Archaeological and Anthropological Sciences (2025) 17:31
https://doi.org/10.1007/s12520-024-02122-1

RESEARCH

Manufacturing and decorating cardial pottery: shell tools at the Neolithic site of Cabecicos Negros (Vera, Almeria, Spain)

Elena Lastra-Alonso[1] · David Cuenca-Solana[2,3] · Asier García-Escárzaga[4,5] · Javier Rodríguez-Santos[6] · Xavier Clop-García[7] · María Dolores Camalich-Massieu[8] · Dimas Martín-Socas[8]

Received: 13 November 2023 / Accepted: 18 November 2024 / Published online: 14 January 2025

Abstract
Traditional research approaches on pottery production based on typological and morphometric classifications have changed in favour of new lines of research. One of them is based on the study of the technological equipment used in ceramic manufacturing processes. For example, ethnographic evidence shows the use of shell tools as technological equipment in different phases of ceramic production. In this study, the methodology of use-wear analysis has been applied to the archaeomalacological material from the Neolithic site of Cabecicos Negros (Andalusia, Spain) to establish if the shells were used as work tools. This analysis has been completed with the development of an experimental program composed of two analytical and one prospective experiments, carried out to provide new data about the cardial decorative technique and to define the use-wear traces that appear on the active area of the shells after their technological use. The results obtained in this investigation show the use of shells in different stages of pottery production. On the one hand, during the modelling and regularization phase of the ceramic surface and, on the other hand, during the cardial decorative phase. In this way, through this work, it has been possible to establish that the archaeological site of Cabecicos Negros was a pottery production center where domestic pieces were made during its Neolithic occupation. In addition, these findings reaffirm the importance of shells in ceramic manufacture during the Neolithic period, mainly in terms of the technical process linked to the cardial-type of ceramic decoration.

Keywords Use-wear analysis · Pottery production · Cardial decoration · Neolithic · Andalusia

✉ Elena Lastra-Alonso
lastraelena@uniovi.es; elenalastraa@gmail.com

David Cuenca-Solana
david.cuenca@unican.es

Asier García-Escárzaga
a.garcia.escarzaga@gmail.com

Javier Rodríguez-Santos
frodriguez@magmacultura.com

Xavier Clop-García
xavier.Clop@uab.cat

María Dolores Camalich-Massieu
dmassieu@ull.edu.es

Dimas Martín-Socas
dsocas@ull.edu.es

1 Departamento de Historia, Área de Prehistoria, Universidad de Oviedo, Asturias, Spain

2 Instituto Internacional de Investigaciones Prehistóricas de Cantabria (Universidad de Cantabria, Santander, Gobierno de Cantabria), Santander, Spain

3 Centre de Recherche en Archéologie, Archéosciences, Histoire (CReAAH), UMR-6869 CNRS, Rennes, France

4 Department of Prehistory and Institute of Environmental Science and Technology (ICTA-UAB), Universitat Autònoma de Barcelona, Bellaterra, Spain

5 Department of Archaeology, Max Planck Institute for Geoanthropology, Jena, Germany

6 Magmacultura S.L, Santander, Cantabria, Spain

7 ARCHAEOM, Departamento de Prehistoria, Universitat Autònoma de Barcelona, Bellaterra, Spain

8 Departamento de Geografía E Historia, Área de Prehistoria, Universidad de La Laguna, Canary Islands, Tenerife, Spain

Introduction

The study of ceramic production is a key element to analyse and understand the economic and social transformations undergone by human groups during the Neolithization process. Nevertheless, archaeological research has traditionally focused on studying pottery through typological and morphological descriptions, leaving aside other highly relevant aspects that could increase our awareness about the way of life of prehistoric societies (Clop-García 2019). In this way, the study of the full *châine opératoire* of the ceramic production process is especially important. Researchers such as Anna O. Shepard (1956), Frederik R. Matson (1965) and Hélène Balfet (1966) were pioneers in this field. Thus, to attain this knowledge, we must use new perspectives and methods that will provide us with new data about the social environment in which ceramic production took place, the interactions between group members, tool management, function, knowledge, know-how, and so forth. To undertake this new line of research, we used the use-wear analysis methodology (Semenov 1964) to define the functionality of the archaeological tools and to provide new data about the *way of life* in prehistoric times. Initially, the application of a functional analysis methodology was essentially linked to the study of stone tools, however, in recent decades it has also been applied to other types of raw materials such as bones or shells. Besides, studies on malacological material in archaeology have been able to demonstrate the use of shell tools and their importance in prehistoric contexts (see Clemente-Conte et al. 2019; Cristiani et al. 2005; Cuenca-Solana 2013; Dupont and Cuenca-Solana 2014; Romagnoli et al. 2015; Manca 2016) as had been previously demonstrated by ethnographic studies (Cuenca-Solana et al. 2011; Emperaire 1955; Gusinde 1986; Mansur and Clemente-Conte 2009; Prous 1992; among others). Additionally, the number of documented remains linking shell tools with ceramic production is increasing, with elements observed in different parts of Europe (Clemente-Conte et al. 2014; Cuenca-Solana et al. 2016; Vijande-Vila et al. 2019; among others).

Thus, the study of Cabecicos Negros site was developed taking the link between shells and ceramic into consideration, paying special attention to cardial decoration and the use of *cardium*-type shells. This traditional statement was accepted by the scientific community for years. It was so socially accepted that it wasn't verify scientifically. No analytical experimental programmes have been developed to confirm this hypothesis, nor to understand the potter's way of use of these tools. However, there has been some preliminary works aimed at study of the cardial pottery type decorative stage. It is worth mentioning that in no case a use-wear analysis has been carried out on this research. The first approach to this subject was developed by L. Salanova (1992) directed to the study of the decoration of Bell Beaker pottery from southern Finistère (France) (1992) and Galicia (Spain) (Salanova and Prieto-Martínez 2011). This interesting proposal is related exclusively with the result of the decorative activity on the ceramic surfaces, not on the analysis of the tools used for this purpose. On the other hand, Jiménez-Guijarro and Rojas Rodríguez-Malo (2018) have also carried out an experiment based on the development of cardial and pseudo-cardial impressions using different raw materials. They define the characteristics of each decoration carried out with each shell taxon. As the previous work presented, this study focuses on analysing the result of shell impressions made on surfaces without given specific information about the shell tool. So, even considering the popular acceptation of *cardium* shell tools for cardial decoration, there was, until now, no evidence of that, not under a use-wear analysis of the shell itself. In this way, the functional analysis carried out on the molluscs documented allowed for a more detailed interpretation of the site during the Neolithic to be made even more considering that Cardial pottery was a fundamental aspect of the Neolithic culture of this context. It also provided a better understanding of the technical processes related to Neolithic ceramic production, allowing us to know how these tools were used and proving that these materials were not only used as food, but also as tools.

The Neolithic site of Cabecicos Negros (Andalusia, Spain): location, description, and chronology

The site is currently located about two kilometres from the mouth of the Antas River at a height of 20 m above sea level (Fig. 1). Together with El Pajarraco site, form a large archaeological complex that spans from the Early Neolithic to the Roman Era, passing through an important Punic occupation. Two archaeological interventions have been carried out, in 1991 and 2000 (Camalich-Massieu and Martín-Socas, 1999; Goñi-Quinteiro et al., 2003; Camalich-Massieu et al., 2004). In the ancient Neolithic, its location would have been close to the coast (Arteaga and Hoffmann 1987), so that its immediate surroundings would have consisted of a wide bay.

In the specific case of Cabecicos Negros (Vera, Almería), during the ancient Neolithic period, it was characterized by a habitation model concentrated in small spaces that are distributed in the six elevations located in the eastern sector of the settlement. (Camalich-Massieu and Martín-Socas 1999; Goñi-Quinteiro et al. 1999; 2003). Remains of domestic structures have been identified with circular or oval floor plans, small

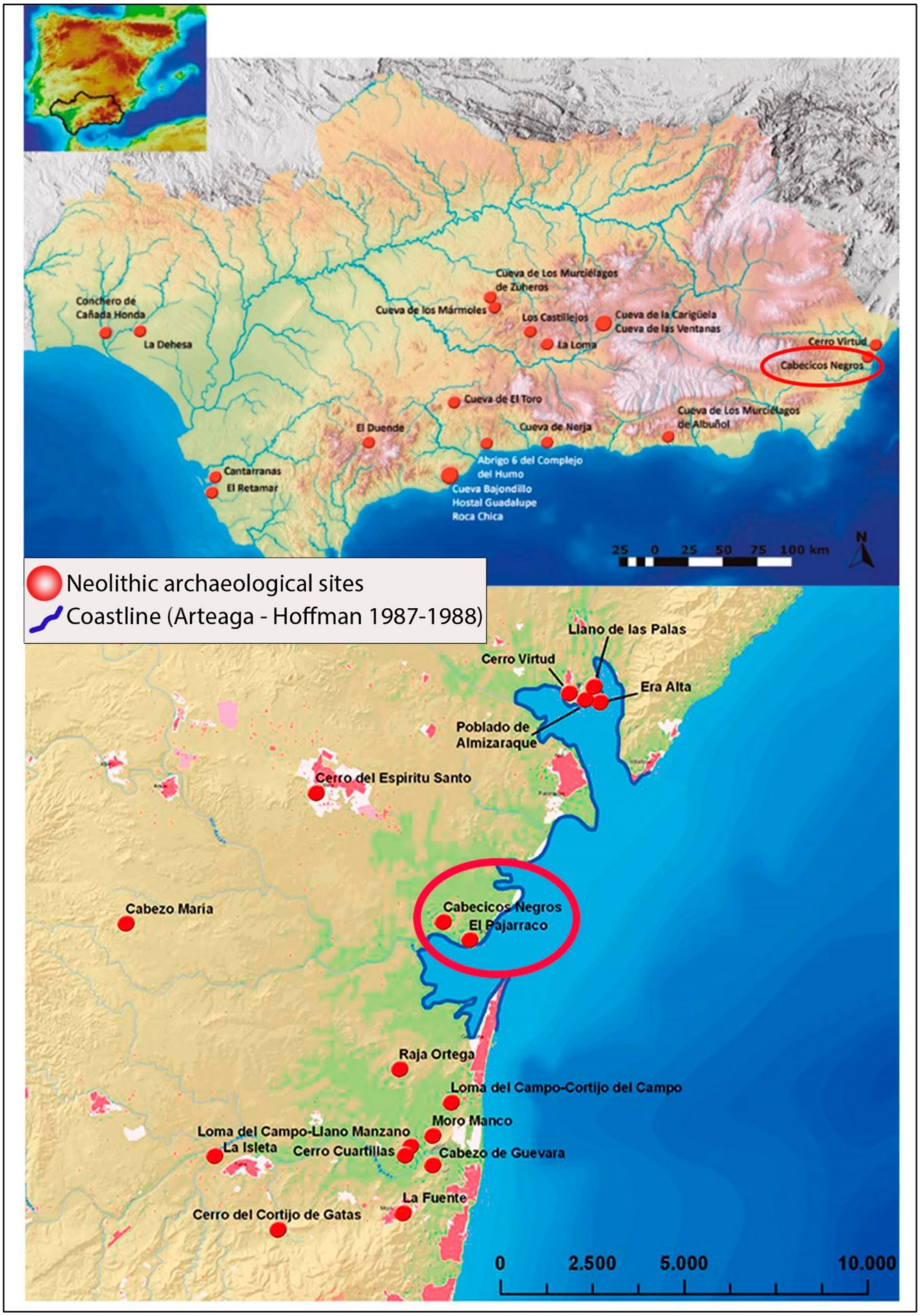

Fig. 1 Location of the archaeological site of Cabecicos Negros (Vera, Almería)

in size, built from stones and mud. The high degree of fragmentation, alteration and the characteristics of the documented material record shows that these are occupations of short duration, perhaps seasonal and/or periodic in nature (Camalich-Massieu and Martín-Socas 1999; Goñi-Quinteiro et al. 1999, 2003; Camalich-Massieu and Martín-Socas 2013; Camalich-Massieu et al. 2020).

The dimensions of Cabecicos Negros are approximately 1.5 hectares. The surface of the excavated area, located on the northernmost hill, is 100 m2. It has provided four dates from *Cerastoderma edule* (Linnaeus 1758) which, together with the techno-morphological characteristics of the identified material assemblages, have made it possible to specify the temporality of the occupations during the ancient Neolithic (late 6th millennium and first half of the 5th millennium cal. BC) (Table 1) (Camalich-Massieu and Martín-Socas 1999; 2013; Martín-Socas et al. 2018). Specifically, we are at the moment when the productive economy begins to develop in the southeast of the peninsula, marked by agricultural, livestock and artisanal diversification activities (Camalich and Martín-Socas 1999; Martín-Socas et al. 2018; Camalich-Massieu et al. 2020).

The considerable natural erosion that has affected the site, together with the small size of the structures, which has generated a low sedimentary power, between 15 and 45 cm of maximum power, together with the rest of the documentation recovered (lack of collagen in the scarce remains of terrestrial fauna, anthracological or carpological), does not make it possible to specify the different phases of occupation that mark the development of the ancient Neolithic. Due to these circumstances, the selection of samples for dating was carried out on malacological material. The criterion followed was to choose individuals collected for possible consumption. All these conditions prevent making major considerations about the subsistence economic activities carried out in the settlement. Thus, the evidence of the handling of domestic animals has only been possible to determine through the analysis of the residues preserved in the ceramic containers, which indicate the predominant presence of pigs and ovicaprine animals among the domestic fauna of ruminants and non-ruminants. Likewise, also highlighted the processing of dairy products for consumption (Tarifa-Mateos et al. 2023).

The use-wear analyses and the characteristics of the manufacturing of the different productions, especially lithic row material (Afonso 1993; Rodríguez-Rodríguez 1999; Rodríguez-Rodríguez et al. 2013) and personal ornamentation (Goñi-Quinteiro et al. 1999; Camalich-Massieu and Martín-Socas 1999; Camalich-Massieu et al. 2020), allow us to establish a craft activity that is carried out in domestic contexts and that is detrimental to other activities directly related to subsistence. In general, it is characterized by being highly normalized, being surplus, and directed at an extra-domestic social sphere for the exchange of goods and raw materials that are not covered within the group in an extensive geographical area (Harrison and Orozco Köhler 2001; Orozco-Köhler 2016; Thomas 2016). In the first case, the treatment of hard animal matter, fundamentally malacofauna, and minerals, essentially mica schist and limestone or marble, are the best represented, and those aimed at working with wood or bone appear with less incidence.

In terms of this research project, it is important to highlight the group of malacological remains found. Although collected alive in a marsh environment in the estuaries close to the site (Arteaga and Hoffmann 1987, 1999; Arteaga et al. 1985), it was only small number of them, which would have provided little protein to the human groups collecting them, and thus were likely of no bromatological interest to them (García-Escárzaga et al. in press). However, their use as raw materials for the manufacture of tools linked to other activities such as those proposed in this work is of relevance here. They contribute additional evidence to that provided by the ceramic remains themselves, of which those with cardial decoration stand out, traditionally considered as the guiding elements when it comes to defining the first phases of the initial Neolithic in the western Mediterranean (Fig. 2).

Table 1 The samples have been calibrated by applying the corresponding IntCal20 (Reimer and Reimer 2017) and Marine20 (Heaton et al. 2021) calibration curves

Period	Phase	Material	Taxon	Laboratory	Date	Dat. 68%	Dat. 95.4%	Bibliography
						BC	**BC**	
Early Neolithic	I	Shell	*C. edule*	Beta-347627	6530 ± 30	4940–4770	5020–4690	Camalich-Massieu & Martín-Socas 2013 Corrected ocean effect
Early Neolithic	I	Shell	*C. edule*	Beta-336255	6490 ± 30	4890–4720	4980–4650	Camalich-Massieu & Martín-Socas 2013 Corrected ocean effect
Early Neolithic	I	Shell	*C. edule*	Beta-336258	6360 ± 30	4750–4580	4830–4490	Camalich-Massieu & Martín-Socas 2013 Corrected ocean effect
Early Neolithic	I	Shell	*C. edule*	Beta-347630	7300 ± 50	5710–5560	5790–5480	Camalich-Massieu & Martín-Socas 2013 Corrected ocean effect

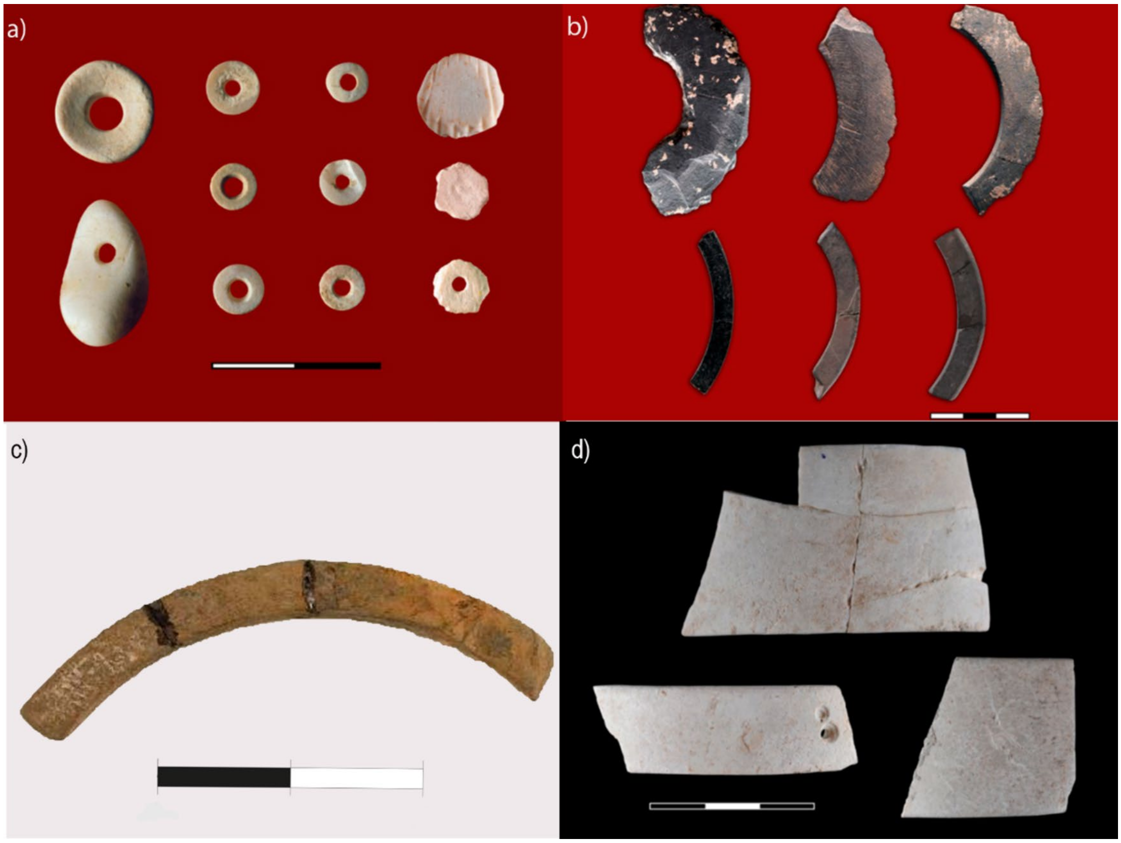

Fig. 2 Remains of personal ornaments from Cabecicos Negros. **a**) Parts of a shell necklace; **b**) Slate bracelets at different stages of the manufacturing process; **c**) and **d**) Calcite bracelets (images obtained from Camalich-Massieu and Martín-Socas 2013)

Regarding ceramic production, the vessels present a fragmentation index that has not allowed a typological classification of the whole set. Nonetheless, some remains with decoration had been documented being able to observe that rectilinear shapes are the most used in this site. In addition, some cases where the form of the vessel could be documented, being characterized by having a conical bottom, converging walls and a volume ranging between 10 l. and 15 l. Besides, a series of ceramic groups were documented in smaller containers, defined by the variety of decorative techniques, simple or combined, such as incised, printed, "boquique"- some with inlay of red "almagra" paste -, or plastic. Among them, ceramics with cardial printed decoration stand out (Fig. 3 and 4), confirming the occupation of these Almeria lowlands since the oldest phase of the Andalusian Neolithic (Camalich-Massieu and Martín-Socas 1999; Goñi-Quinteiro et al. 1999; 2003; Camalich-Massieu and Martín-Socas 2013; Martín-Socas et al., 2018; Camalich-Massieu et al. 2020).

Cardial ceramics, like the rest of the sets of materials identified in Cabecicos Negros, are associated with domestic contexts, in which the different defined craft activities are located.

Material and methods

The archaeomalacological collection of Cabecicos Negros

The archaeomalacological analysis carried out allowed us to study 1403 malacological remains, of which 92% could be assigned to genus level, and a high number also to the species level. The results of this study determined that the *Cerastoderma* and *Glycymeris* genera are the most represented in the group. The former represents ~ 64% of the total, whereas the latter ~ 17%. In this way, both genera represent more than 80% of the archaeomalacological material recovered at the site. At the same time, the presence of different species has been identified within both genera: *Cerastoderma edule* and *Cerastoderma glaucum* (Bruguière, 1789); *Glycymeris violacescens* (Lamarck, 1819), *Glycymeris bimaculata* (Poli, 1795) and *Glycymeris glycymeris* (Linnaeus, 1758). In addition, the estimate of the minimum number of individuals (MNI) from the different fragmentation categories (Gutiérrez-Zugasti 2009; Moreno 1994) shows a minimum number of 138 specimens, among which bivalves predominate over gastropods (Table 2).

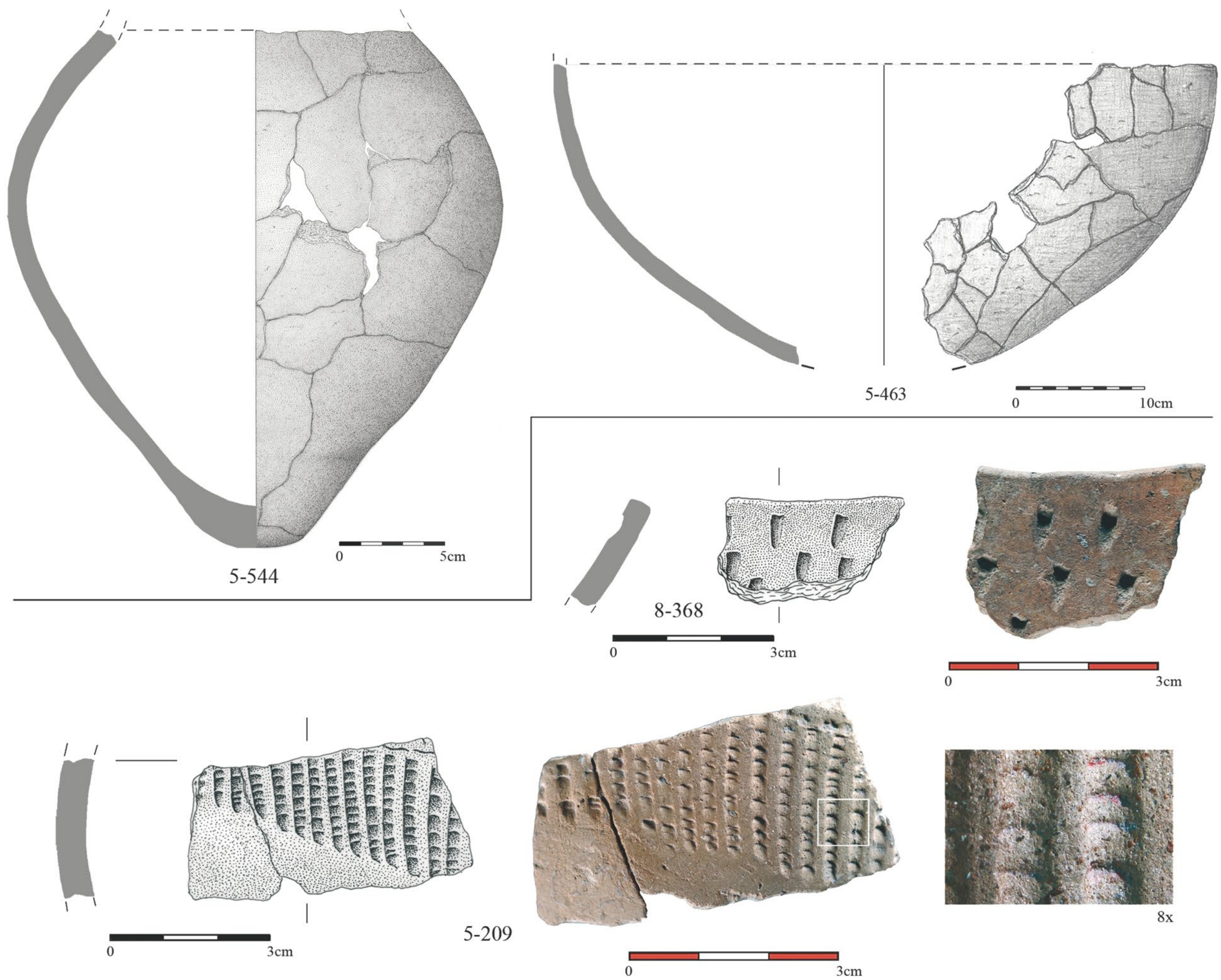

Fig. 3 Ceramic forms and decorative techniques present in Cabecicos Negros

Fig. 4 Ceramic forms and decorative techniques present in Cabecicos Negros

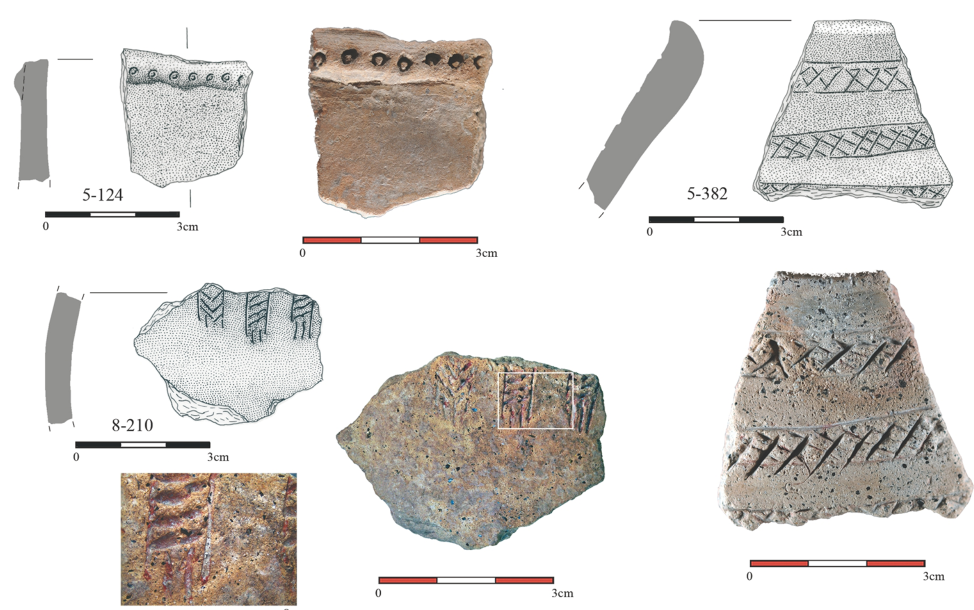

Table 2 Archaeomalacological taxa documented in Cabecicos Negros (García-Escárzaga, et al. in press). NR = Number of remains; MNI = Minimum Number of Individuals

Species				
Marine bivalves	NR	NR%	MNI	MNI%
Cerastoderma sp.	1262	90	90	65.2
Glycymeris violacescens	9	0.6	6	4.3
Glycymeris bimaculata	2	0.1	2	1.4
Lutraria lutraria	1	0.1	1	0.7
Glycymeris glycymeris	6	0.4	6	4.3
Glycymeris sp.	76	5.4	9	6.5
Ruditapes decussatus	1	0.1	1	0.7
Total Marine Bivalves	1357	96.7	115	83.3
Marine Gastropods	NR	NR%	MNI	MNI%
Tricola tenuis	1	0.1	1	0.7
Nassarius sp.	1	0.1	1	0.7
Conus mediterraneus	1	0.1	1	0.7
Dikoleps sp.	1	0.1	1	0.7
Charonia lampas	1	0.1	1	0.7
Fasciolaria lignaria	2	0.1	2	1.4
Haliotis tuberculata	1	0.1	1	0.7
Patella sp.	4	0.3	3	2.2
Cerithium vulgatum	8	0.6	5	3.6
Total Marine Gastropods	20	1.9	16	11.6
Terrestrial gastropods	NR	NR%	MNI	MNI%
Iberus gualtieranus	4	0.3	3	2.2
Helix sp.	22	1.6	4	2.9
Total Terrestrial Gastr	26	1.9	7	5.1
Indeterminate	NR	NR%	MNI	MNI%
	112	8.0		
Total	1403	100	138	100

Furthermore, the taphonomic study carried out (García-Escárzaga et al. in press) shows that there are no *postmortem* signs in most shells, so some of the shell tools could have been consumed before being used, although not all of them, since some had to be collected *postmortem* (Fig. 15). This kind of exploitation has already been documented in other Neolithic contexts, for example, Campo de Hockey and Set Parralejos (Cadiz, Spain) in the region (Cuenca-Solana et al. 2013a) or Benzú cave in Africa (Ceuta, Spain) (Vijande-Vila et al. 2019).

Methods

Use-wear analysis was used (Semenov 1964) to undertake this research project. The aim was to understand the functionality of the tools through the alteration patterns caused by their manufacture or use. As a result, these samples were examined under various microscopic lenses between 10 and 200X magnifications. To manage these observations, we used a Leica S8 APO stereomicroscope and a Leica DM2500M microscope with a 10-megapixel Leica 190HD camera fitted on both pieces of equipment. Finally, to develop the photographic record we used a Nikon D750 camera with a 60 mm macro lens. To carry through the functional interpretation of the material analyzed, the experimental reference collection available at BIOPAL (*Bioarqueología, Paleoclima y Transformaciones Sociales en la Prehistoria*) was used. Likewise, a large part of this reference collection has been the result of a research where it can be seen the wear produced on the surface of various species of shells as working tools for different raw materials Clemente-Conte and Orozco-Kölher 2012; Clemente-Conte et al. 2014; 2019; Cristiani et al. 2005; Cuenca-Solana 2013; 2015; Cuenca-Solana and Clemente-Conte 2017; Cuenca-Solana et al. 2010; 2013b; 2015; 2016; 2021; Dupont and Cuenca-Solana 2014, among others). The experiments carried out included several stages within the ceramic production process and the observations of different variables. For example, the use of different types of clay; the working of the ceramic clay in its different states; the development of various actions such as smoothing or burnishing the ceramic walls; and the use of different shell taxa such as *Mytilus galloprovincialis* (Lamarck 1819), *Ruditapes decussatus* (Linnaeus, 1758) or *Glycymeris Glycymeris*, among others.

The results obtained after the comparison between the experimental collection and the archaeological material have left a series of unanswered questions that led us to develop an additional experimental program to increase the size of the sample available for comparative experiments related to shell tools and ceramic production.

The experimental program

As noted above, despite our experimental base, it was necessary to develop an additional experimental protocol to provide answers to the new questions arising as a result of our research, especially those linked to cardial decoration. The structure and development of the experimental protocol was based on the information obtained through the functional analysis of the archaeomalacological material, along with the studies carried out at this time about the ceramic material of the site: decorations, raw material, etc. (Camalich-Massieu and Martín-Socas 1999). This experimental program comprised two analytical and one prospective stage, with a total of 24 experiments.

Analytical experiments were carried out to record the wear produced on the shells following the cardial ceramic decoration. We considered several unknows when undertaking this experimental program. Firstly, our concern was the working time. We wanted to document the use-wear degree on the surface of the shell during the decoration activity with different durations. Because of this, we define experiments that included decoration activity during different times, from one hour to one minute of activity. Another key issue was the kind of ceramic paste; our concern was to document the type of wear left on the surface of the shell by the decorative activity developed on a ceramic paste with and without degreaser. Likewise, we thought about the importance of the angle of the tool during the action. To document this, the experimentation has a variable based on the works with a closed angle (75º) and another with a ninety angle to see if there were any differences in the shell wear. Therefore, we have included a prospective experiment to find out preliminarily if shell tools show use-wear traces following short-duration activities. If the result were to be positive, we decided we would carry out a further analytical experiment to record this information (Fig. 5).

Description of the ceramic paste

The first part of the two analytical experiments comprised manufacturing two ceramic vessels, one for each of the experiments. For this, we used natural clays with a similar composition and morphology to those documented at the site. In the pottery samples from Cabecicos Negros analyzed petrographically, the use of two types of clays has been determined: 1) clay from a metamorphic context, where the presence of mineral elements such as green schists, mica schists, quartzites, muscovites and, eventually, garnets, hematite, or tourmalines was noted; 2) clay of volcanic origin, in which quartz, biotites, pyroxenes, plagioclases, augites, orthopyroxenes, and volcanic glass can be seen (Clop-García, personal communication). For our experimental program, clays with similar compositions were collected from the locality of Revilla de Camargo (Cantabria), specifically located at coordinates 30 T 430896 4,806,392 (Vega-Maeso 2017). This clay comes from the Weald facies of the Lower Cretaceous, characterized by an alternation of reddish siltstone clays and silts, with intercalations of micaceous and ferruginous sandstones of medium to fine grain, of whitish to reddish colours, and by the presence of red shales and quartzite. A total of 8.04 kg of clay were obtained, subsequently worked to achieve a total of 5.93 kg of processed clay ready to manufacture the vessel (Fig. 6). Following on from this, the ceramic vessel was hand modelled, and then left to dry for 24 h to achieve the plasticity necessary to begin the cardial decorative stage (Fig. 7). At the same time, shell tools of the *C. edule* taxon were prepared and documented before being used in the experiment, with a single heavy thud the shell of *C. edule* was fractured perfectly.

First stage of the analytical experimental program

For the first stage of the analytical experimental program, we decided to use clay with calcite temper to model the vase. In addition, even though most of the archaeological use-wear traces were documented in fragments instead of complete shells, we decided to use both to document all possible cases. Besides, we kept the same decorative design as the one found in the archaeological cardial vessels from the site (Fig. 8).

To make the decoration, the active area of the tool was the inner edge of the shell, the kinematics of the action were transversal and unidirectional in all the experiments (Fig. 9). The type of tools used were fragments or whole shells, the working angle varying approximately from 75º to 90º, and the working time modified throughout with intervals ranging from 15, 30, 45 to 60 min (Table 3).

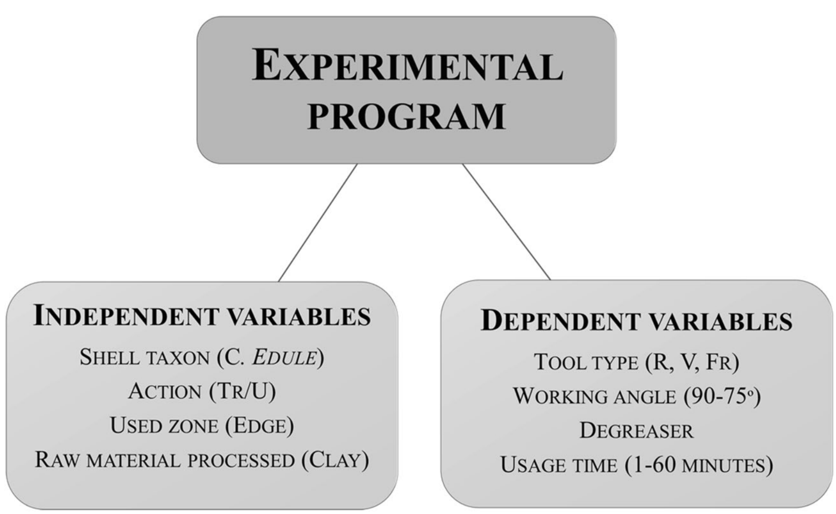

Fig. 5 Dependent and independent variables that make up the experimental program. Tool type: R = complete right valve/ L = complete left valve/ Fr = Fragment of valve; Working angle = contact angle between the tool and the material worked; Degreaser: Use or non-use of calcite degreaser; Action: TR/U = Transversal-Unidirectional action

Fig. 6 First stage of the analytical experimental protocol. **a**) Obtaining the clay to subsequently manufacture the ceramic vase; **b**) Drying the clay; **c**) Raw material after being sieved with a 1 mm mesh; **d**) Preparation of the calcite temper; e) Sieving the temper with a 1 mm mesh

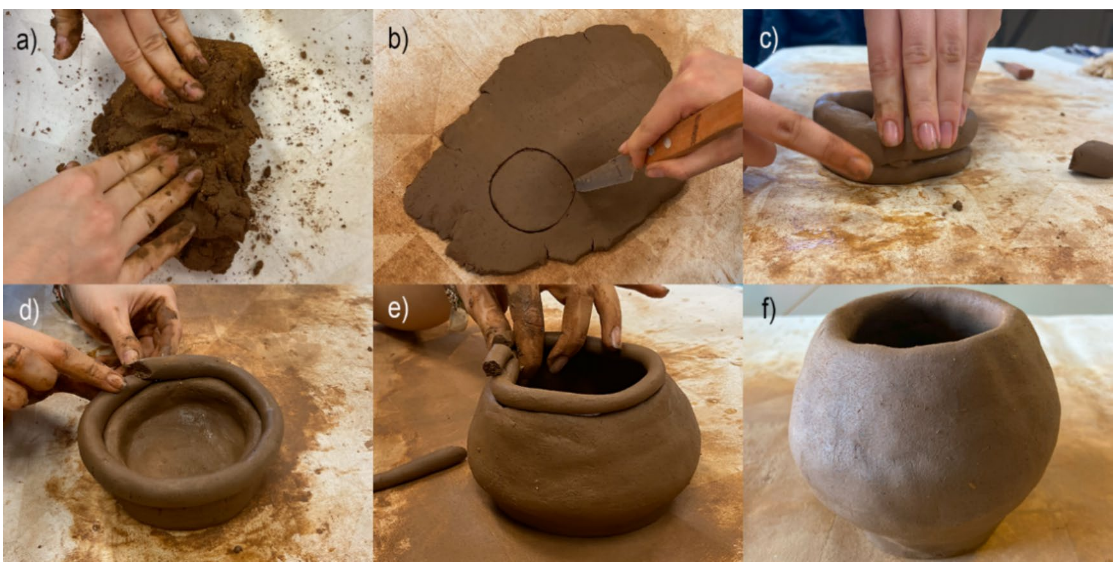

Fig. 7 **a**) Mixing of dry clay with water to prepare the ceramic clay; **b**) Preparation of the base of the ceramic vessel; **c**), **d**) and **e**) Application of overlapping cordons to manufacture the ceramic vessel; **f**) Final result of the ceramic vessel

Prospective experimental program

Later, based on the results obtained after developing the first stage of the experiment, we carried out a prospective one with fewer variables to complete the information and analyse the degree to which the use-wear traces developed. The experiment entailed working clays with and without temper, as well as reducing the work time doing this activity (Table 4). Since it was only a prospective experiment, we just wanted to know if the use-wear traces would change by adding these new variables. Therefore, in this case we used a smooth plate with the same clay, and we started to print the cardial decoration during short periods of activity (Fig. 10).

Second stage of the experimental program

Finally, as a result of the favourable results obtained during the prospective experimental program, we decided to accomplish a second stage, analytical in this case,

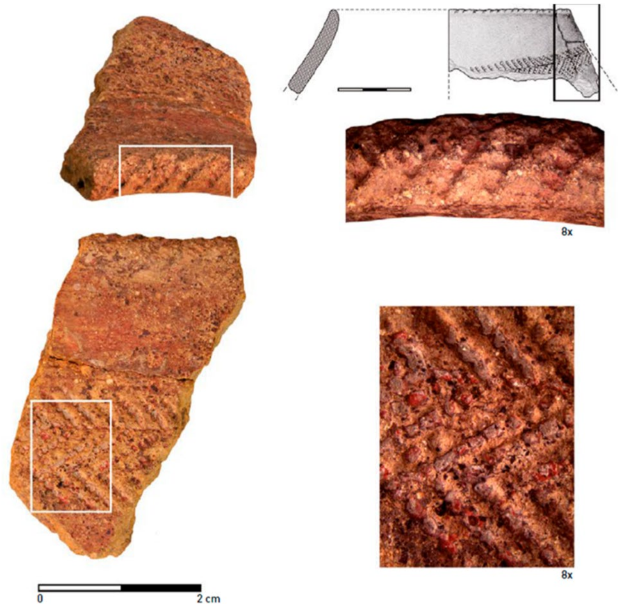

Fig. 8 Cardial pottery from Cabecicos Negros site (Camalich-Massieu and Martín-Socas 2013)

comprising the same variables, and which entailed modelling a new vessel without temper (Fig. 11). This experiment was aimed at documenting the traces left by short working times (Table 5).

And thus, we completed a total of 24 experiments noting different variables in the development of the cardial decoration.

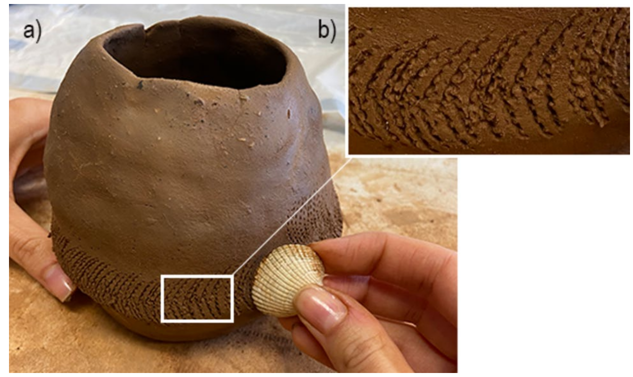

Fig. 9 Ceramic vessel used during the first stage of the analytical experimental protocol. **a**) Working tool carrying out cardial decoration in a 75º angle, with a unidirectional transversal action, for 30 min on a ceramic paste with temper; **b**) detail of the cardial type decoration produced by this tool

Results

The experimental program: effectiveness and use-wear analysis of the experimental shell tools

The effectiveness of shell tools to carry out cardial decoration

Based on the results obtained during the experimental process, we can conclude that *C. edule* shells are highly effective tools to use to develop cardial decoration work. At a

Table 3 Analytical experiments carried during the first experimental protocol. # = Identification number; Type: R = complete right valve/ L = complete left valve/ Fr = Fragment of valve; Angle = contact angle between the tool and the material worked; Action: TR/U = Transversal-Unidirectional action

#	Taxon	Type	Angle	Action	Used Zone	Material	Degreaser	Time
1	*C. edule*	L	90°	TR/U	Edge	Clay	Calcite	15´
2	*C. edule*	R	90°	TR/U	Edge	Clay	Calcite	30´
3	*C. edule*	L	90°	TR/U	Edge	Clay	Calcite	45´
4	*C. edule*	R	90°	TR/U	Edge	Clay	Calcite	60´
5	*C. edule*	R	75°	TR/U	Edge	Clay	Calcite	15´
6	*C. edule*	L	75°	TR/U	Edge	Clay	Calcite	30´
7	*C. edule*	L	75°	TR/U	Edge	Clay	Calcite	45´
8	*C. edule*	R	75°	TR/U	Edge	Clay	Calcite	60´
9	*C. edule*	Fr	90°	TR/U	Edge	Clay	Calcite	15´
10	*C. edule*	Fr	90°	TR/U	Edge	Clay	Calcite	30´
11	*C. edule*	Fr	90°	TR/U	Edge	Clay	Calcite	45´
12	*C. edule*	Fr	90°	TR/U	Edge	Clay	Calcite	60´
13	*C. edule*	Fr	75°	TR/U	Edge	Clay	Calcite	15´
14	*C. edule*	Fr	75°	TR/U	Edge	Clay	Calcite	30´
15	*C. edule*	Fr	75°	TR/U	Edge	Clay	Calcite	45´
16	*C. edule*	Fr	75°	TR/U	Edge	Clay	Calcite	60´

Table 4 Prospective experiments. # = Identification number; Type: Fr = Fragment of valve; Angle = contact angle between the tool and the material worked; Action: TR/U = Transversal-Unidirectional action

#	Taxon	Type	Angle	Action	Used Zone	Material	Degreaser	Time
17	*C. edule*	Fr	90˚	TR/U	Inner face	Clay	No	1´
18	*C. edule*	Fr	90˚	TR/U	Inner face	Clay	No	2´
19	*C. edule*	Fr	90˚	TR/U	Inner face	Clay	No	5´
20	*C. edule*	Fr	90˚	TR/U	Inner face	Clay	No	15´

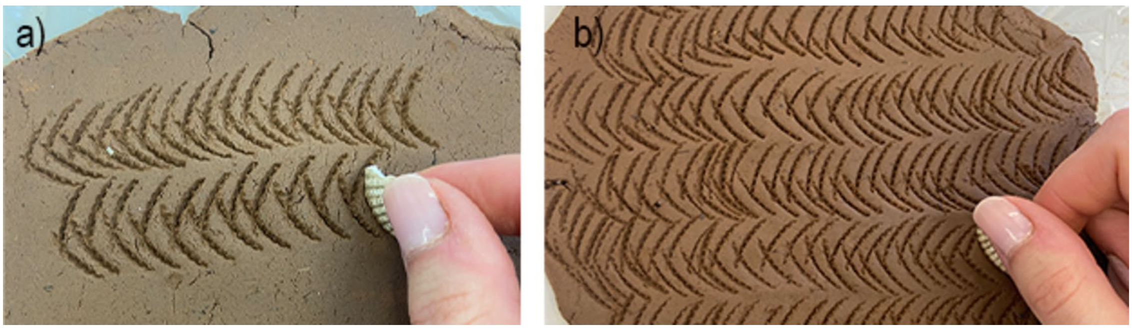

Fig. 10 Two different stages of the prospective experimental program using different shell fragment tools. Cardial impression activity carried out from an approximately 90º working angle developing a unidirectional transversal action on a clay plate without temper; **a**) for 1 min; **b**) for 5 min

functional level, all the tools used in each experiment have carried out the activity, nevertheless, as we will discuss later, some tools have been more useful than others, even though the result has always been favourable.

In this way, we can presume that the level of effectiveness of shell tools to carry through this activity is based on two factors: the working angle and the morphology of the tool. Using different angles to develop this activity, we have been able to verify the difficulty of maintaining a 75º inclination over time. In contrast, the use of 90º angles was much more suitable when undertaking the activity. On the other hand, the morphology of the tool was also important: through this experiment we have been able to note certain differences in the decoration according to the type of tool used (complete vs fragment valve). Thus, the use of fragments of *C. edule* make more accurate impressions on the vessel than complete shells. In addition, the use of complete shells produces larger decorations due to the larger contact surface with the clay. For this reason, the design is also different when using complete valves or just fragments. In our case, the designs resulting from the use of fragments are alike those documented archaeologically (Fig. 12).

Use-wear traces of the experimental tools

The development of the experimental program allowed us to document use-wear patterns on the edge of the valve at a macroscopic level (10X augmentations) after just 2 min of work. On the other hand, at a microscopic level, use-wear experimental traces were mostly identical in all of the samples. Thus, at higher magnifications we find a shiny and rough polish characteristic of pottery works associated with narrow striations parallel to each other, with a dark background. Furthermore, these alterations show transversal and unidirectional actions, located on the inner edge of the valve, regardless of whether it is complete or only a fragment. However, the development degree of the use-wear traces changes between the tools, increasing depending on

Table 5 Analytical experiments carried during the second experimental protocol. # = Identification number; Type: Fr = Fragment of valve; Angle = contact angle between the tool and the material worked; Action: TR/U = Transversal-Unidirectional action

#	Taxon	Type	Angle	Action	Used Zone	Material	Degreaser	Time
21	*C. edule*	Fr	90˚	TR/U	Inner face	Clay	No	1´
22	*C. edule*	Fr	90˚	TR/U	Inner face	Clay	No	2´
23	*C. edule*	Fr	90˚	TR/U	Inner face	Clay	No	5´
24	*C. edule*	Fr	90˚	TR/U	Inner face	Clay	No	15´

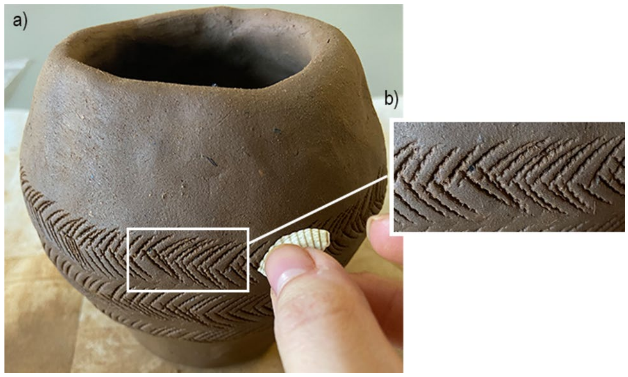

Fig. 11 Ceramic vessel used during the second stage of the analytical experimental protocol. **a**) Working tool carrying out the cardial-type decoration with a 90º angle with a unidirectional transversal action for 5 min on a ceramic paste without temper; **b**) detail of the cardial type decoration produced by this tool

the duration of the work activity. Thus, it has been documented a closed polish or semi-closed polish depending on the duration of the activity. The greatest wear was observed in shell tools that performed the action for a longer period.

Significantly, these alterations have been documented after one only minute of activity even if the development is more significant after 60 min of work. So, even if the use-wear traces remain the same, their development grows as working time increases. In addition, the polishing tends to become more compact and spread, covering a greater amount of the active zone, sometimes even over the lowest areas of the microtopography. The same happens with the striations, the number of which will also increase significantly as the working time increases (Fig. 13).

On the other hand, we documented that the calcite temper included in one of the vessels also affects the development of the alterations. In this way, the tools that worked with the clay with temper have shown higher use-wear traces at a microscopic level. And finally, regarding the variable of the working angle used, we can state that 75º results in a greater amount of surface showing alterations, since the clay comes into contact with a greater part of the active surface of the tool.

The archaeomalacological collection of Cabecicos Negros: the use-wear analysis

The functional analysis carried out on the archaeomalacological collection from Cabecicos Negros allowed us to document 31 shell tools among the 1403 remains recovered, 20 of which showing definite evidence of use, and 11 with possible traces of use. Since most of the archaeomalacological material was made up of very small fragments that could not be analysed, and many of these presented a high degree of taphonomic alteration, the total number of shells used as tools is quite significant, representing approximately 2% of the archaeomalacological remains analysed (Fig. 14).

Among the shell tools documented, the highest percentage corresponds to the *Cerastoderma* taxon, representing 81% of the total, followed by *Glycymeris* (~13%, and ~6%) whose poor preservation did not allow for it to be defined at a taxonomical level (García Escárzaga et al. in press). On the other hand, the predominant use of fragments as tools has been documented, which corresponds to ~68% of the total, compared to ~32% that corresponds to the use of complete shells (Table 6).

Among the shell tools analysed in Cabecicos Negros, we have established three groups based on the use-wear traces documented on the shells and therefore linked to their different uses within the ceramic production process: shell smoothers, shell tools to develop cardial decoration, and shells with probable use.

Shell smoothers

The first group comprises four work tools (#27, #249a, #474, #567) linked to the task of smoothing the ceramic clay (Table 6). From a functional point of view, at the

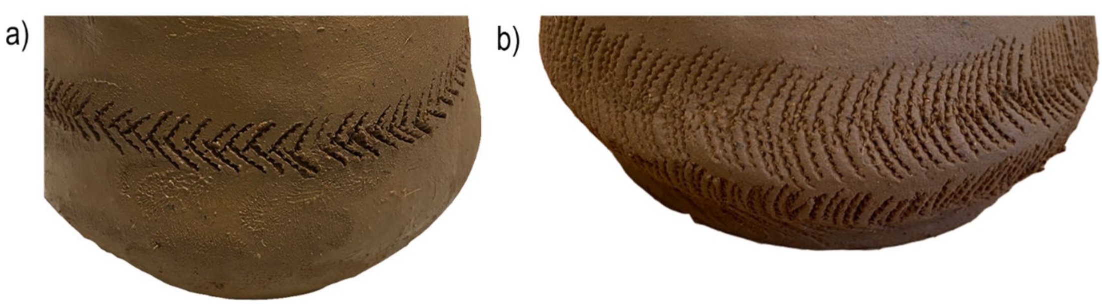

Fig. 12 Differences between the designs of the cardial decoration. **a**) Cardial decoration made during the experiment using a shell fragment tool of *C. edule* at a 90º working angle through a transversal-unidirectional action; **b**) Cardial decoration made with a complete shell tool of *C. edule* using a 90º working angle through a transversal-unidirectional action

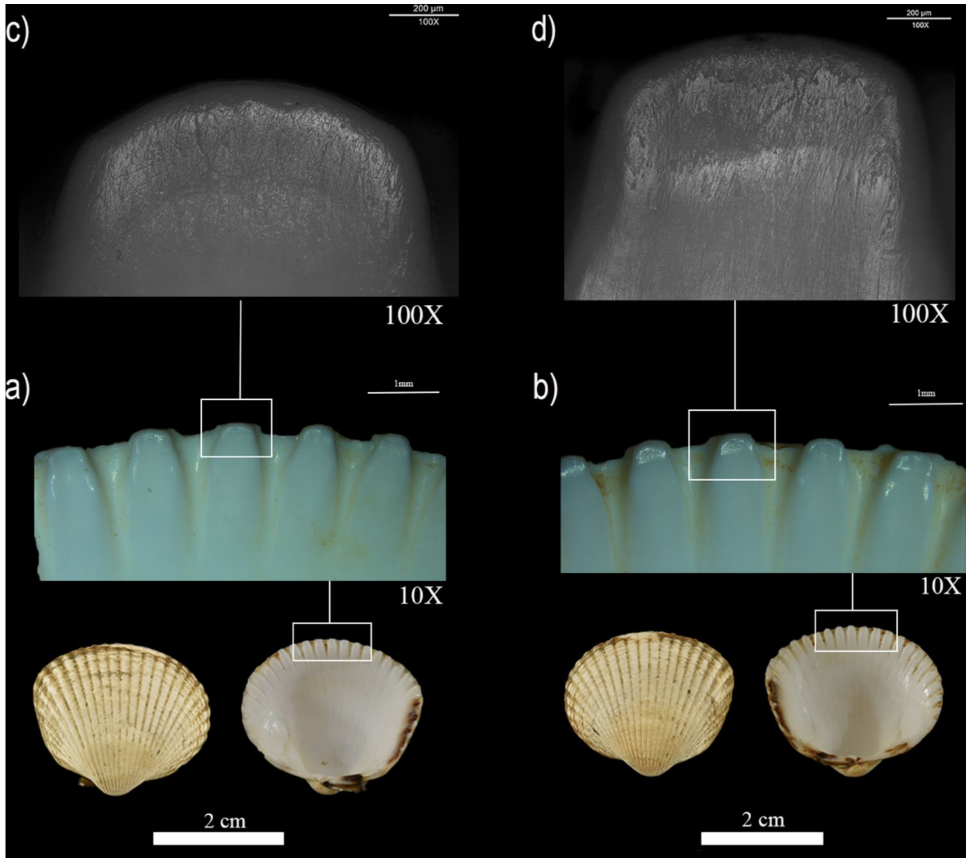

Fig. 13 Comparison of the use-wear traces on experimental tools of *C. edule* carrying out cardial decoration for 15 min (on the left) and 60 min (on the right). **a**) and **b**) Rounding of the inner face; **c**) and **d**) polished, rough, and shiny microtopography with thin striations with dark background

macroscopic level we found significant alterations in the shape of very evident wear and rounding on the edge of the shell (Fig. 15).

At the microscopic level they are characterized by a shiny and rough polishing associated with a variable number of dark striations, which are usually wide. The number of striations varies on each shell, showing greater numbers on certain tools. In addition, #27 and #249a feature the most developed traces in this group, characterized by a polish that becomes more compact in the higher areas of the shells' microtopography. Moreover, tool #27 presents a non-anthropic perforation on the umbo, where certain use-wear patterns have been documented. In this way, considering these traces, and even though the perforation is a natural one, this shell could have maybe been suspended to transport the tool (Fig. 16).

Thus, from a functional point of view, the analysis confirms that the edges of these shells were used to develop transversal actions upon mineral matter. These alterations are located on the edge on the inner face of the shell, which indicates that this part of the valve worked as an active face during the development of the activity for which these tools were used.

Shell tools to develop cardial decoration

In addition, we have also documented 16 tools that would have been used to make the cardial decoration (#119, #182, #236, #237, #256a, #256b, #287a, #287b, #293a, #309, #343, #393, #796, #828, #833a and #833b) (Table 6). In contrast with the smoothers, although these tools do not show great development of the traces at the macroscopic level, they do at the microscopic level (Fig. 17).

The degree of use-wear trace development fluctuates among the tools. From a microscopic point of view, the use-wear traces are characterized by a shiny polish associated with narrow striations, with a dark background, parallel to each other. Thus, although all these alterations are always showing the same type of action (transversal and unidirectional to the active zone), we can see some differences regarding the development degree of these traces, probably as result of the contact time with the material worked. Within this second group, we can differentiate a series of tools that show the most significant use-wear at the microscopic level: #83, #119, #182, #236, #256a, #256b, #287a, #287b and #293a (Fig. 18).

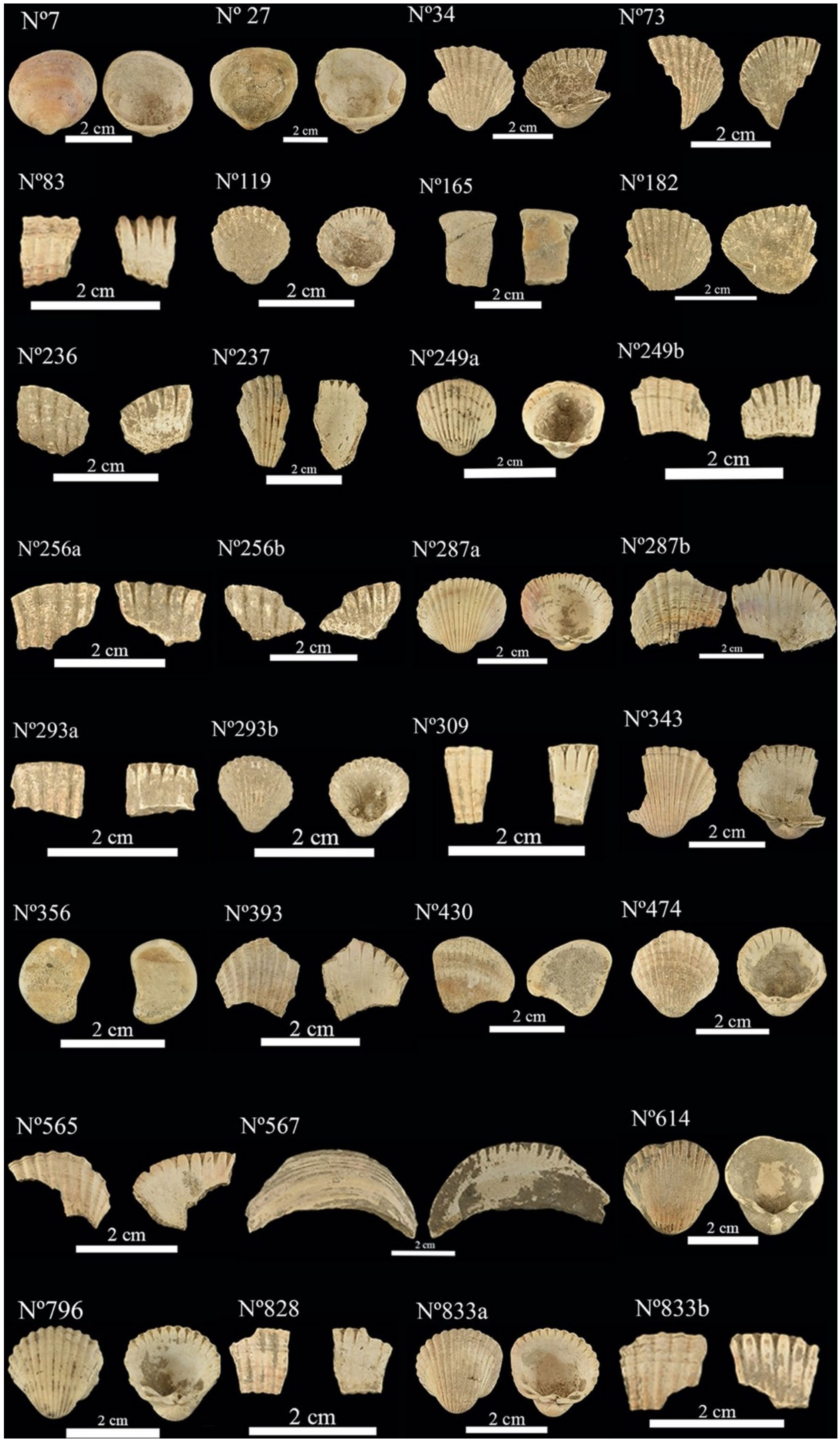

Fig. 14 Shell tools documented at Cabecicos Negros with definite use and probable use. Smoother: #27, #249a, #474, #567; print tools: #119, #182, #236, #237, #256a, #256b, #287a, #287b, #293a, #309, #343, #393, #796, #828, #833a, #833b; and potential tools with probable use: #7, #34, #73, #83, #165, #249b, #293, #356, #430, #565 #614

Table 6 Shell tools and shells with probable use documented at Cabecicos Negros site. Use = Shell tools Pr = Shell with probable use; TR = Transversal action; TR/U = Transversal-unidirectional action; TB/OB = Transverse and oblique action; TR/L = Transversal and longitudinal action; Type: R = Complete right valve; L = Complete left valve; Fr = Fragment of valve

236	*Cerastoderma* sp.	Fr	Use	TR/U	Clay	Print
237	*Cerastoderma* sp.	Fr	Use	TR/U	Clay	Print
249 a	*Cerastoderma* sp.	R	Use	TR	Clay	Smooth
249 b	*Cerastoderma* sp.	Fr	Pr	TR/U	-	-
256 a	*Cerastoderma* sp.	Fr	Use	TR/U	Clay	Print
256 b	*Cerastoderma* sp.	Fr	Use	TR/U	Clay	Print
287 a	*Cerastoderma* sp.	R	Use	TR/U	Clay	Print
287 b	*Cerastoderma* sp.	Fr	Use	TR/U	Clay	Print
293 a	*Cerastoderma* sp.	Fr	Use	TR/U	Clay	Print
293 b	*Cerastoderma* sp.	R	Pr	TR/U	-	-
309	*Cerastoderma* sp.	Fr	Use	TR/U	Clay	Print
343	*Cerastoderma* sp.	Fr	Use	TR/U	Clay	Print
356	-	Fr	Pr	TR/OB	-	-
393	*Cerastoderma* sp.	Fr	Use	TR/U	Clay	Print
430	*Glycymeris* sp.	Fr	Pr	TR	-	-
474	*Cerastoderma* sp.	R	Use	TR	Clay	Smooth
565	*Cerastoderma* sp.	Fr	Pr	TR/U	-	-
567	*Glycymeris* sp.	Fr	Use	TR/L	Clay	Smooth
614	*Cerastoderma* sp.	R	Pr	TR	-	-
796	*Cerastoderma* sp.	R	Use	TR/U	Clay	Print
828	*Cerastoderma* sp.	Fr	Use	TR/U	Clay	Print
833 a	*Cerastoderma* sp.	L	Use	TR/U	Clay	Print
833 b	*Cerastoderma* sp.	Fr	Use	TR/U	Clay	Print

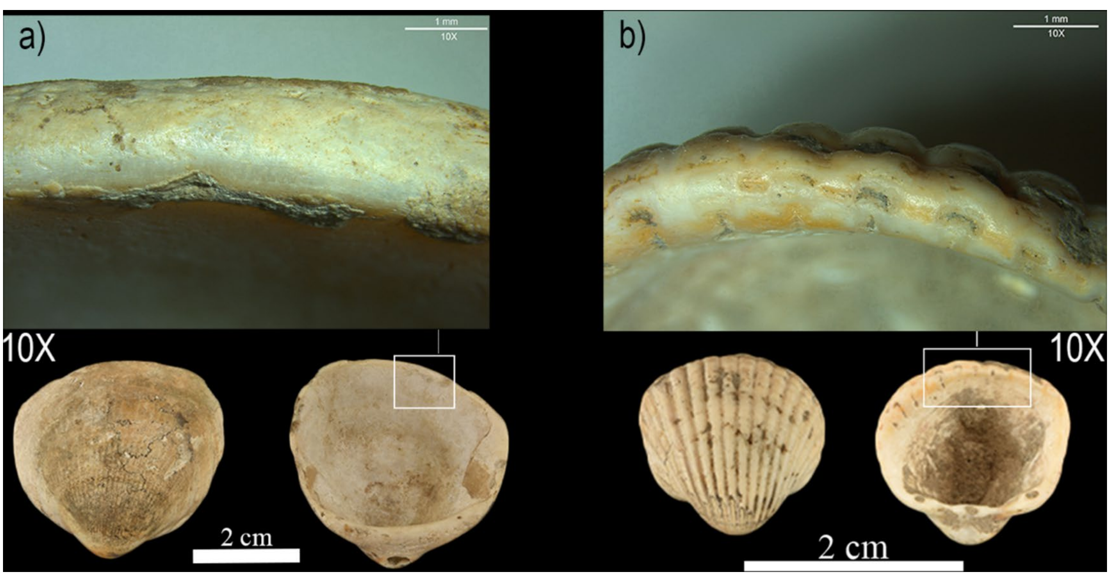

Fig. 15 Macroscopic use-wear traces documented in two shells of *Glycymeris* sp. #27 (left) and #249a (right) from Cabecicos Negros. These shells have been classed as smoothers

On the other hand, #343, #393, #565, #833a, #833b, and show fewer alterations on their active zones. In addition, #237 and #828 have a somewhat different polish to the rest, characterized by less development, and less presence of striations compared to other tools within this second group, probably because of minor contact with the worked material. And finally, #309 and #796 show very light polishing, with a semi-closed weft due to less use over time.

Thus, in general for the whole of this second group, the use-wear traces are located on the edge and on the inner face

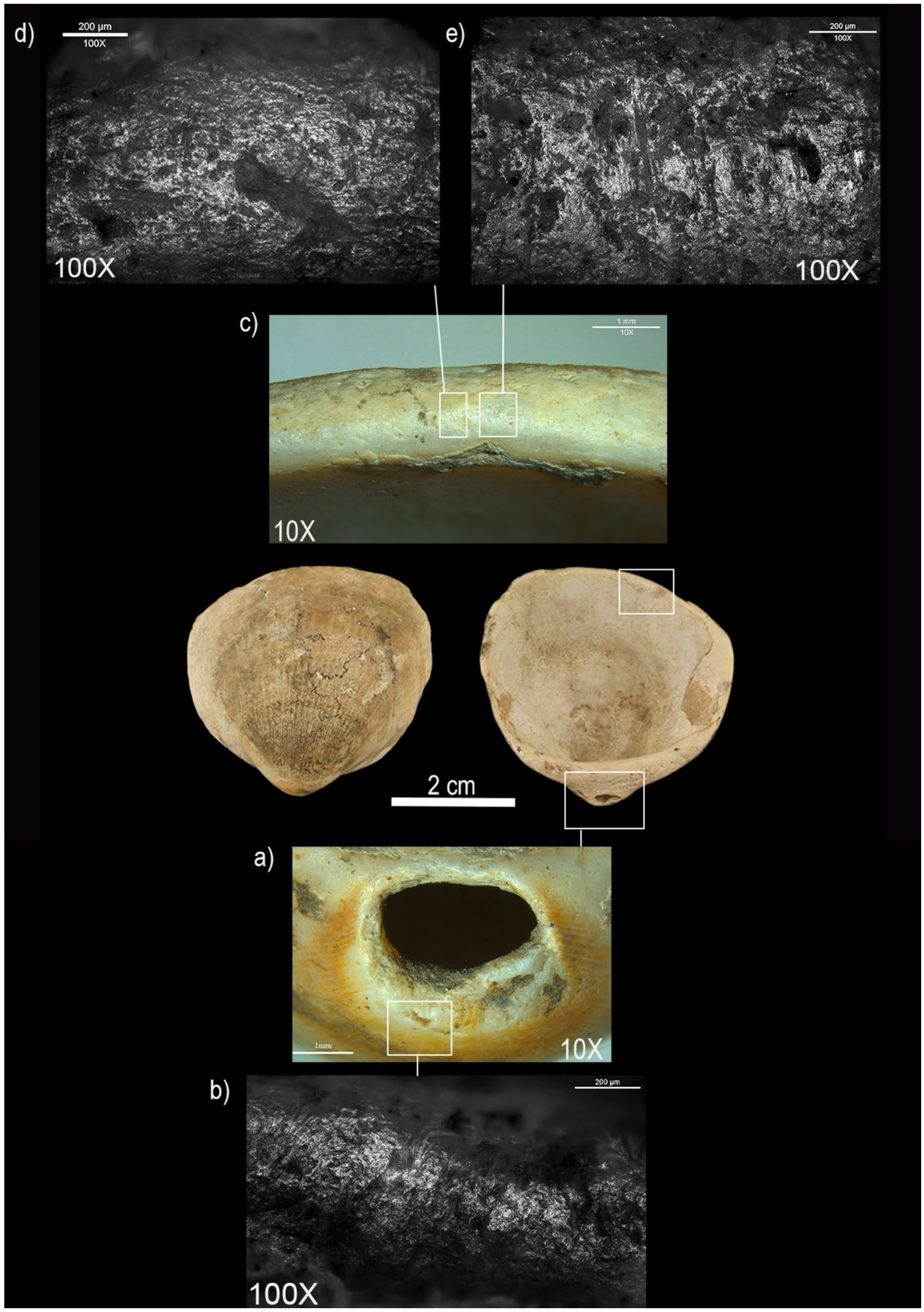

Fig. 16 Use-wear traces documented on a *Glycymeris* sp. shell smoother (#27). **a**) Alterations on the outer face of the valve, specifically on the area behind the umbo; **b**) detail of the polishing and striations on the external face of the shell at 100X. **c**) Rounding on the inner face of the edge of the shell to 10X; **d**) and **e**) detail of the polishing and striations developed on the inner face of the edge of the shell at 100X

of the edge of the shell, specifically on the highest areas of the microtopography. In addition, in the tools with greater development of the alterations, the wear was also documented in the interspaces of the edge of the shell. In the same way, another characteristic of this group is that these alterations have been generated in a specific area of the edge approximately 1 cm and never more than 2 cm wide, relating exactly to the areas of greatest contact with the raw material.

To conclude, based on the results obtained in the functional analysis and during the development of the experimental program, we propose that these 16 fragments and complete shells were used to achieve a transversal and unidirectional impression on a mineral material: clay. In this way, we propose that this set of tools would have been used to perform cardial decoration.

Shell tools with probable use

Finally, we have separated a third group of tools made up of 11 shells with a probable use (#7, #34, #73, #83, #165,

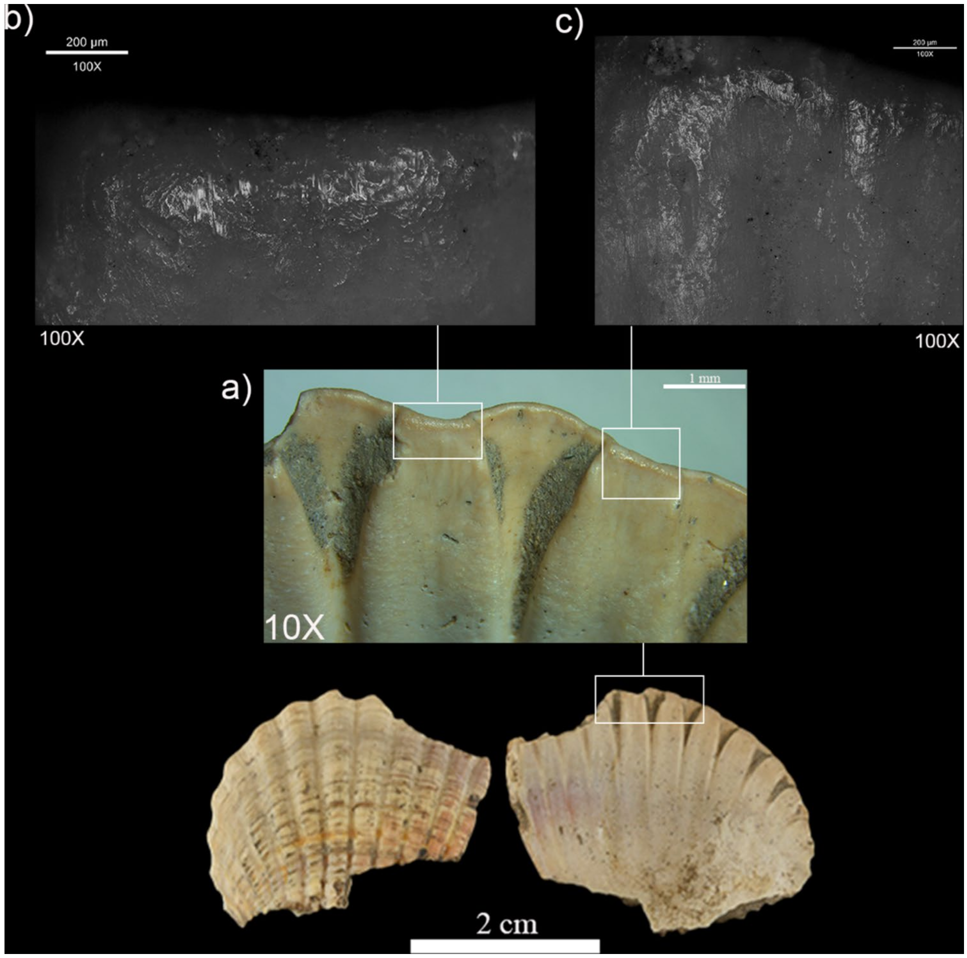

Fig. 17 Use-wear traces on *Cerastoderma* sp. tool (#287b) used to achieve cardial decoration. **a**) Rounding of the inner face of the edge at 10X; **b**) and **c**) polishing and striation on the inner side of the edge of the shell at 100X

#249b, #293b, #356, #430, #565 and #614). In this case, the small number traces found on these pieces, both at a macroscopic and microscopic level, has not allowed us to establish their use as tools. However, despite the low density of the use patterns, certain alterations on the shells were observed, which could be associated to the job of smoothing a mineral material (#7, #165, #356, #430 and #614), and others with cardial decoration (#34, #73, #83, #249, #293b and #565). In this way, as a conclusion, despite having documented certain alterations at the microscopic level, their low density does not allow us to confirm their use as tools.

Discussion

Shell tools and pottery production at Cabecicos Negros

The analysis of the archaeomalacological material recovered from Cabecicos Negros, the development of the analytical experimental protocol and the comparison with the reference experimental collection (Cuenca-Solana 2013; Cuenca-Solana et al. 2015) have allowed us to interpret the function of the site. Thus, it has been possible to verify the hypothesis initially proposed that links 20 of the 31 shell tools documented at the site with the development of different stages of the ceramic manufacturing process.

The role of shell smoothers

On the one hand, it has been possible to document a first group of tools comprising 4 remains (#27, #249a, #474 and #567) (Table 6) which, at the macroscopic and microscopic levels, showed similar use-wear traces. These alterations, defined earlier in sub-Sect. "Shell Smoothers". have been linked to the development of smoothing, a process aimed at standardizing the ceramic walls in an initial stage of the pottery production *chaîne opératoire*, when the clay was still wet. After carrying out the analysis, we could see how the development of the alterations was not the same for all the shells. In this way, those tools with greater wear (#27 and #249a) led us to propose that the wear was due to a more repeated and prolonged use of these shells over time. Therefore, these were tools aimed at carrying out a greater number

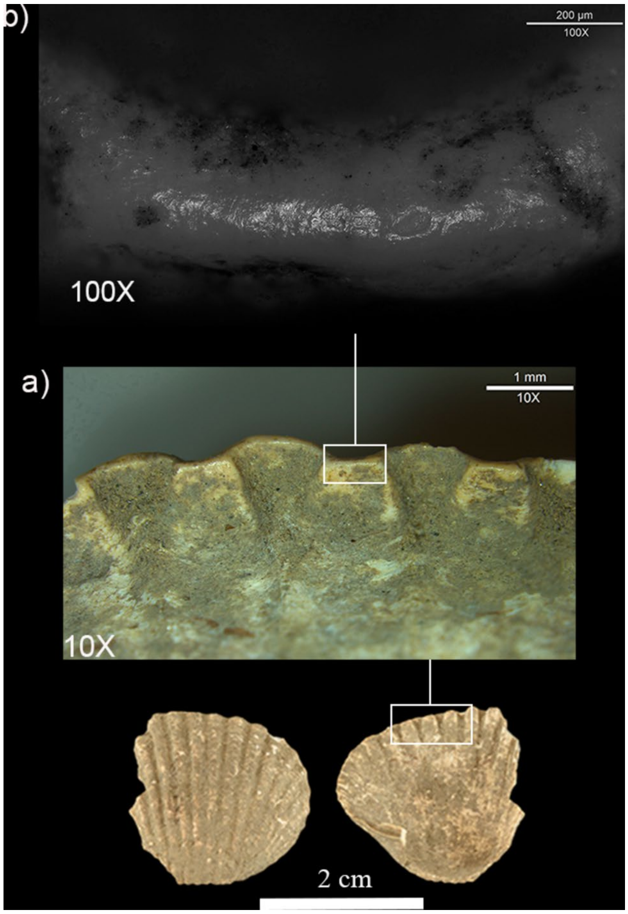

Fig. 18 Use-wear traces documented on a *Cerastoderma* sp. tool (#182). **a**) Rounding of the inner face of the edge to 10X; **b**) and **c**) polishing and striation on the inner face of the edge of the shell at 100X

of production cycles. This kind of management of ceramic production shell tools has already been documented archaeologically (Clemente-Conte et al. 2019; Cuenca-Solana et al. 2015, 2021; Manca 2016; Rousseau et al. 2020) as well as ethnographically (Dupont 2003; Prous 1992; Rodríguez and Navarro 1999). On the other hand, within this group, piece #27 shows a natural perforation in the umbo area, which is non-anthropic in origin. The functional analysis shows alterations on that perforation. Although it was not possible to verify the use for this perforation, we can propose suspension as a hypothesis, based on what has been documented at other archaeological sites (Clemente-Conte et al. 2019; Manca 2016; Vijande-Vila et al. 2019). The presence of natural perforation on shells would have been of interest to the potters as it would have allowed them to transport and preserve their tools, perhaps as fixed elements in their pottery production toolkit. This would be a plausible explanation considering the case of tool #27 and the patterns found around the perforation, which led us to hypothesize that the shell was carried around by the potters suspended from a cord. As noted earlier, similar uses have been documented at other Neolithic sites such as Coro Trasito (Huesca) (Clemente-Conte et al. 2019) or Benzú cave (Ceuta) (Vijande-Vila et al. 2019).

Table 7 Biometric data of the smoothers documented at Cabecicos Negros

#	Taxa	Type	Height (mm)	Length (mm)
27	*Glycymeris* sp.	R	37.36	38.72
249 a	*Cerastoderma* sp.	R	16.84	17.14
474	*Cerastoderma* sp.	R	24.32	23.56
567	*Glycymeris* sp.	Fr	22.18	54.4

From the taxonomic point of view, the results show a greater use of shells of the *Glycymeris* genus to develop the smoothing of the ceramic. *Glycymeris* shells represent 52%, whereas shells of the *Cerastoderma* genus comprise 42% of the total assemblage. In this way, at Cabecicos Negros the difference between the technological use of both genera is not significant. Archeologically we have found similar cases where different kinds of shells were used to carry through the same task, for example, at El Toro cave (Málaga, Spain) (Cuenca-Solana et al. 2021), and at Diconche (Saintes, France) (Cuenca-Solana et al. 2015).

From the biometric analysis (Table 7), we hypothesize that, in some cases, the selection of small-sized shells could be linked to the undertaking of specific activities. In this way, piece #249a, which is small in size (16.84 mm in height × 17.14 mm in length), was used to standardize ceramic walls. As a result, it could have also been used in other specialized tasks within the ceramic process, such as the treatment of the edge of the vessel or the treatment of the handle system when the ceramic paste was still wet.

Cardial pottery decorations

As a result of the functional analysis, it has also been possible to document a second group of tools, made up, in this case, of 16 pieces (#119, #182, #236, #237, #256a, #256b, #287a, #287b, #293a, #309, #343, #393, #796, #828, #833a and #833b) (Table 6). The use-wear traces on these tools show the development of a transversal kinematics action, using the edge and the internal face as the active zone. The results obtained during the analytical experimental program allowed us to verify that these tools were used to make cardial decoration impressions on clay. It was also possible to determine that the alterations did not show the same development degree in each of the 16 tools.

By carrying out the experimental program it was possible to verify that the traces increased as working time increased. The results obtained allowed us to hypothesize that the tools with greater wear (#119, #182, #236, #256a, #256b, #287a, #287b and #293a) were used for longer periods, and therefore could be reused in several production cycles. Taking these data into account, we consider that the remains with greater development of the traces could have been used either to decorate more than one ceramic vase (given that the degree of the alterations is linked to a use longer than 2 min), or larger ceramic vessels. Despite this, it is worth mentioning that none of the pieces aimed at carrying out the cardial decoration process reaches the development level of the smoothers #27 and #249a. For this reason, we think that, at least in the case of Cabecicos Negros, the shell tools used to develop cardial decoration were used more expeditiously than the smoothers. In this way, these elements would have been discarded after the end of each production cycle, that is, at the end of the decoration process of the ceramic vessel or vessels for which they were used.

From a taxonomic point of view, all the cardial decoration shell tools are associated with the use of complete valves or fragments of the genus *Cerastoderma*, which fits with the traditional interpretation that associates cardial-type ceramic decoration with the use of shells of the *Cardiidae* family. On the other hand, in terms of the size and morphology of these tools (Table 8), 77.23% of them correspond to the use of shell fragments, compared to 22.73%, which represents complete vales. In addition, it is worth mentioning that despite being complete valves, their dimensions are very small. These data verify the hypothesis generated by the first stage of analytical experimental work, which established a preferential use of fragments to achieve the cardial decoration process, while the reduced size of the complete shells seems to be linked to a selection for a specific activity within the ceramic manufacturing and decoration process.

Table 8 Biometric data of the cardial pottery decoration shell tools documented at Cabecicos Negros

#	Taxon	Type	Height (mm)	Length (mm)
119	*Cerastoderma* sp.	L	16.78	16.55
182	*Cerastoderma* sp.	Fr	22.75	23.97
236	*Cerastoderma* sp.	Fr	12.06	14.12
237	*Cerastoderma* sp.	Fr	24.58	14.14
256 a	*Cerastoderma* sp.	Fr	11.04	16.82
256 b	*Cerastoderma* sp.	Fr	12.59	21.29
287 a	*Cerastoderma* sp.	R	21.82	25.43
287 b	*Cerastoderma* sp.	Fr	26.69	31.77
293 a	*Cerastoderma* sp.	Fr	7.86	10.87
309	*Cerastoderma* sp.	Fr	11.3	5.77
343	*Cerastoderma* sp.	Fr	24.56	19.85
565	*Cerastoderma* sp.	Fr	16.03	22.07
796	*Cerastoderma* sp.	L	19.67	19.9
828	*Cerastoderma* sp.	Fr	10.45	8.23
833 a	*Cerastoderma* sp.	L	21.05	21.79
833 b	*Cerastoderma* sp.	Fr	11.45	12.06

Social and sexual organization of the pottery production at Cabecicos Negros

The analytical experimental program made it possible to obtain different results. The greater efficiency of the shell fragments for cardial decoration, as well as the reduced size of all the shells, have led us to consider new hypotheses regarding the social distribution of work. During the experiment with these tools, we observed that the size of the hands to skilfully handle such small tools should also be small. For this reason, considering what was experienced during the experiment, as well as the biometric analysis of the archaeological tools, could be probable that, at least the cardial decoration stage of pottery production may have been developed mainly by women and even children as one of the many maintenance activities that were carried out in the daily life of the place. That is, children helping their mothers, or even as some sort of game. We can find examples of the sexual organization of pottery work in a large number of ethnographic studies. For example, in Spain, the traditional pottery production process developed in the Canary Islands is carried out by women (Rodríguez and Navarro 1999), or the case of the potters of the Gzaua tribe (Chefchauen, Morocco) (González-Urquijo et al. 2001). On the other hand, the participation of the youngest members of the human groups cannot be discarded. Ethnographic sources show us that, for example, the gathering of marine molluscs in some groups of Australian aborigines (Meehan 1982) or among populations of the west coast of North America (González-Vázquez 2000) is done by children. Going further, we also have ethnographic examples where children are part of the ceramic production process, being taught how to produce it from a young age. This is the case, for example, with Swahili children aged 1 to 5 (Donley-Reid 1990; Kamp 2001a, 2001b), the Asurini do Xingu (Brazil) (Silva 2008), or Cameroon's Dii, (Wallaert 2001) where apprenticeship begins at age 7 and lasts between 5 and 8 years, with about 4 h of apprenticeship per day in the dry seasons and 2 h a day the rest of the year. Another interesting example is the case of the Shipibo Conibo (Kamp 2001a), an indigenous group from North America, where girls receive lessons and practice on vessels previously made by adults where the decorative patterns are not yet clearly made. On the other hand, it is also worth highlighting the ceramic miniatures recognizable by their small size and/or low quality made by children during their apprenticeship. For instance, the case of the Swahili girls (Donley-Reid 1990) who make small pots to practice, which they also use as toys and to learn to cook (Garrido-Pena and Herrero-Corral 2015). Despite this ethnographic evidence, proposing a definite interpretation of a social nature is extremely complex, although we hope that in the future it will be possible to verify these hypotheses based on the development of new analyses on other archaeological assemblages as well as from new experimental approaches.

The interpretation of Cabecicos Negros

The results obtained in this study, along with those that have been developed in recent years in other similar contexts (Clemente-Conte et al. 2019; Cuenca-Solana et al. 2015; Vijande-Vila et al. 2019, etc.), show the importance that shell tools have had in the development of different technical processes linked to ceramic manufacturing and decoration. Specifically, at Cabecicos Negros it has been possible to verify that all the shell tools documented were only used to develop different stages of the ceramic manufacturing process. *Glycymeris* and *Cerastoderma* for smoothing, and only *Cerastoderma* for decorating, with no other use of these tools to work on other types of raw materials. On the other hand, we have been able to see that the wear levels of some tools are linked to their continued use. Therefore, these human groups had their own toolkits, which they preserved and kept for a long time. On the other hand, for other stages of the ceramic process, specifically for decorating, the tools had an expeditious use, that is, they used them and discarded them. This action is consistent with the ease with which you can find and collect *Cerastoderma* shells, and how easy it would be to fracture the shell at the site if necessary. This is something that we were able to verify during the preparation of the material for the experimentation (see 3.3.1.). Thus, we can hypothesize that this type of tool was prepared in situ due to the need to respond to a specific demand: to manage the cardial decoration of a specific vessel at a specific moment in time. However, other remains, such as smoothers, seem to have a specific morphology and characteristics that make them unique, and therefore not so easy to obtain. For this reason, it makes sense that Neolithic potters showed concern for preserving these tools, to reuse them and always be able to achieve this activity efficiently. In relation to this, it is worth mentioning the perforations found in some of these tools, which further support this theory.

The archaeomalocological study showed that some shells could initially be oriented towards a bromatological use, and later, to a technological use. However, in some cases we know from the taphonomic analysis and the pronounced marine abrasion that some shells were collected post-mortem and, therefore, were only used as raw materials in the production of tools. This is the case of smoothers #27 and #249a. In this way, we are faced with evidence that shows an intentional selection of this type of tools, which also fits with their recurrent use and them being part of the stable toolkit of potters.

The research carried out has also allowed for a general interpretation of the context of Cabecicos Negros and to better understand the characteristics of the Neolithic occupation. On the one hand, as we have already indicated, during the ancient Neolithic this archaeological site functioned as a production and distribution centre of ornamental elements, basically bone and stone bracelets manufactured using lithic tools and with a high degree of standardization (Goñi-Quinteiro et al. 1999, Rodríguez-Rodríguez 1999). The results we have obtained show that some specific areas within the site were used to manufacture in situ at least part of the recovered ceramic production. This interpretation is based on the presence of smoothers and expeditive cardial decoration tools in some specific areas of the site. In this way, the hypothesis that could explain the presence of these tools at Cabecicos Negros, especially the expeditious ones, is that at least part of the ceramic production was carried out at the site itself. At the same time, it is worth mentioning that a study of the ceramic paste, which is currently underway, has allowed researchers to locate -near the site- the outcrops of clays that were exploited by the human groups of Cabecicos Negros (Clop-García, personal communication). Finally, regarding the type of ceramic production that took place at Cabecicos Negros, we propose that it would have been domestic in nature considering the small amount of remains found, and especially the lack of large combustion structures. For this reason, we propose that the ceramic production at Cabecicos Negros would have been for the daily use of the group.

Conclusions

To conclude, highlight the importance of pottery studies, especially those related to the *chaîne opératoire,* to learn about past societies. Thus, as we have seen before, we can learn new things about people behind pottery production, their way of life, their social relationships, and their relationship with their environment.

We must consider the interesting results obtained when we analyse archaeological remains using new perspectives. This is the case of the archeomalacological material, traditionally related as a food source, but through the application of functional analysis, we have been able to define different types of uses, such as their participation in the ceramic manufacturing process.

Thereby, the study of other tools that took part in the ceramic production and the application of the functional analysis methodology have allowed us to confirm something that until now had not been proven, that is, the use of *cardium* shells to make cardial decorations on ceramics. In this way, besides confirming their use to make cardial decorations, we have also been able to characterize and define the use-wear traces through the development of the experimental program. In addition, we also see the different types of management that each tool can have according to its functionality, for example, the reuse of the smoothers in contrast to the expeditious use of the cardial shell tools.

Acknowledgements We must thank the *Instituto Internacional de Investigaciones Prehistóricas de Cantabria* (IIIPC) for the loan of the microscope spaces and equipment, without which it would not have been possible to manage this research. And, specifically, to the BIOPAL group for their collaboration and willingness, as well as to our colleagues Julia Sañudo (University of Cantabria) and Antonio León Castelao (University of Cantabria) for their collaboration in the development of the experimental program.

Author contribution DCS and ELA designed the study.

DMCM, DMS, ELA obtained the original images.

AGE, DCS, DMSM, DMS, ELA, XCG obtained the data used in the study.

DCS and ELA wrote the main manuscript.

ELA, DCS, DMCM, DMS prepared the figures.

ASG, DMCM, DMS, JSR, XCG reviewed the manuscript.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. The publication of this paper is supported by the project PID2021-124589NA-I00 financed by MCIN/AEI/10.13039/501100011033/ FEDER, UE. During the development of this research project, DCS was funded by the Ramón y Cajal program, (grant RYC2022-036585-I)(Ministerio de Ciencia e Innovación, Spain). Also, during the development of this research project, AGE was funded by the Catalonia Postdoctoral Programme through a Beatriu de Pinós Fellowship (grant number 2020 BP 00240) and he is currently working in the framework of a Marie Skłodowska Curie – Postdoctoral Fellowship (grant reference: HEU-101064225-NEAR-COAST), funded by the European Union. As well as the I + D project *Producción y Consumo*:*Las artesanías de las primeras sociedades campesinas en Andalucía oriental entre VI y el III milenio A.C.* (PID2019-104442 GB-I00). IP: M.D.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Afonso JA (1993) Aspectos Técnicos de la Producción Lítica de la Prehistoria Reciente de la Alta Andalucía y del Sureste. Tesis Doctoral Universidad de Granada, Microfilmada

Arteaga O, Hoffmann G (1987) Investigaciones geológicas y arqueológicas sobre los cambios de la línea costera en el litoral de la Andalucía mediterránea. Anuario Arqueológico De Andalucía II:194–195

Arteaga O, Hoffman, G (1999) Dialéctica del proceso natural y sociológico en las costas mediterráneas de Andalucía. *Revista atlántica-mediterránea de prehistoria y arqueología social* (1138945) 2: 13–121

Arteaga O, Hoffmann G, Schubart H (1985) Schulz HD (1985) Investigaciones geológicas y arqueológicas sobre los cambios de la línea costera en el litoral de la Andalucía mediterránea. Anuario Arqueológico De Andalucía II:117–122

Balfet H (1966) La céramique comme document archéologique. Bulletin De La Société Préhistorique Francaise 63(2):279–310

Camalich-Massieu MD, Martín-Socas D (1999) El territorio almeriense desde los inicios de la producción hasta fines de la Antigüedad. Un modelo: la depresión de Vera y cuenca del río Almanzora. *Arqueología Monografías, Junta de Andalucía*. Consejería de Cultura. Dirección General de Bienes Culturales, Servicio de Investigación y Difusión del Patrimonio Histórico. Sevilla

Camalich-Massieu MD, Martín-Socas D, González-Quintero P, Mederos-Martín A, Goñi-Quintero A (2004) Análisis diacrónico del poblamiento en la Depresión de Vera y valle del río Almanzora entre el VI y el III milenio ANE. *Actas de las Jornadas Temáticas Andaluzas de Arqueología: Sociedades recolectoras y primeros productores*, Sánchez de las Heras C, coord. Dirección General de Bienes Culturales, Sevilla: 163–176

Camalich-Massieu MD, Rodríguez-Santos FJ, Santana-Cabrera J, Caro-Herrero JL, Martos-Romero JA, Cacho Quesada C, Martín-Socas D (2020) Implantación y desarrollo de las estrategias agropecuarias en el Sureste: la depresión de Vera (Almería), Díaz del Río P, Lillios K, Sastre I, coord. *The matter of Prehistory: Papers in honor of Antonio Gilman Guillen*. *Bibliotheca Praehistorica Hispana* XXXVI. Madrid 173–192

Camalich-Massieu MD, Martín-Socas D (2013) Los inicios de Neolítico en Andalucía. Entre la tradición y la innovación. Entre Dos Aguas. Tradición e Innovación en las Sociedades Neolíticas de Andalucía. Menga Revista De Prehistoria De Andalucía 04:103–129

Clemente-Conte I, Orozco-Köhler T (2012) El uso de conchas marinas como soporte de útiles pulimentados: una pieza recuperada en Costamar (Castellón). *SAGVNTVM* Papeles del Laboratorio de Arqueología de Valencia, 44:39–46. https://doi.org/10.7203/SAGVNTVM.44.1773

Clemente-Conte I, Cuenca-Solana D, Oliva-Poveda M, Rosillo-Turra R, Palomo-Pérez A (2014) Comparative analysis of Mytilus shell implements from two Neolithic sites in NE Iberia: La Draga and Serra del Mas Bonet (Girona). *Int Conf Use-Wear Anal. Use-Wear:* 615–626

Clemente-Conte I, Mazzucco N, Cuenca-Solana D, Mozota-Holgueras M, Díaz-Bonilla S (2019) Cerámica prehistórica y kit instrumental para su producción cerámica. Descripción del registro arqueológico de Coro Trasito (Tella-Sin, Huesca). *Treballs d´Arqueologia* 23:117–152. https://doi.org/10.5565/rev/tda.100

Clop-García X (2019) Tierras, pastas y vasos. Algunas cuestiones en torno a la investigación sobre la gestión de las materias primas para hacer cerámica. *Treballs d´Arqueologia* 23:13–35. https://doi.org/10.5565/rev/tda.105

Cristiani E, Lemorini C, Martini F, Sarti L (2005) Scrappers of Callista chione from Grotta del Cavallo (Middle Paleolithic cave in Apulia): evaluating use-wear potential, *From hooves to horns, from mollusc, to mammoth. Manufacture and use of bone artefacts from prehistoric times to the present.* Procedings of the 4th meeting of the ICAZ Worked bone Research Group at Tallin: 319–324

Cuenca-Solana D (2013) Utilización de instrumentos de concha para la realización de actividades productivas en las formaciones económico-sociales de cazadores-recolectores-pescadores y primeras sociedades tribales de la fachada atlántica europea. PhD. PUbliCan, Ediciones Universidad de Cantabria. http://hdl.handle.net/10902/1879

Cuenca-Solana D (2015) The use of shells by Hunter-Fisher-Gatherers and Farmers from the Early Upper Paleolithic to the Neolithic in the European Atlantic Façade: A technological perspective. The Journal of Island and Coastal Archaeology 10(1):52–75. https://doi.org/10.1080/15564894.2014.934491

Cuenca-Solana D, Clemente-Conte I (2017) Pasado presente y futuro del análisis funcional aplicado al estudio de los instrumentos de concha prehistóricos. CPAG 27:293–314

Cuenca-Solana D, Clemente-Conte I, Fi G-Z (2010) Utilización de instrumentos de concha durante el Mesolítico y Neolítico inicial en contextos litorales de la región cantábrica; programa experimental para el análisis de las huellas de uso en materiales malacológicos. Trab Prehist 67(1):211–225

Cuenca-Solana D, Gutiérrez-Zugasti I, Clemente-Conte I (2011) The use of molusc shells as tool by coastal human groups. Contribution of ethnographical studies to research on Mesolithic and Early Neolithic technologies in Northen Spain. J Anthropol Res Spring 67(1):77–102

Cuenca-Solana D, Gutiérrez-Zugasti I, Mr G-M, Setién-Marquinez J, Ruiz-Martinez E, García-Moreno A, Clemente-Conte I (2013b) Shell Technology, Rock Art, and the Role of Marine Resources during the Upper Paleolithic. Curr Anthropol 54(3):370–380

Cuenca-Solana D, Gutiérrez Zugasti I, Ruiz Redondo A, Mr GM, Seitén J, Ruiz-Martínez E, De Las H-M, Prada-Freixedo A, Lasheras-Corruchaga JA (2016) Painting Altamira Cave? Shell tools for ochre-processing in the Upper Paleolithic in northern Iberia. J Archaeol Sci 74:135–151

Cuenca-Solana D, Cantillo-Duarte Jj, Vijande-Vila E, Montañés-Caballero M, Clemente-Conte I, Villapando-Moreno A (2013a) Utilización de instrumentos de concha para la realización de actividades productivas en sociedades tribales comunitarias del sur de la Península Ibérica. El ejemplo de Campo de Hockey (San Fernando, Cádiz) y SET Parralejos (Vejer de la Frontera, Cádiz). *Zephyrus*, LXXII:95–111. https://doi.org/10.14201/zephyrus20137295111

Cuenca-Solana D, Dupont C, Hamon G (2015) Instrumentos de concha y producción cerámica en los grupos neolíticos de la costa Atlántica del oeste de Francia, *La investigación arqueomalacológica en la Península Ibérica: Nuevas Aportaciones.* Acticas de la IV Reunión de Arqueomalacología de la Península Ibérica 101–111

Cuenca-Solana D, Rodríguez-Santos FJ, Nonza-Micaelli A, Cantillo-Durante Jj, Clop-García X, Camalich-Massieu MD, Martín-Socas D (2021) Los instrumentos de concha y la producción alfarera durante el Neolítico en la Cueva del Toro (Antequera, Málaga). In *Avances en Arqueología. Nuevos conocimientos sobre las sociedades pasadas y su entorno natural gracias a los moluscos. Monografies de la Societat d'Història Natural de les Balears,* 32:121 – 152. ISBN 978–84–09–27590–8

Donley-Reid LW (1990) A structuring of structure: the Swahili house. In: Kent S (ed.) *Domestic Architectura and the Use of Space*. Cambrige University Press, 114–126

Dupont C (2003) La malacofaune de sites mésolithiques et néolithiques de la façade atlantique de la France: contribution à l'économie et à l'identité culturelle des groupes concernés. Université Paris I, PhD

Dupont C and Cuenca-Solana D (2014) Outil ou parure sur coquille marine. *Une enceinte du Néolithique moyen II, des fosses du Néolithique moyen I et du Bronze final sur le littoral de la Mer du Nord. Escalles «Mont d'Hubert»*, Nord-pas-de-Calais, Contribution au rapport de fouille préventive (Praud, I., dir.), Inrap 138–159

Emperaire J (1955) *Les nomades de la mer,* Collection L´ espèce humaine, Gallica

García-Escárzaga A, Rodríguez-Santos Fj, Martínez-Minchero M, Camalich-Massieu M D, Martín-Socas D (in press) Análisis arqueomalacológico y relaciones elementales Sr/Li en *Cerastoderma Edule* (Linnaeus, 1758) del yacimiento Neolítico de Cabecicos Negros (Vera, Almería). *III Congreso e Jóvenes investigadoras/es de la Prehistoria y Protohistoria de Andalucía* (Antequera, 2017) Antequera. *Menga. Revista de prehistoria en Andalucía*

Garrido-Pena R, Herrero-Corral A (2015) Children as potters: apprenticeship patterns from bell breaker pottery of Copper Age Inner Iberia (Spain) (C, 2500–200 cal BC). *Children, Spaces and Identity* (ed.) Sánchez Romero M, Alarcón García E and Aranda Jiménez G, Oxbow Books 4:40–58

Goñi-Quinteiro A, Chávez-Álvarez E, Cámalich-Massieu MD, Martín-Socas D, González-Quintero P (2003) Intervención arqueológica de urgencia en el poblado de Cabecicos Negros (Vera, Almería) Informe Preliminar. Anuario Arqueológico De Andalucia 1:73–87

Goñi-Quinteiro A., Rodríguez-Rodríguez AC, Camalich-Massieu MD, Martín-Socas D, Francisco-Ortega MI (1999) La Tecnología de los elementos de adorno personal en materias minerales durante el Neolítico Medio. El ejemplo del poblado de Cabecicos Negros (Almería), en *II Congrés del néolitic a la Península Ibérica*. *Sagvntvm-Plav*, Extra-2:163–170

González-Urquijo J, Ibáñez-EstévezZapata-Peña JjL, Peña-Chocarro L (2001) Estudio etnoarqueológico sobre la cerámica gzaua (Marruecos). Técnica y contexto social de un artesanado arcaico. Trabajos de Prehistoria 58(1):5–27

González-Vázquez A (2000) Aprovechamiento de recursos acuáticos en California y Alaska: cazadores-recolectores en las fuentes escritas de los siglos XVI XVII y XVIII. Nivel Cero 8(2000):77–93

Gusinde M (1986) *Los Indios de Tierra de Fuego. Los Yámana,* Centro Argentino de Etnología Americana, Consejo Nacional de Investigacones Cietífcas y Técnica. Buenos Aires

Gutiérrez-Zugasti I (2009) La explotación de moluscos y otros recursos litorales en la región cantábrica durante el Pleistoceno final y el Holoceno inicial. Publican, Ediciones Universidad de Cantabria, Santander

Harrison R, Orozco Köhler T (2001) Beyond Characterisation: Polished Stone Exchange in the Western Mediterranean. Oxford J Archeol 20(2):107–127

Heaton TJ, Bard E, Bronk Ramsey C, Butzin M, Köhler P, Muscheler R, Reimer PJ, Wacker L (2021) Radiocarbon: A key tracer for studying Earth's dynamo climate system carbon cycle and Sun Using carbon-14 *Science* 374(6568). https://doi.org/10.1126/science.abd7096

Jiménez-Guijarro J, Rojas Rodríguez-Malo JJ (2018) Caracterización de las cerámicas impresas cardiales y pseudocardiales de la cuenca del Tajo, Mauro S. Hernández Pérez, Jorge A. Soler Díaz, Juan Antonio López Padilla coord. *IV Congreso del Neolítico Peninsular* (2)*:*222–230

Kamp KA (2001a) Prehistoric children working and playing: a southwestern case study in ceramics. J Anthropol Res 57(4):427–450

Kamp KA (2001b) Where have all the children gone?: The archaeology of childhood. J Archaeol Method Theory 8(1):1–4

Manca L (2016) The shell industry in Final Neolithic societies in Sardinia: characterizing the production and utilization of Glycymeris da Costa, 1778 valves. Anthropozoologica 51(2):149–171

Mansur ME, Clemente-Conte I (2009) ¿Tecnologías invisibles? Confección, uso y conservación de instrumentos de valva en Tierra

del Fuego, *Arqueología Argentina en los inicios de un nuevo siglo: publicación del XIV Congreso Nacional de Arqueología Argentina*, Rosario. Universidad Nacional de Rosario, 359–367
Martin-Socas D, Camalich-Massieu MD, Herrero-Carol JL, Rodríguez-Santos FJ (2018) The beginning of the Neolithic in Andalusia. Quaternary International 470:451–471. https://doi.org/10.1016/j.quaint.2017.06.057
Matson FR (ed) (1965) Ceramic and man. Aldine Publising Company. Chicago
Meehan B (1982) Shell bed to shell midden. Camberra, Humanitie Press, Australian Institute of Aboriginal Studies
Moreno, R. (1994). Análisis arqueomalacológicos en la Península Ibérica. Contribución metodológica y biocultural, PhD, Universidad Autónoma de Madrid, Madrid. https://hdl.handle.net/10486/673139
Orozco-Köhler T (2016) Los brazaletes de esquisto: un element de la identidad cardial. Del neolitic a l'edat del bronze en el Mediterrani occidental. Estudis en homenatge a Bernat Martí Oliver, Valencia, TV SIP 119:141–146
Prous A (1992) Os moluscos e a arqueologia brasileira. Arquivos Do Museu De História Natural 11:241–298
Reimer R, Reimer PJ (2017) An Online Application for ΔR Calculation. *Radiocarbon Journal*. https://doi.org/10.1017/RDC.2016.117
Rodríguez A, Navarro JF (1999) La industria malacológica de la cueva de El Tendal (San Andrés y Sauces, isla de La Palma). Vegueta 4:75–100
Rodríguez-Rodríguez A, Jf G-B, Perales-Barrón U, Clemente-Conte I (2013) Comunidades campesinas, pastoras y artesanas. Traceología de los procesos de trabajo durante el Neolítico andaluz. Menga Revista d Prehistoria De Andalucía 04:35–50
Rodríguez-Rodríguez A (1999) Análisis funcional del instrumental lítico tallado del poblado de Cabecicos Negros. In *El territorio almeriense desde los inicios de la producción hasta finales de la antigüedad, Arqueología Monografías,* Junta de Andalucía. Consejería d Cultura 225–235
Romagnoli F, Baena J, Sarti L (2015) Neanderthal retouched shell tool and Quina economic and technical strategies: an integrated behavior. Quaternary International 407(B):29-44. https://doi.org/10.1016/j.quaint.2015.07.034
Rousseau L, Gandois H, Favrel Q, Cuenca-Solana D, Dupont C, Garnier N, Guéret C, Laforge M, Poissonnier B, Vigneau T (2020) Cinquante ans après la découverte : état des connaissances et apport des fouilles récentes sur le site campaniforme de la République à Talmont-Saint-Hilaire (Vendée). Bulletin De La Société Préhistorique Française 117(1):47–84
Salanova L (1992) Le décor à la coquille dans le campaniforme du Sud-Finistère. *Revue Archéologique De L'ouest* 9:79–81
Salanova L and Prieto-Martínez MP (2011) Una aproximación al empleo de la concha para decorar la cerámica campaniforme en Galicia. Las Comunidades Campaniformes en Galicia. *Cambios sociales en el III y II milenios BC en el NW de la Península Ibérica,* María Pilar Prieto Martínez, Laure Salanova coord. Pontevedra, Diputación de Pontevedra 297–307.
Semenov SA (1964) *Prehistoric Technology*, 211. Cory, Adams & Mackay, London
Shepard A (1956) Ceramics for the Archaeologist. Carniege Institute of Washington, Washington
Silva FA (2008) Ceramic technology of the Asurini do Xingu, Brazil: an ethnoarchaeological study of artifact variability. J Archaeol Method Theory 15(3):217–265
Tarifa-Mateos N, Saña M, Clop-García X, Rosell-Melé A, Camalich-Massieu Md, Martín-Socas D (2023) Investigating livestock management in the Early Neolithic archaeological site of Cabecicos Negros (Almería, Spain) from the organic residue analysis in pottery. Nat Sci Rep 13:47–97
Thomas J (2016) House Societies and the Beginning of the British Neolithic. Debert J, Larsson M, Thomas J, eds. In *Dialogue: Tradition and Interaction in the Mesolithic-Neolithic Transition,* 2809:3–10. British Archaeological Reports (BAR), International Series. Archaeopress, Oxford
Vega-Maeso C (2017) La cerámica inciso-impresa en el tránsito del III al II milenio cal. B.C. en la región Cantábrica. PhD, Universidad de Cantabria, *Nadir Edic*. Santander
Vijande-Vila E, Jj C-D, Ramos-Muñoz J, Bernal-Casasola D, Domínguez-Bella S, Almisas-Cruz S, Clemente-Conte I, Mazzucco N, Soriguer Escofet M, Ruiz-Zapata B, Mj G, Uzquiano P, Zurro D, Antonio Riquelme J, Sánchez-Marco A, Rosas A, Estalrich A, Bastir M, Cuenca-Solana D, Moreno-Márquez A, Martínez-Cuesta R, Ramos-García P (2019) The occupation of Benzú cave (Ceuta, Spain) by Neolithic and Bronze age societies. Afr Archaeol Rev 36:17–338
Wallaert H (2001) Learning how to make the right pots: apprenticeship strategies and material culture, a case study in handmade pottery from Cameroon. J Anthropol Res 57:471–493