževi I Školjke Jadrana. Split, Marjan tisak.
Miracle, P.T., 1995. Broad Spectrum Adaptations Re-examinated: Hunter Gatherers Responses to Late Glacial Enviromental Changes in Eastern Adriatic. Mitchigan (unpublished PhD).
Miracle, P.T., 2007. The late glacial 'Great Adriatic plain': 'garden of eden' or 'No Man's land' during the Epipalaeolithic? A view from Istria (Croatia). In: Whallon, R. (Ed.), Late Paleolithic Environments and Cultural Relations Adriatic, British Archaeological Reports Int.Ser., vol. 1716. Archaeopress, Oxford, pp. 41–51.
Mussi, M., 2002. Earliest Italy. An Overview of the Italian Paleolithic and Mesolithic. Kluwer Academic/Plenum Publishers.
Orschiedt, J., 2016. Bodies, bits, and pieces II: the late palaeolithic and early mesolithic burial practices in Europe. In: Gramsch, B., Larsson, L., Orschiedt, J., Meller, H. (Eds.), Mesolithic Burials—Rites, Symbols and Social Organisation of Early Postglacial Communities. Tagunden des Landesmuseums für Vorgeschichte Halle, pp. 809–826.
Perlès, C., 2018. Ornaments and Other Ambiguous Artifacts from Franchthi. Indiana University Press.
Perlès, C., 2016. Modern reference collections of Columbella rustica from Greece. The Arkeotek Journal 1, 2016. www.thearkeotekjournal.org.
Perlès, C., Vanhaeren, M., 2010. Black cyclope neritea marine shell ornaments in the upper palaeolithic and mesolithic of franchthi cave, Greece: arguments for intentional heat treatment. J. Field Archaeol. 35 (3), 298–309. https://doi.org/10.1179/009346910X12707321358874.
Peresani, M., Monegato, G., Ravazzi, C., Bertola, S., Margaritora, D., et al., 2021. Hunter-gatherers across the great adriatic-Po region during the last glacial maximum: environmental and cultural dynamics. Quat. Int. 581–582, 128–163.
Pilaar Birch, S.E., Miracle, P.T., 2017. Human response to climate change in the Northern Adriatic during the late Pleistocene and early Holocene. In: Monks, G. (Ed.), Climate Change and Past Human Responses: an Archaeozoological Perspective. Vertebrate Paleobiology and Paleoanthropology Series. Springer, New York, pp. 87–100.
Poppe, G.T., Goto, Y., 1991. European Seashells, Volume 1 Polyplacophora, Caudofoveata, Solenogastra, Gastropoda. Verlag Christa Hemmen.
Radić, D., Lugović, B., Marjanac, L.J., 2008. Napuljski žuti tuf (NYT) iz pleistocenskih naslaga u Veloj spili na Korčuli: dragocjeni marker prijelaza iz paleolitika u mezolitik. Opusc. Archaeol. 31, 7–26.
Radović, S., Spry-Marqués, P., Vujević, D., 2021. A tale of foxes and deer or how people changed their eating habitats during the Mesolithic al Vlakno cave (Croatia). In: Borić, D., Antonović, D., Mihailović, B. (Eds.), Foraging Assemblages: Papers Presented at the Ninth International Conference on the Mesolithic in Europe, Volume 2, Srpsko Arheološko Društvo ; the Italian Academy for Advanced Studies in America. Columbia University, pp. 374–381, 2021.

Radovčić, D., Sršen, A.O., Radovčić, J., Frayer, D., 2015. Evidence for neandertal jewelry: modified white-tailed eagle claws at Krapina. PLoS One 10 (3), e0119802. https://doi.org/10.1371/journal.pone.0119802.
Rainsford, C., O'Connor, T., Miracle, P., 2014. Fishing in the adriatic at the mesolithic–neolithic transition: evidence from Vela spila, Croatia. Environ. Archaeol. 19 (3), 311–320. https://doi.org/10.1179/1749631414Y.0000000018.
Rigaud, S., 2011. In: La parure: traceur de la géographie culturelle et des dynamiques de peuplement au passage Mésolithique– Néolithique en Europe. University of Bordeaux. Unpublished PhD dissertation. http://tel.archives-ouvertes.fr/tel-00668694.
Rigaud, S., Costamagno, S., Pétillon, J.-M., Chalard, P., Laroulandie, V., et al., 2019. Settlement dynamic and beadwork: new insights on the Late Upper Paleolithic craft activities. PaleoAnthropology 2019, 137–155. https://doi.org/10.4207/PA.2019.ART128.
Rigaud, S., O'Hara, J., Charles, L., Man-Estier, E., Paillet, P., 2022. The management of symbolic raw materials in the Late Upper Paleolithic of South-Western France: a shell ornaments perspective. SocArXiv. https://doi.org/10.31235/osf.io/z7pqg z7pqg, ver. 4 peer-reviewed and recommended by Peer community in Archaeology.
Rodríguez-Hidalgo, A.J., Canals, A., Saladié, P., García, A.B., García, M., 2010. Upper Paleolithic ornament seashells from Sala de las Chimeneas, Maltravieso cave (Cáceres, Spain). Munibe Suplimento 31, 36–46.
Russini, V., Fassio, G., Modica, M.V., deMaintenon, M.J., Oliverio, M., 2017. An assessment of the genus Columbella lamarck, 1799 (gastropoda: columbellidae) from eastern atlantic. Zoosystema 39 (2), 197–212.
Sehasseh, E.M., Fernandez, P., Kuhn, S., Stiner, M., Mentzer, S., Colarossi, D., et al., 2021. Early Middle stone age personal ornaments from Bizmoune cave, essaouira, Morocco. Sci. Adv. 7 (39), eabi8620, 7.
Sikora, M., Mihanović, H., Vilibić, I., 2014. Paleo-coastline of the central eastern Adriatic Sea, and paleo-channels of the cetina and neretva rivers during the last glacial maximum. Acta Adriat. 55 (1), 3–18.
Stafford, E.S., Dietl, G.P., Gingras, M.P., Leighton, L.R., 2015. Caedichnus, a new ichnogenus representing predatory attack on the gastropod shell aperture. Ichnos 22 (2), 87–102. https://doi.org/10.1080/10420940.2015.1031899.
Stiner, M.C., 1999. Palaeolithic mollusk exploitation at riparo mochi (balzi rossi, italiy): food and ornaments from the aurignacien through epigravettian. Antiquity 73 (282), 735–754.
Stiner, M.C., 2014. Finding a common bandwidth: causes of convergence and diversity in Paleolithic beads. Biological Theory 9, 51–64.
Surić, M., 2006. Promjene U Okolišu Tijekom Mlađeg Pleistocena I Holocena – Zapisi Iz Morem Potopljenih Siga Istočnog Jadrana. Prirodoslovno-matematički fakultet. Zagreb (unpublished PhD).
Syrides, G., 2019. Marine and terrestrial molluscs in the sanctuary. The molluscan remains from the 2003–2004 excavations in the Sanctuary of Poseidon at Kalaureia. Opuscula. Annual of the Swedish Institutes at Athens and Rome. (OpAthRom) 12, 241–254. https://doi.org/10.30549/opathrom-12-07.
Taborin, Y., 1993. La parure en coquillage au Paléolithique. CNRS Éditions.
Taborin, Y., 2004. Langage sans parole : la parure aux temps préhistoriques. La maison des roches, Paris.
Vanhaeren, M., d'Errico, F., 2001. La Parure de l'enfant de la Madeleine (Fouilles Peyrony). Un nouveau regard sur l'enfance au Paléolithique supérieur. Paléo 13, 201–240.
Vanhaeren, M., d'Errico, F., 2006. Aurignacian ethno-linguistic geography of Europe revealed by personal ornaments. J. Archaeol. Sci. 33, 1105–1128.
Vanhaeren, M., d'Errico, F., 2011. L'émergence du corps paré. Civilisations 59–2, 59–86. https://doi.org/10.4000/civilisations.2589.
Vujević, D., 2011. R. br. 254 - Špilja Vlakno. Hrvatski arheološki godišnjak 8/2011, 551–553.
Vujević, D., 2016. Adriatic connections: exploring relationships from the Middle palaeolithic to the mesolithic. In: Davison, D., Gaffney, V., Miracle, P., Sofaer, J. (Eds.), Croatia at the Crossroads: A Consideration of Archaeological and Historical Connectivity, vol. 2016. Archaeopress Archaeology, pp. 19–32.
Vujević, D., 2021. Pećina Vlakno na dugom otoku. In: Janković, I., Drnić, I., Paar, D. (Eds.), Arheologija I Speleologija: Iz Tame Podzemlja Do Svjetla, Arheološki Muzej U Zagrebu, pp. 35–45. Zagreb.
Vujević, D., Bodružić, M., 2014. Mezolitičke zajednice špilje Vlakno. Diadora 26/27 (2013/2014), 9–30. Zadar.
Vujević, D., Bodružić, M., 2021. Transition and tradition: lithic variability in the cave of Vlakno. In: Borić, D., Antonović, D., Mihailović, B. (Eds.), Foraging Assemblages: Papers Presented at the Ninth International Conference on the Mesolithic in Europe, Volume 1, Srpsko Arheološko Društvo ; the Italian Academy for Advanced Studies in America, vol. 2021. Columbia University, pp. 5–11.
Vujević, D., Parica, M., 2011. Nakit i umjetnost pećine Vlakno, archeologia adriatica (2009), Zadar, 3 (1), 23–34.
Vukosavljević, N., Perhoč, Z., Altherr, R., 2014. Pleistocene-holocene transition in the Vlakno cave on the island of Dugi otok (Dalmatia, Croatia): lithic perspective. Pril. Instituta za Arheol. u Zagrebu 31, 5–72.
Wahl, M., Saderne, V., Sawall, Y., 2016. How good are we at assessing the impact of ocean acidification in coastal systems? Limitations, omissions and strengths of commonly used experimental approaches with special emphasis on the neglected role of fluctuations. Mar. Freshw. Res. 67, 25–36.
Werker, E., 1988. Nahal Hemar Cave – botanical identification of worked wood remains. Atiqot 18, 73–75.
White, R., 1989. Production complexity and standardisation in early aurignacian bead and pendant manufacture: evolutionary implications. In: Mellars, P., Stringer, C. (Eds.), The Human Revolution: Behavioral and Biological Perspectives on the Origins of Modern Humans. Princeton University Press, Princeton, pp. 366–390.
White, R., 1992. Beyond art: toward an understanding of the origins of material representation in Europe. Annu. Rev. Anthropol. 21, 537.
White, R., 1999. Intégrer la complexité sociale et opérationnelle: la construction matérielle de l'identité sociale à Sungir. In: Préhistoire d'os (recueil d'études sur l'industrie osseuse préhistorique offert à Henriette Camps-Fabrer). Publications de l'Université de Provence, Aix-en-Provence, pp. 319–331.
White, R., 2007. Systems of personal ornamentation in the early upper palaeolithic: methodological challenges and new observations. In: Mellars, P., Stringer, C. (Eds.), Rethinking the Human Revolution: New Behavioural & Biological Perspectives on the Origins and Dispersal of Modern Humans. McDonald Institute for Archaeological Research, Cambridge, UK, pp. 1–30.
Wei, Y., d'Errico, F., Vanhaeren, M., et al., 2017. A technological and morphological study of Late Paleolithic ostrich eggshell beads from Shuidonggou, North China. J. Archaeol. Sci. 85, 83–104.
Wiessner, P., 1982. Risk, reciprocity and social influences on! Kung San economics. In: Leacock, E., Lee, R. (Eds.), Politics and History in (Vol. Societies. Cambridge University Press, pp. 61–84.