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RESEARCH

Shell Tools and Use-Wear Analysis: a Reference Collection for Prehistoric Arabia

Kevin Lidour[1,2] · **David Cuenca Solana**[1,3]

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Abstract
Prehistoric and Archaeological research has pointed out the role of marine resources in modern humans' cognitive and cultural developments. Maritime adaptations constitute a key component of the sociocultural evolution in Eastern Arabia. During the Neolithic (c. 6500–3300 BCE), it is expressed by the colonisation of offshore islands supported by advanced seafaring and the exploitation of marine resources not only for staple food but also for obtaining hard animal materials used for both symbolic and technological productions, respectively in the form of personal adornments and tooling. Although tools made of retouched large marine mollusc shells are reported on several sites, no detailed study has been conducted on their function and role within the socio-technological processes.
The present study introduces a prospective approach for the functional analysis of archaeological shell tools from Eastern Arabia. A reference collection of use-wear traces made experimentally has been built: it compiles the results of 65 experiments (23 are documented and illustrated in the present study), including the processing of various animal, vegetal, and mineral materials. Use-wear traces have been observed and described using both low and high-power magnifications (conducted mainly at 100×). It provides helpful methodological support for future comparisons with archaeological specimens. The procurement conditions of the shell valves and the techniques of retouch have been discussed in detail, allowing further considerations on the degree of the socio-technological investment devoted to these peculiar artefacts.

Keywords Archaeomalacology · Shell tools · Use-wear analysis · Arabia · Prehistory

Extended author information available on the last page of the article

Introduction

General

The coastal ecosystems constitute major reservoirs of biomass and biodiversity that humans exploited quite early on. First evidence of consumption of seafood (marine molluscs and fish) has been documented by c. 165 ka at Pinnacle Point and c. 75 ka at Blombos Cave in South Africa for anatomically modern human populations (*e.g.* Henshilwood & Sealy, 1997; Marean et al., 2007), and by 150–65 ka in the Iberian Peninsula (*e.g.*, at El Bajondillo, Andalusia) for Neanderthals (Cortés Sánchez et al., 2011). Meanwhile, shell industries took a prominent place within studies discussing human cognitive and behavioural developments (*e.g.* Erlandson, 2001; Parkington, 2001; Toth & Schick, 1993; Will et al., 2019): first and foremost, shell adornments which are related to the earliest manifestations of symbolism and aesthetic (c. 135–75 ka in Africa, Levant, and southern Spain) (*e.g.* D'Errico et al., 2009; Hoffmann et al., 2018), and shell tools whose ancient use has been reported not only for modern humans but also for *Homo erectus* (c. 540–430 kya at Trinil, Java Island, Indonesia) (Joordens et al., 2015) and *Homo neanderthalensis* (during the MIS 5–3 in the Mediterranean) (*e.g.* Cristiani et al., 2005; Douka & Spinapolice, 2012; Romagnoli et al., 2015, 2016).

Shell tools receive a growing interest during the second half of the twentieth century, firstly in regions where ethnographic information took a great place within the archaeological research: in the Americas (*e.g.* Emperaire, 1958; Suárez Díez, 1974; Johnson, 1978; Dacal Moure, 1978; Armstrong, 1979; Dacal Moure & Rivero de la Calle, 1984; Gusinde, 1986; Suárez Díez, 1989; Prous, 1990; Marquardt, 1992), in Australia (*e.g.* Akerman, 1975; Akerman & Bindon, 1984), and in the Pacific (*e.g.* Leroi-Gourhan, 1945; Rosendahl, 1969; Craib, 1977; Spennemann, 1993)—including in the form of shell fishhooks (*e.g.* Allen, 1996; Bowdler, 1976; Davidson, 1967; Emory et al., 1959; Lampert & Turnbull, 1970; Sinoto, 1962; Skinner, 1942). Ethnographic sources have highlighted the universal use of shell tools by pre-industrial coastal societies (Cuenca Solana & Clemente Conte, 2017; Cuenca Solana et al., 2011). In these regions, studies have consisted essentially of typo-functional classifications based on morphological analyses of the shell tools.

In parallel, new approaches have been developed during the 1980s–1990s, especially in France, driven by technical system studies. Here, we have to mention the works of Vigié and Courtin (*e.g.* Courtin & Vigié, 1987; Vigié, 1987, 1992; Vigié & Courtin, 1986) on the 'denticulated shells' from Mesolithic and Neolithic assemblages of southern France, which were based on the observation of the modified areas of the valves at low magnification (below 100×) using stereomicroscopy. Barton and White (1993) from the University of Sydney had a similar approach for studying shell tools recovered from Papua New Guinea in the early 1990s. Low magnifications, however, did not allow to identify the materials that have been processed. The use-wear analysis methodology using higher magnifications by scanning electron microscopy (SEM) has been performed in the late 1990s by Gruet et al. (1999) on Neolithic shells from Atlantic France. This functional analysis is based on the macro- and the microscopic observation of use-wear traces produced on the active area of the tool—a methodology initiated by Semenov (1964) for the study of lithic tools. It has developed mainly during the 1970s with the works of Tringham and his students (*e.g.* Keeley, 1974; Odell, 1977; Tringham et al., 1974). During the last decades, use-wear studies have been extended to tooling made of other materials, particularly bone (*e.g.* Bradfield, 2015; Maigrot, 2003; Peltier & Plisson, 1986) and mollusc shells.

The use-wear analysis methodology was more systematically applied for the study of shell tools during the last 20 years: in the Caribbean (Lammers Keijsers, 2008), in Oceania (*e.g.* Szabó & Koppel, 2015; Weston et al., 2017), and in Europe with the support of increased exploitation of experimental data—comparisons of use-wear traces produced experimentally with archaeological specimens are facilitating the identification of the material processed (Cuenca Solana et al., 2010; Gutiérrez Zugasti et al., 2011). It includes the recent works of Cristiani and Romagnoli on shell scrapers from Neanderthal-associated contexts in Italy and Greece (Cristiani et al., 2005; Romagnoli et al., 2017); of Manca (2013, 2016) on shell tools from Neolithic-Chalcolithic Sardinia (Italy); and the contribution of Cuenca Solana and other scholars on assemblages from the Upper Palaeolithic to the Neolithic in the Iberian Peninsula and Atlantic France (*e.g.* Cuenca Solana, 2013; Cuenca Solana & Clemente Conte, 2017; Cuenca Solana et al., 2010, 2011, 2013a, 2013b, 2014, 2015, 2021; Dupont & Cuenca Solana, 2014; Gutiérrez Zugasti et al., 2011; Tumung et al., 2015).

Archaeological Setting

Although the human presence in the Arabian Peninsula remains little documented during the Pleistocene—restricted to a few areas (*e.g.* Armitage et al., 2011; Bretzke et al., 2022; Petraglia et al., 2012)—archaeological evidence dating from the Neolithic (c. 6500–3300 BCE) are significantly more numerous. Arid and semi-arid conditions occurring in the Arabo-Saharan belt have bound, quite early on, the past human groups to migrate towards coastal areas that could have constituted important ecological refuges by providing abundant faunal and vegetal resources (Rose, 2010). These coastal refuges have been recently conceptualised as a 'Southern Crescent' by Rose (2022). Indeed, coastal Arabia hosts a diversified range of marine ecosystems, including mangroves, seagrass meadows, and coral reefs that are recognised as major tropical marine 'biodiversity hotspots' (Harold et al., 2010; Sheppard et al., 1992) (Fig. 1). These ecosystems have supported the development of mixed economies based mainly on pastoralism and the exploitation of marine resources. Rainfall has never been sufficient in the region to support the development of rain-fed agriculture—oasis agriculture has developed from the Bronze Age onwards using original irrigation systems. In that respect, the exploitation of marine resources took on greater importance and has greatly developed in this region throughout the

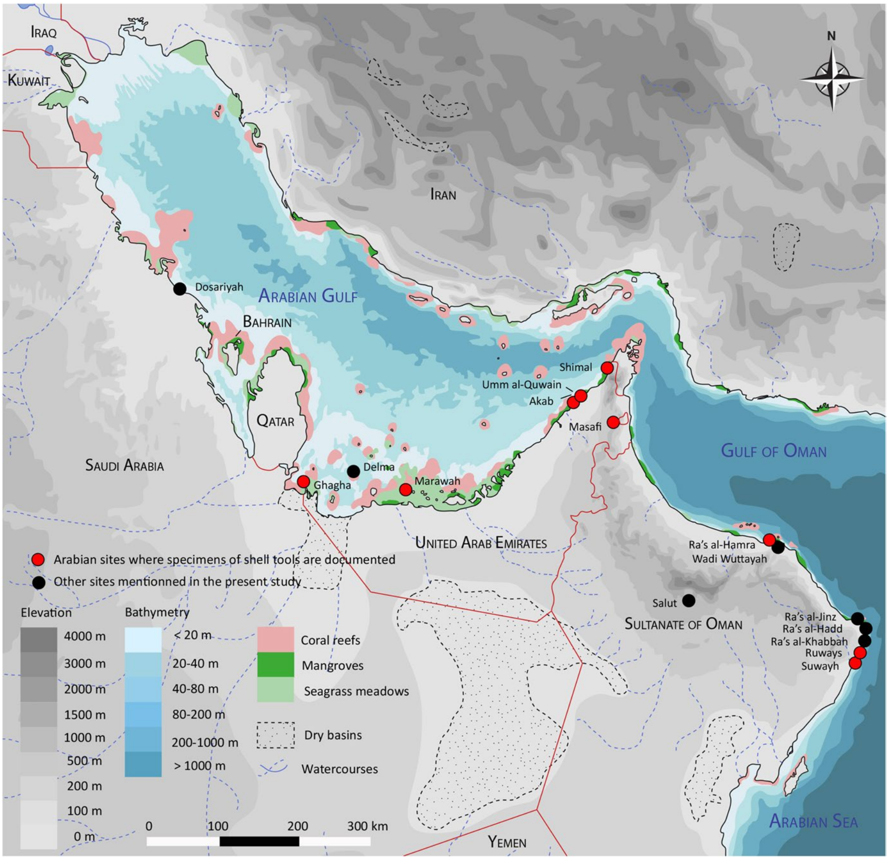


Fig. 1 Map of Eastern Arabia showing the location of the site where valve tools have been documented so far and the other sites mentioned in the present paper (CAD with Adobe Illustrator)

Holocene, showing a high degree of sophistication that has been rarely reached in South-West Asia (Beech, 2004; Lidour, 2018, 2023).

Shell adornments take a prominent place in the discussion regarding the material cultures and identities of Late Prehistoric Arabia,[1] mainly because they abound in the form of grave goods. Conversely, tools made of marine shells are less attested. Charpentier et al. (2004) have highlighted the presence of shell tools from several coastal sites dating from the Neolithic to the Late Bronze Age (c. 1600–1300 BCE)—or the Early Iron Age (from c. 1300 BCE onwards) (Fig. 2). They correspond to large valves showing scalariform retouches on their ventral margin. At that time, most of these shell tools were reported in the areas of Suwayh and Ruways, in the Sultanate of Oman. Their use has been suggested for a variety of purposes:

[1] In this article, the definition of the Arabian 'Late Prehistory' has been adapted from Magee (2014) by including the Neolithic, the Bronze Age, and the Iron Age.

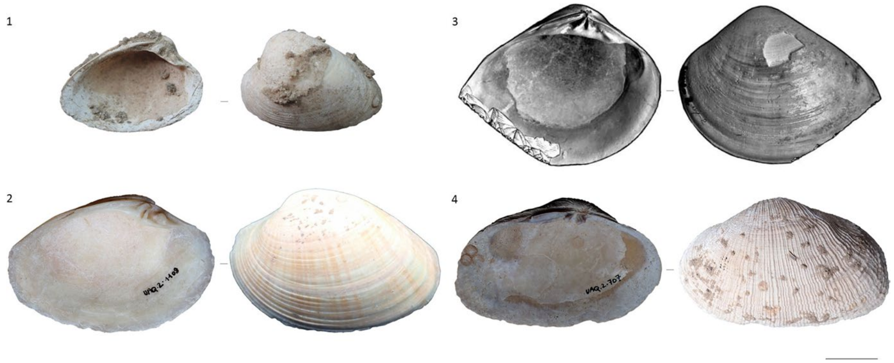


Fig. 2 Examples of archaeological shell tools from Eastern Arabia. **1** Left valve of *Callista umbonella* (Lamarck, 1818) from MR11 Area C (DCT Abu Dhabi). **2** Left valve of *Callista erycina* (Linnaeus, 1758) from UAQ2 (DTA Umm al-Quwain & French Archaeological Mission in the UAE). **3** Left valve of *Meretrix* sp. from SWY2 (illustration by G. Devilder) (Charpentier et al., 2004: fig. 4n°1). **4** Left valve of *Asaphis violascens* (Forsskål, 1775) from UAQ2 (DTA Umm al-Quwain & French Archaeological Mission in the UAE). Scale: 2 cm

for butchering activities, including fish scaling, the processing of animal skins and woodworking. However, up to now, none of these uses has been evidenced by a functional analysis.

During the last 20 years, further specimens have been found including, for the Neolithic, at Umm al-Quwain UAQ2 (Emirate of Umm al-Quwain, UAE[2]) (Méry, 2015: fig. 2.E), at Marawah MR11 (Emirate of Abu Dhabi, UAE) (Beech et al., 2022: fig. 8 n°3), on Ghagha Island (Emirate of Abu Dhabi, UAE) (N. Hamad Al Hameli pers. com.), at Ra's al-Hamra RH6 (Sultanate of Oman) (Marcucci et al., 2014: 242, Fig. 5; Marcucci et al., 2021: 114, fig. 6.13), and Ruways RWY1 (Berger et al., 2020: 9). Several specimens have also been identified from Late Bronze Age contexts from Masafi 5 in the Emirate of Fujairah, UAE (Lidour et al., 2023) (Fig. 1).

The present paper aims to provide detailed documentation devoted to the functional analysis of archaeological shell tools—firstly from Eastern Arabia, but there is little doubt that it will reach a wider audience of archaeologists working in other study areas. Descriptions and illustrations of use-wear traces are based on a comparative reference collection of shell tools specially produced and used experimentally for this research.

Material and Methods

The experiments and, consequently, the use of a reference collection have become an important component of the functional analysis method over the last decades. They allow a better understanding of the formation of archaeological use-wear

[2] UAE stands for United Arab Emirates

traces and their description and to understand aspects such as the management of this raw material or the manufacturing processes related through retouching these tools. The latter are intended for a more accurate interpretation of archaeological use-wear traces.

Moss and Newcomer (1982) have listed the main parameters that would be considered preferentially during the experiments. It includes (1) The raw material of the tool; (2) the manufacturing technique; (3) the morphology of the working edge; (4) the nature of the material worked; (5) the gestures or motion during the use; (6) the duration of the experiment. On this basis, the different steps of the construction of our reference collection can be listed as follows: Phase 1. The procurement of the shell valves; Phase 2. The production of an efficient working edge; Phase 3. The experiments; Phase 4. The use-wear and residue analyses.

Phase 1. The Procurement of the Shell Valves

We have chosen to use the same taxa for composing the reference collection as those of archaeological shell tools retrieved from the study area (Fig. 3). Indeed, Szabó (2008) has shown that each mollusc species provides a shell of distinct mineral compositions and microstructural properties, behaving almost as a unique raw material both when knapped and when used. They are responsible for distinct use-wear developments (Cuenca Solana et al., 2010: 215). The species used for the production of shell tools in Eastern Arabia are large bivalves that principally consist of *Callista erycina* (Linnaeus, 1758) and *Callista umbonella* (Lamarck, 1818) (formerly reported as *Amiantis umbonella* (Lamarck, 1818) by archaeologists working in the region). Lesser quantities of *Asaphis violascens* (Forsskål, 1775) and *Meretrix* sp. are also reported being used (Charpentier et al., 2004).

Marine shells can be collected either fresh or washed up on the shore (*i.e.* beach thanatocoenosis). The availability of fresh marine molluscs would greatly depend on

Fig. 3 Modern specimens of shell valves used for the reference collection. **1** Left valve of *Callista umbonella* (Lamarck, 1818). **2** Left valve of *Callista erycina* (Linnaeus, 1758). **3** Left valve of *Meretrix lyrata* (G. B. Sowerby II, 1851). **4** Left valve of *Asaphis violascens* (Forsskål, 1775). Scale: 2 cm

the location of their habitat, which can be more or less distant and accessible from the coastline.

C. umbonella, *A. violascens*, and *Meretrix* sp. are available in the intertidal substrates (Bernard et al., 1993; Bosch et al., 1995: 259, 269). Therefore, their exploitation should not have caused difficulties for Prehistoric fishers living on the coast. Large quantities of *C. umbonella* have been exploited for food at Neolithic coastal sites located in the Sultanate of Oman, such as at Ra's al-Khabbah KHB1, Suwayh SWY1 and SWY11, and Ruways RWY1 (Martin, 2004: 51, fig. 2; Martin, 2005: 172, figs. 3-4; Charpentier et al., 2000: fig. 8; Charpentier et al., 2003; Berger et al., 2020: 6). *A. violascens* valves have been identified in more moderate quantities from the Neolithic sites of Delma DA11 (Beech & Glover, 2005: tab. 4) and Marawah MR11 (Lidour *et al.*, in press: tab. 2) in the Emirate of Abu Dhabi (UAE). On the other hand, *Meretrix* sp. specimens are reported only from Neolithic sites of the Suwayh micro-region and do not seem to be still available there nowadays (Martin, 2004: 51, fig. 2).

Conversely, *C. erycina* is reported as strictly inhabiting offshore substrates (Bosch et al., 1995: 269). At first glance, it is pretty unlikely that Prehistoric fishers could localize and exploit marine molluscs down to several metres underwater. It is, however, what has been assumed by Villa et al. (2020) in the context of the collection of *Callista chione* (Linnaeus, 1758) valves used by Neanderthals at Moscerini Cave (Latium, Italy). This species is also encountered below the low tide line (Leontarakis & Richardson, 2005: 189), making the study's authors suggest that shell-collecting was carried out by skin diving. A similar assertion has been held by Szabó et al., (2007: 710) regarding the gathering of *Turbo marmoratus* Linnaeus, 1758 by 32–28 kya on Gebe Island (Indonesia). However, this gastropod can be encountered in shallow subtidal rocks, allowing its collection on foot during large tide ranges. The hypothesis of ancient skin diving is questionable since this activity is particularly challenging and costly in time and effort to obtain marine shells that could have been directly collected when washed up on the shore. Personal shell collections of *C. erycina* and *C. chione* along beaches carried out respectively in Umm al-Quwain (UAE) and Laredo (Cantabria, Spain) allowed collecting over 15 complete valves in half an hour. The hypothesis of skin diving supported in Villa et al. (2020) is based essentially on microscopic observation of the surface of the archaeological shells that have been carried out by C. Smriglio (Italian Institute of Human Paleontology, Rome): about 24% of the specimens he studied did not show any visible trace of marine erosion (due to the wave action) nor of boring or encrusting marine organisms (*e.g.* predatory gastropods, polychaete worms, boring sponges). However, the presence and the visibility of such traces depend greatly on the amount of time the shell has spent in the sea after the mollusc's death—if it occurred relatively recently, the shell would look pretty fresh. Therefore, shells from species encountered in intertidal and shallow subtidal habitats—such as *T. marmoratus*—are expected to have been less affected by marine bioerosion processes than species inhabiting offshore substrates. Indeed, not all shell valves we have collected for the present study show marine bioerosion traces. Furthermore, the observation of such traces on archaeological specimens can be greatly complicated by both taphonomic alterations (*e.g.* post-depositional dissolutions and concretions) and the fact that the shells have been deliberately worked and used.

Uerpmann and Uerpmann (2003: tab. 9.2) have reported that *C. erycina* valves have been frequently identified (representing from 100 g to 1 kg of shell fragments) at Ra's al-Hamra RH5 and Wadi Wuttayah (Muscat, Sultanate of Oman). However, no information given in this study has specified if some specimens have been worked. More recent publications from Ra's al-Hamra sites have confirmed the presence of several *C. erycina* tools associated with Neolithic contexts (Marcucci et al., 2014: 242, fig. 5; Marcucci et al., 2021: 114, Fig. 6.13). According to our preceding remarks, *C. erycina* valves were more than likely collected washed up on the shore. In contrast, shells from other taxa used to produce shell tools were also potentially available from living specimens encountered in intertidal substrates.

To construct the reference collection, 21 *C. erycina* valves have been exclusively collected on beaches. A total of 76 *C. umbonella* and 4 *A. violascens* valves have been obtained both from fresh specimens bought at local markets and from gatherings of washed up material. As *Meretrix* sp. is no longer reported among the modern lists of taxa available in the region (it is possibly an extinct species according to Martin, 2004: footnote 3), 10 *Meretrix lyrata* (G. B. Sowerby II, 1851) (Fig. 3 n°3) valves have been bought from a private wholesaler based in Paris (France). Specimens composing the collection measure from 51 to 75 mm in length and from 39 to 57 mm in height (Fig. 4). They are found in the average size documented for these species at the archaeological sites of the region (Bosch et al., 1995). Each valve has been photographed and labelled with an individual code (written in the inner valve, below the hinge). From this ensemble, a representative sample of 23 shell tools has been documented and illustrated for the present study (Table 1).

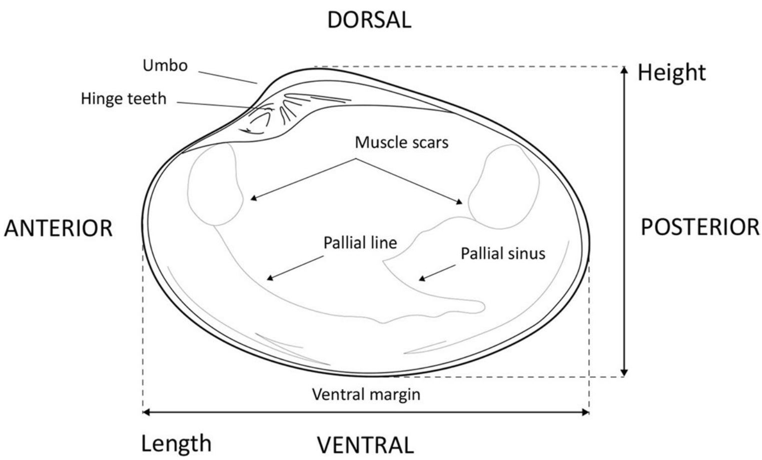


Fig. 4 Denomination of the main anatomical elements of a shell valve. Based on a right valve of *Callista erycina* (labelling modified from Cesari & Pellizzato, 1990)

Table 1 Table of the shell valves used for the experiments documented and illustrated in the present study

Code	Species	Laterality	Length (mm)	Height (mm)
CE.04	*Callista erycina*	Left	73.39	50.11
CE.10	*Callista erycina*	Right	70.21	49.65
CE.11	*Callista erycina*	Left	74.02	53.31
CE.12	*Callista erycina*	Left	71.53	50.46
CE.13	*Callista erycina*	Left	67	49.78
CE.15	*Callista erycina*	Left	70.56	51.35
CE.19	*Callista erycina*	Right	68.87	48.98
CU.05	*Callista umbonella*	Right	60.07	46.4
CU.08	*Callista umbonella*	Right	60.05	44.35
CU.16	*Callista umbonella*	Right	63.52	47.94
CU.18	*Callista umbonella*	Left	62.33	47.2
CU.19	*Callista umbonella*	Right	59.09	44.92
CU.22	*Callista umbonella*	Left	58.17	44.69
CU.27	*Callista umbonella*	Right	58.21	43.59
CU.34	*Callista umbonella*	Left	68.71	52.99
CU.36	*Callista umbonella*	Right	68.66	51.77
CU.39	*Callista umbonella*	Right	54.82	41.49
CU.40	*Callista umbonella*	Right	58.39	44.12
CU.53	*Callista umbonella*	Left	52.76	39.99
CU.59	*Callista umbonella*	Right	54.36	41.2
CU.70	*Callista umbonella*	Left	54.27	41.13
CU.74	*Callista umbonella*	Right	52.06	39.46
ML.03	*Meretrix lyrata*	Right	62.84	49.07

Phase 2. The Production of an Efficient Working Edge

Mollusc shells are frequently considered as a substitute raw material for the production of tools—the intentional use of this material is supposed to result from the lack of lithic resources (Toth & Woods, 1989). Indeed, the ethnographic information indicates that shell tools have mainly an expedient use. It is why, in most cases, the shell is little transformed—its natural characteristics of shape and robustness being exploited to the maximum (Cuenca Solana & Clemente Conte, 2017). However, the use of shell tools can also be motivated by the greater adequacy of these instruments compared to lithic tools to develop some specific work or associated with several other reasons that might escape us, such as cultural tradition.

The use of shell valves as tools is reported for various purposes, including the processing of animal, vegetal, and mineral materials.

They are used as knives for butchering tasks among many native peoples from the Americas, including in Brazil (Prous, 1990) and among the Kawésqar in Chile (Emperaire, 1958) for cutting meat. The use of shell valves for fish scaling has also been reported in various ethnographic works, such as among the Chugach in Alaska (Dupont, 2003), the Patwin in Northern California (Johnson, 1978), the Aboriginals living along the Murray River in New South Wales (Australia) (Allen, 2009: Fig. 5), and in Southern Palestine as well (Courtin & Vigié, 1987). Although less effective, the use of shell valves for the working of bone is also possible—reported for shaping bone staffs among the Wauja (Upper Xingu, Brazil), for instance (Prous, 1990). Shell valves are used as scrapers for cleaning, treating, and smoothing animal skins in different regions, such as in Northern Africa (Vigié, 1987), in Northern America (including in Alaska and Greenland) (Bocquenet, 1998: 268–269; Cade, 1998: 347), and Southern America (among the Kawésqar in Chile and the Yagán in Tierra del Fuego) (Leroi-Gourhan, 1945: 219; Emperaire, 1958; Gusinde, 1986).

Shell valves can have a multi-purpose function as a knife or a scraper. It is, for instance, the case among the Yagán from Tierra del Fuego where large shell valves were shafted using an elongated beach pebble. This tool was used for various tasks, including cutting, scraping, and carving wood (Gusinde, 1986; Mansur & Clemente Conte, 2009). Shell knives are sometimes used to cut wood in other regions, such as Brazil and the Magallanes region in Chile (Gusinde, 1986). Other kinds of vegetal material can be worked using shell tools, such as for scraping wood bark, cutting, and relaxing herbaceous plants that are traditionally used for making textiles, ropes, and baskets (Cleyet Merle, 1990: 51). In Cuba and among the Kamayura from Buraçao (Brazil), shell valves are used for scraping and cutting manioc (*Manihot*

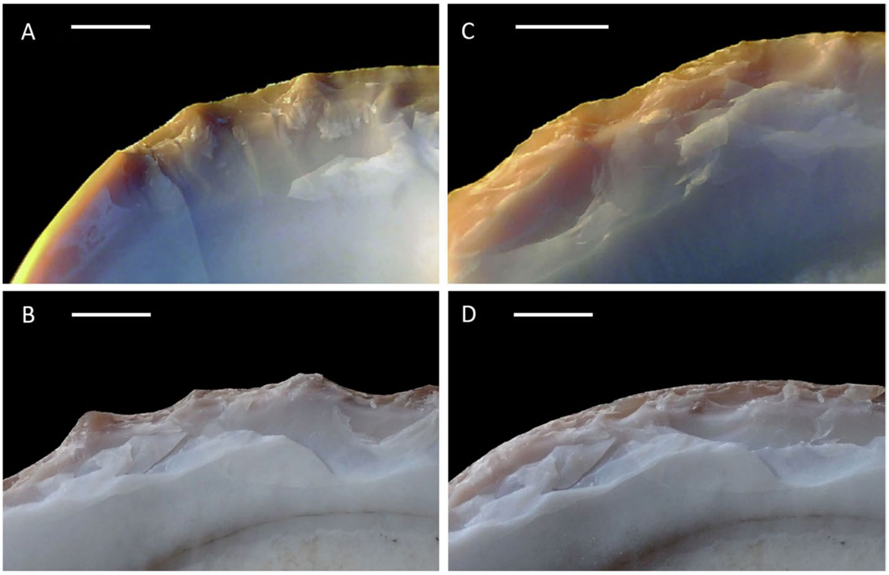


Fig. 5 Experimental retouch following the 'Quina retouch' (Retouch type 1). **A**, **B** Stage 1—A series of retouch creates micro-denticulations along the ventral margin of the valve, with **A** on a *Callista chione* specimen (Romagnoli et al., 2016: fig. 7.A) and **B** on a *Callista erycina* specimen (present study); Stage 2—A second series of retouch has regularised the edge, showing a flat and stepped flaking, with **C** on a *Callista chione* specimen (Romagnoli et al., 2016: fig. 7.B) and **B** on a *Callista erycina* specimen (present study). Scale: 5 mm

esculenta) (Dacal Moure & Rivero de la Calle, 1984; Prous, 1990). In Hokkaido (Japan), shell valves were also traditionally used by the Ainu-Utari as sickles for harvesting crops (Cade, 1998: 348).

Shell valves can have been used as tools for pottery making as well, such as for the regularisation of the thickness (Prous, 1990: 249) and the smoothing of the walls in Africa and in the Canary Islands (Vigié & Courtin, 1986: 60; Cade, 1998: 348; Rodríguez Rodríguez & Navarro Mederos, 1999).

These activities can be gathered within two main groups of actions: (1) transversal actions (scraping or chopping); (2) longitudinal actions (cutting or sawing). Indeed, shell valves show a natural disposition to be used as either scrapers or knives. Large valves of the Veneridae family, particularly the genus *Callista*, can reach sizes allowing them to be easily taken in hand and show a remarkable thickness and robustness. However, most unmodified shell valves are generally inefficient to be used as scrapers or knives since their edges are naturally rounded—it has been shown by experiments conducted by Toth and Woods (1989), who have compared the efficiency of both unmodified and sharpened *Ostrea* valves to process animal carcasses. Therefore, the transformation of the shell valve into an efficient tool can involve retouching its edge. However, the potential use of unmodified shell valves as tools in Late Prehistoric Arabia cannot be assessed as long as they have not been properly sought within the malacological assemblages—it is a key issue for future research.

Many valves of *C. erycina* and *C. umbonella* (as well as of *Meretrix* sp. and *A. violascens* in lesser quantities) from Late Prehistoric Arabia have been transformed before being used as tools. As Charpentier et al. (2004) show, the retouch is 'scalariform' and limited to the ventral margin of the valve (distal to the hinge)—sometimes only to a specific part of the edge—corresponding to the future active area. It results in a series of overlapping small fractures showing semi-circular and half-moon shapes. The retouch can either follow the natural curve of the ventral margin or modify it into a straight edge (Fig. 2 n°3). Although a more detailed study and further experiments are necessary on that particular issue, it can be stated that this human-made 'scalariform' retouch clearly differs from natural and taphonomical breakages that have a more abrupt profile as it has been observed on a large number of shell valves resulting from archaeological food wastes. Romagnoli et al. (2016) studied this type of retouch in the context of shell tools made of valves of *C. chione* reported within Neanderthal-associated contexts in the Mediterranean. They have evidenced a direct percussion made in two stages:

- Retouch type 1, stage 1 (Fig. 5A, B). A first series of small retouches are made on the ventral margin using a rounded surface of the hammerstone. The gesture is tangential and follows a curvilinear trajectory to strike the outer side of the valve (inverse retouch). It produces micro-denticulations forming a distinctive 'sharp thorn' on the ventral margin;
- Retouch type 1, stage 2 (Fig. 5 C, D). The ventral margin is regularised by a second row of retouches using a flatter surface of the hammerstone. Supposedly, less force is applied during this second stage.

This type of retouch has been associated with the Quina techno-complex by the study's authors. The Quina techno-complex is a Middle Palaeolithic socio-technologic system defined by Delagnes et al. (2007). It includes the production and use of characteristic 'Quina scrapers' (in lithic) showing stepped retouches—generally along one of the longest sides of the tool. The authors have suggested the transference of this knapping technique to marine shells to produce tools with a continuous convex cutting edge. A similar technical transfer has been tested by Szabó et al., (2007: 711) for the 'flaked shell artefacts' retrieved from Golo Cave (Indonesia, c. 32–28 ka) but was ultimately rejected.

Shell tools are frequently (but not systematically) associated with large lithic scrapers showing typical convex edges and 'scale-like' or 'scalariform' (Bordes, 1988: 19) retouch in the Neolithic assemblages of Eastern Arabia. The latter, known as 'tile knives', are made either from large flakes or from tabular flint—and are frequently attested at coastal sites from the Arabian Gulf (Edens, 1982: pl. 102, B; Kapel, 1967: 21, fig. 44b; Méry & Charpentier, 2013: 75). It includes specimens reported from major stratified sites such as Dosariyah (Saudi Arabia) (Drechsler, 2018: 247, pl. 11.11–12), Marawah MR11 (Beech et al., 2020: fig. 10, n°8), and Akab (Emirate of Umm al-Quwain, UAE) (Méry & Charpentier, 2012: figs. 16–17). Edens (1988: 21) outlined that this type of tool is absent in the interior. Similar to assumptions suggested for Palaeolithic cultures in Europe and Indonesia (see above), technical transfers and, possibly, similar uses could be presumed for lithic and shell scrapers/knives from Neolithic Eastern Arabia. However, at this stage, a detailed study of these flint 'tile knives' is highly required to specify their mode of production, uses, and potential relationships with shell tools attested at the same sites.

Experiments have confirmed the efficiency of the 'Quina' retouch technique but with a quite high degree of fracture of the shell valves (also noticed by S. Soriano in Villa et al., 2020)—which could also be due to a variable skill level in knapping. Other techniques are documented for the production of 'scale-like' and 'scalariform' retouches within lithic studies (see Bordes, 1988: 19, fig. 2). However, it is worth noting that working mollusc shell is not producing conchoidal fractures that can be obtained for siliceous rocks such as flint and chalcedony because of their glass-like properties. In the case of most bivalves, the fracture of the edge of the valve during the knapping process tends to follow the weakened lines of its natural multi-layered structure—creating distinctive step-like fractures on the inner valve only (unifacial retouch). Therefore, other techniques of retouching have been experimented:

– Retouch type 2. 'Flat retouch' (Fig. 6A, B). The retouch can be described as 'flat' when the flakes form angles lower than 45° relative to the striking platform (Laplace, 1968). The hammerstone is struck on the valve following a series of short retouches all along its ventral margin. However, it does not strike with an inclined angle on one side of the valve (direct retouch from inside or inverse retouch from outside), but abruptly against the edge with a controlled blow of force. As mentioned above, the shell structure is naturally flaking off on the inner side of the valve;

Fig. 6 Further experimental retouches were performed for this study. **A** Flat retouch (Retouch type 2) gesture. **B** 'Block-on-block' technique (Retouch type 3) gesture. **C** Retouch type 2 creates deep crushings and smaller stepped retouches which are overlapping all along the ventral margin, on a *Callista erycina* specimen. **D** Retouch type 3 produces a series of distinctive half-moon shaped fractures resulting in a 'sharp thorn' pattern, on a *Callista erycina* specimen. **E** and **F** Details of the worked edges of archaeological specimens of *Callista erycina* valve tools—they are comparable to experimental specimens (from UAQ2, DTA Umm al-Quwain & French Archaeological Mission in the UAE). Scale: 5 mm

– Retouch type 3 (Fig. 6D, E). The 'block-on-block' technique, also known as 'on resting hammer' (Cheynier, 1949: 190; Bordes, 1988: 25). Although usually documented for debitage within lithic studies, this technique has been used for knapping and retouching by L. Coutier in his experiments according to Bordes (1947: 17). The ventral margin of the valve is abruptly struck against a stationary stone (resting on the ground or held in the other hand) which is used as an anvil.

In both cases, a slightly rounded surface of the hammerstone (or resting hammer) is used, and the gesture always follows a linear trajectory, resulting in a flat and stepped flaking caused by the abrupt percussion of the plane perpendicular to the ventral margin. In practice, Retouch type 3 allows a better accuracy of the contact area and greater control of the force applied. However, the specification of the type of retouch remains hard on archaeological shells since their edges are quite abraded and rounded because of both their use as tools and taphonomic alterations (Moss, 1983). Nevertheless, all the retouch types described above are suitable for the production of efficient cutting edges comparable to archaeological specimens (Fig. 6C, F). Retouch types 2 and 3 have been used mainly to produce the valve tools documented in the present study (Table 2). A total of 23 specimens are documented in the present study among the 87 shell valves that have been worked for the reference collection.

Phase 3. The Experimental Works

Shell tools can be used for a variety of purposes associated with processing various animal, vegetal, and mineral materials. The experimental program has been based on the use of shell valves for several specific activities likely to have been carried out by Neolithic fisher-herders living in the Arabian Peninsula. It includes, among many others, cutting meat, fish scaling, cleaning and softening animal skins, woodworking (*e.g.* debarking, planing), stretching and cutting vegetal fibres, and scraping ochre (Fig. 7). So far, 65 experiments have been conducted for the reference collection—a representative sample of 23 experiments is documented and illustrated in the present study (Table 2).

Since most experiments have been conducted in Northern Spain (Cantabria), animal and vegetal taxa commonly encountered in Eastern Arabia have not been available—apart from CU.53, which has been used for debarking a branch of mangrove (*Avicennia marina*) and other specimens for the processing of date palm (*Phoenix dactylifera*) fibres (CE.10, CE.19, CU.08, CU.18, CU.39, and CU.74) on the occasion of archaeological fieldwork on Marawah Island (Emirate of Abu Dhabi, UAE) in March 2022.

Sheep (*Ovis aries*) and goats (*Capra hircus*) are the main terrestrial mammals consumed by coastal communities in Eastern Arabia during the Neolithic. At UAQ2, kill-off profiles have indicated the preferential slaughtering of young livestock (*e.g.*, Mashkour et al., 2016), suggesting a herding economy specialised in animal milk production. On this basis, lamb meat and skin have been used for experiments of butchering and tasks associated with the processing of animal skins. CU.36 was used to soften a dry roe deer (*Capreolus capreolus*) skin for a comparative purpose. Seabreams (Sparidae) are among the main fish catches during the Neolithic in Eastern Arabia (Lidour, 2023): a specimen of Red porgy (*Pagrus pagrus*) caught in the Cantabrian Sea has been selected for fish scaling experiments.

Woodworking tasks have been carried out mainly using false acacia (*Robinia pseudoacacia*). It shows a strip-like bark structure and an average wood density (c. 0.7 g.cm^{-3}) comparable to those of acacia-related taxa (*Vachellia* spp., *Prosopis*

Table 2 Table of the experiments documented and illustrated in the present study

Code	Retouch	Material	Category of activity	Description	Support	Movement	Duration
CE.15	2	Animal	Butchering	Defleshing a lamb limb	-	Longitudinal	20 min
CU.40	2			Defleshing a lamb limb	-	Longitudinal	20 min
CE.11	2			Scraping meat from a lamb long bone	-	Transversal	30 min
CE.12	3			Scaling a Red porgy	-	Transversal	10 min
ML.03	2		Processing animal skins	Cleaning and softening a fresh sheep skin	Wood support	Transversal	60 min
CU.70	3			Softening a fresh sheep skin	Frame	Transversal	20 min
CE.13	2			Softening a half-dry sheep skin	Frame	Transversal	20 min
CU.22	2			Softening a half-dry sheep skin	Wood support	Transversal	60 min
CU.36	3			Softening a dry roe deer skin	Wood support	Transversal and oblique	30 min
CU.27	3			Cleaning and treating a sheep skin (with ochre)	Wood support	Transversal	35 min
CU.08	2	Vegetal	Processing vegetal fibres	Cutting half-dry date palm leaves in bulk	-	Longitudinal	10 min
CU.18	3			Cutting dry date palm leaves in bulk	-	Longitudinal	10 min
CE.10	3			Cutting date palm leaf sheath in bulk	-	Longitudinal	10 min
CU.39	2			Cutting coconut palm leaf sheath in bulk	-	Longitudinal	10 min
CE.19	3			Cutting threads of date palm leaf sheath	-	Longitudinal	5 min
CU.74	3			Stretching date palm leaf sheath in bulk	-	Transversal and oblique	10 min
CU.59	3		Woodworking	Debarking a branch of fresh false acacia	-	Transversal	10 min
CE.04	3			Debarking a branch of fresh false acacia	-	Transversal	20 min
CU.53	3			Debarking a branch of fresh mangrove	-	Transversal	10 min
CU.16	2			Debarking a branch of dry false acacia	-	Transversal and oblique	10 min
CU.34	3			Planing a branch of half-dry false acacia	-	Transversal	10 min
CU.19	2			Planing a branch of dry false acacia	-	Transversal	10 min
CU.05	3	Mineral	Producing ochre powder	Scraping a hard nodule of haematite (ochre)	-	Transversal	10 min

CE stands for Callista erycina, *CU* for Callista umbonella, *ML* for Meretrix lyrata

Fig. 7 Examples of experimental sessions. **A** Cutting of half-dry palm leaves, 10 min (ref. CU.08). **B** Working (debarking and planing) a branch of half-dry false acacia, 20 min (ref. CU.34). **C** Debarking a branch of fresh acacia, 20 min (ref. CU.13). **D** Re-sharpening a bone point, 10 min (ref. CU.01). **E** Cleaning and treating a sheep skin using an emulsified solution of lamb brain mixed with ochre powder, 35 min (ref. CU.27). **F** Defleshing a lamb limb, 20 min (ref. CE. 15)

cineraria) and the Christ's thorn jujube (*Ziziphus spina-christi*) composing most of the native tree cover in Eastern Arabia (Brown, 1997: appx; Sydor et al., 2020: tab.1; Ghalehno et al., 2021: tab. 1). One specimen (CU.53) was used to work a branch of grey mangrove (*Avicennia marina*) which has a smooth bark and a mid-heavy density (c. 0.65 g.cm^{-3}). It, however, differs from the loop-root mangrove (*Rhizophora mucronata*), which has a bark composed of peeling strips and shows a greater wood density (c. 0.79 g.cm^{-3}) (IDEAS Consultancy Services, 2013: tab. 2; Ardhana *et al.*, 2018: tab. 1)—working wood from the latter taxa did not have been experimented so far. Regarding the non-woody fibres, activities have focused on the processing of fibres (leaflets and leaf sheath, the fibre covering the trunk) of the date palm, whose exploitation took on a great importance in Eastern Arabian pre-oil material culture such as for basketry and the production of ropes (Crocker Jones, 1991). A sample of leaf sheath from the coconut palm (*Cocos nucifera*) (CU.39) has also been processed for a comparative purpose.

Different states of matter of each material worked have been experimented. Hardness, density, and hydration can be significant variables in use-wear formation: *e.g.* wood density increases with dryness; dry vegetal fibres and dry animal skins are less flexible and more abrasive than when fresh. The grip in hand, the movement, the applied force, and the working angle are also to be taken into account (Clemente Conte, 1997: 29–34). Although it has not been systematically documented for the present study, the working angle almost always shows a certain variability, especially when performing transversal movements (Cuenca Solana, 2013: 97). The duration of the experiments we have conducted varies greatly from one to another (from 5 min to almost an hour) (Table 2), resulting in a gradual development of the use-wear (González Urquijo & Ibáñez Estévez, 1994: 31; Cuenca Solana et al., 2010: 216).

Because of residues covering the use-wear, most valves have been cleaned after the experiments (except for those potentially concerned by residue analyses, such as CU.05, which was used for scraping ochre). Cleaning has consisted of placing the shell valves in an ultrasonic bath (distilled water warmed at 40 °C) for about 20 min. In very few cases, this treatment seems to have slightly damaged the use-wear (observed on specimens of *A. violascens* used for processing vegetal fibres) (also observed in Cuenca Solana, 2013: 100). Further research is necessary to assess this phenomenon in more detail.

Phase 4. The Use-Wear Analysis

Use-wear observations have been conducted using both stereomicroscopy (Leica S8 APO) and digital microscopy (Leica DM2500 M), allowing magnifications from 10 to 200×. Photographies have been taken with a digital microscope camera (Leica MC190 HD) linked to a computer using the Leica Application Suite v. 4.13.0—most photographs have been taken at the micro level 100×, combining enough detail and field of view simultaneously. Multifocal pictures can be processed using either the Leica software or Helicon Focus v. 8.1.0. These photographs were used to construct a digital synoptic reference collection. An energy dispersive X-ray analyser (EDX) has been used to provide elemental identification and quantitative compositional information of residues identified on shell tools. EDX measures the X-rays emitted by a sample when excited by an energy source (an electron beam from a SEM for instance). The energy spectrum obtained is analysed by comparing peak intensities with known standards, allowing to document its elemental makeup. The laboratory work has been conducted at the Instituto Internacional de Investigaciones Prehistóricas de Cantabria (IIIPC) and at the Laboratorio de la División de Ciencia e Ingeniería de los Materiales (LADICIM) (Universidad de Cantabria, Santander, Spain).

Observations using stereomicroscopy allow a general description of the shell tool, of its surface modifications, and a preliminary localisation of the active area. In most cases, abrasions, rounding, and scarring are already visible at low magnification and would confirm the presence of a use-wear (*e.g.* Douka, 2011; Pascual Benito, 2008). Observations at high magnification using digital microscopy allow a more detailed description of the use-wear traces. The latter include the polish and the striations principally, but the edge rounding and fracturing can also be observed (Kamminga, 1982). Ideally, observations at high magnification would permit to specify what material has been processed and the characteristics of the action performed (Keeley & Newcomer, 1977).

Striations are grooves and scratches produced by the contact and the movement of abrasive particles between the active area of the tool and the material processed (Mansur-Franchomme, 1980). These abrasive particles can be exogenous or additive: intended in the case of ochre, for instance, not intended for sand or dirt that could be present in the work environment. They can be endogenous, corresponding to fragments detached from the tool's edge or the material processed during the action. The morphology, dimension, frequency, and orientation of striations are observed. It allows to specify the movement of the action (González Urquijo & Ibáñez Estévez, 1994: 59). Indeed, striations can be parallel or perpendicular to the edge of the tool, showing unidirectional or bidirectional movements as well. The edge rounding and fracturing indicate the hardness, abrasivity, and plasticity of the material worked: soft materials cause more rounding than hard materials, leading to a more frequent fracturing of the tool's edge. Therefore, a hard material will cause a frequent renewal of the active area, leaving less developed use-wear traces on the tool at the end of the action.

In this study, we retain the definition of the 'polish'—or 'micro-polish' when it is observed at high magnification—as the change in the micro-topography and the reflectivity of the active area that has been abraded (Jensen, 1988: 55). In fact, the polish is supposedly formed as a result of combined mechanical and chemical actions (Anderson-Gerfaud, 1980; Yamada, 1993). In practice, it is described considering both spatial parameters (location, extension, and contouring) and its surface aspect. The latter is detailed by a series of characteristics, including the pattern (or network), the texture, and the brightness (sheen or shine). It is important to note that the inclination of the shell tool on the microscope stage as well as both the intensity and the incidence of light are important factors that affect the visibility of the polish (Cuenca Solana et al., 2010: 221). Some authors also often refer to the 'coalescence' for designating the surfaces affected by the micro-polish (Plisson & Van Gijn, 1989: 632–633). The way the coalescent surfaces extend in relief (or micro-topography) can vary following a continuum of states from fluent to hard. It usually provides useful information on the plasticity of the material worked. The pattern is directly determined by the spatial distribution and the interconnection of coalescent surfaces (*i.e.* surfaces affected by the micro-polish). The latter can be loose, more or less narrow, closed, or unified (Plisson, 1985: 15–20, figs. 1–2; González Urquijo & Ibáñez Estévez, 1994: 47). On the name of convenience and for facilitating comparisons with other studies, we preferred to refer to the way the 'micro-polish' develop in relief and affect it than using the term 'coalescence' in the present paper. One also refers directly to how the action modifies the 'original micro-topography', showing smooth or rough aspects (*e.g.* Cuenca Solana et al., 2010; Cuenca Solana et al., 2013a following the terminology of González Urquijo & Ibáñez Estévez, 1994: 51). Indeed, one of the main problems when comparing the literature specialised in functional analysis is the variability of the glossary used. There is no consensus on using a certain number of terms such as 'coalescence' and how to describe 'texture' and 'brightness' objectively. Therefore, the description of some characteristics of the use-wear seems to depend on subjective assessments. The impossibility of building an objective and systematic way of describing use-wear is one of the main reasons why many scholars have developed their own experimental programs (Grace, 1989; Wiederhold, 2004: 46).

On all species used for composing the reference collection, the original edge of the valves shows a shiny and smooth surface, sometimes showing striations and scratches when the latter have spent a while in the sea after the mollusc's death (Fig. 8B). In the case of *A. violascens* valves, the shell is thinner and tends to break

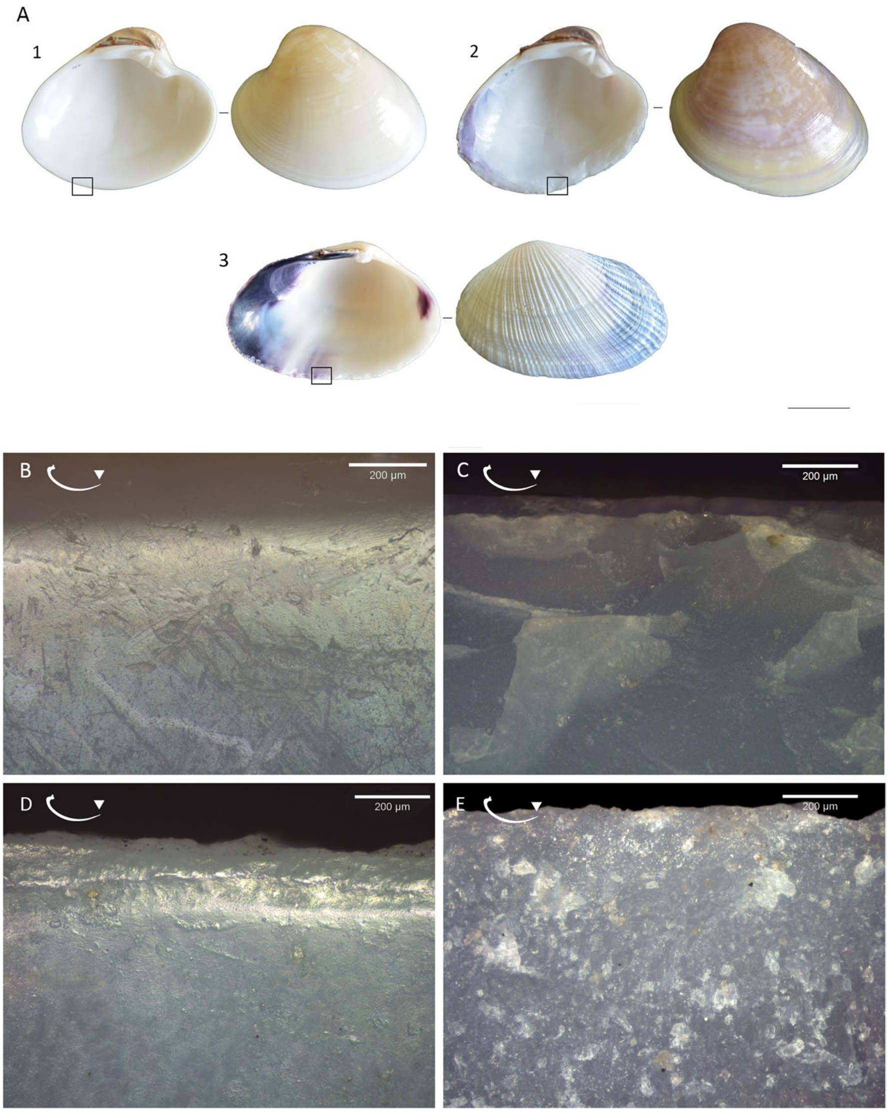


Fig. 8 **A** 1. Unworked left valve of *Callista umbonella* (found washed up on the shore). 2. Worked (Retouch type 3) left valve of *Callista umbonella* (obtained fresh). 3. Worked (Retouch type 2) left valve of *Asaphis violascens* (found washed up on the shore), scale: 2 cm. **B** Detail of the internal edge of the unworked valve illustrated in A1—striations and scars are produced by marine erosion (at 100×). **C** Detail of the internal edge of the worked valve illustrated in A2—the retouch has produced an uneven microtopography composed of peaks and crevasses (at 100×). **D** Detail of the internal edge of the valve illustrated in A3 prior having been worked—the surface is shiny and shows some roundings and lump-like structures (at 100×). **E** Detail of the internal edge of the worked valve illustrated in A3—the uneven microtopography shows irregular micro-fractures (at 100×)

easier along the ventral margin, thus showing small irregular fractures on its edge. Lump-like structures can be observed on the inner valve (Fig. 8D), corresponding to fine sand grains and dirt jammed and imbedded in the shell layers during their formation. As we saw above, the retouch aims to transform the regularly polished margin of the valve into an effective cutting edge. It results in the removal of the superficial layer (*i.e.* periostracum) covering the inner shell and fracturing its multi-layered structure. Subsequently, the edge shows a matte and uneven surface composed of peaks, crevasses, and micro-fractures (Fig. 8C, E). Therefore, the 'original microtopography' of shell tools before their use greatly differs between worked and unworked specimens. This parameter is susceptible to affect how the use-wear would develop.

Results

In the following parts, we describe the use-wear of a selection of experimentally made shell tools that have been deemed representative of the most recurrent activities documented in other functional analyses. They illustrate the variety of the materials processed during the experiments. The use-wear descriptions consist of methodological support for future use-wear analyses intended to be conducted on archaeological specimens.

Animal Materials

Experiments on animal materials include mainly butchering activities and the processing of animal skins. Butchering activities include defleshing and scraping meat from bones. In the present study, only scaling has been documented among the fish processing tasks. Activities on animal skins have included scouring, 'tanning' (treating by spreading an emulsified solution of lamb brain mixed with ochre powder), and softening at various stages of dryness.

Butchering

Cutting meat produces a micro-polish visible mainly when positioning the valve almost flat on the microscope stage—it evidences a wide contact with the material processed. Indeed, the micro-polish is developing on a wide surface, with blurred limits. It has a loose pattern, sometimes moderately narrow, with a greasy texture, and a dull brightness—similar characteristics are observed for use-wear produced on bone tools (Maigrot, 1997: fig. 7) (Fig. 9A, B). It develops in relief, following the uneven microtopography initially created by the retouch. Therefore, the working surface between the active area and the material is fluent. The material worked is soft and not abrasive (no roundings). However, on some high points, the micro-polish is brighter and has a closer pattern showing contact with a harder material (*i.e.* bone) (Clemente Conte et al., 2015: fig. 5.2)—see also Odell (1980: 41) for use-wear traces produced on lithic tools. The micro-polish is oriented longitudinally

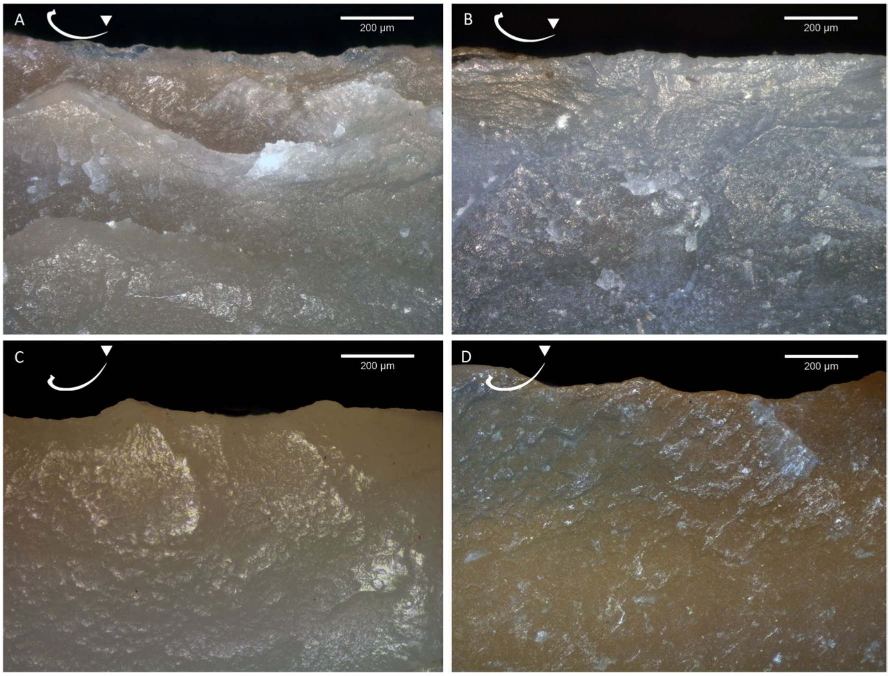


Fig. 9 Use-wear produced by butchering activities, at 100×. **A** Defleshing a lamb limb (cutting action), 20 min (ref. CE.15). **B** Defleshing a lamb limb (cutting action), 20 min (ref. CU.40). **C** Scraping meat from a lamb long bone, 30 min (ref. CE.11) **D** Descaling a Red porgy, 10 min (ref. CE.12)

to the edge, confirming a cutting action. Striations are rare, but sometimes visible on high points, confirming a longitudinal movement (examples would also be visible on the outer side of the valve).

When the valve is used for disarticulating, scraping meat from a bone, and fish descaling, the use-wear is similar but areas showing a closed micro-polish are more developed—as seen above, it results from contacts with a harder material such as bone and bony scales (Fig. 9C, D). No great difference has been observed for the use-wear traces produced respectively when cutting mammal meat and fish. However, it is worth noting that the development of the use-wear appears to be slower in the case of processing fish.

Processing Animal Skins

When scraping animal skins, the micro-polish develops at various angles but is better visible when the valve is inclined. It indicates an action concentrated mainly on the edge but with variations of the working angle, which could explain a certain flexibility of the material processed. The micro-polish extends on a continuous surface along the edge and develops moderately following the relief (Fig. 10). It is slightly bright and shows a variable pattern, from narrow to closed depending on the micro-topography: the relief's edge and high points show a closer pattern. The texture is

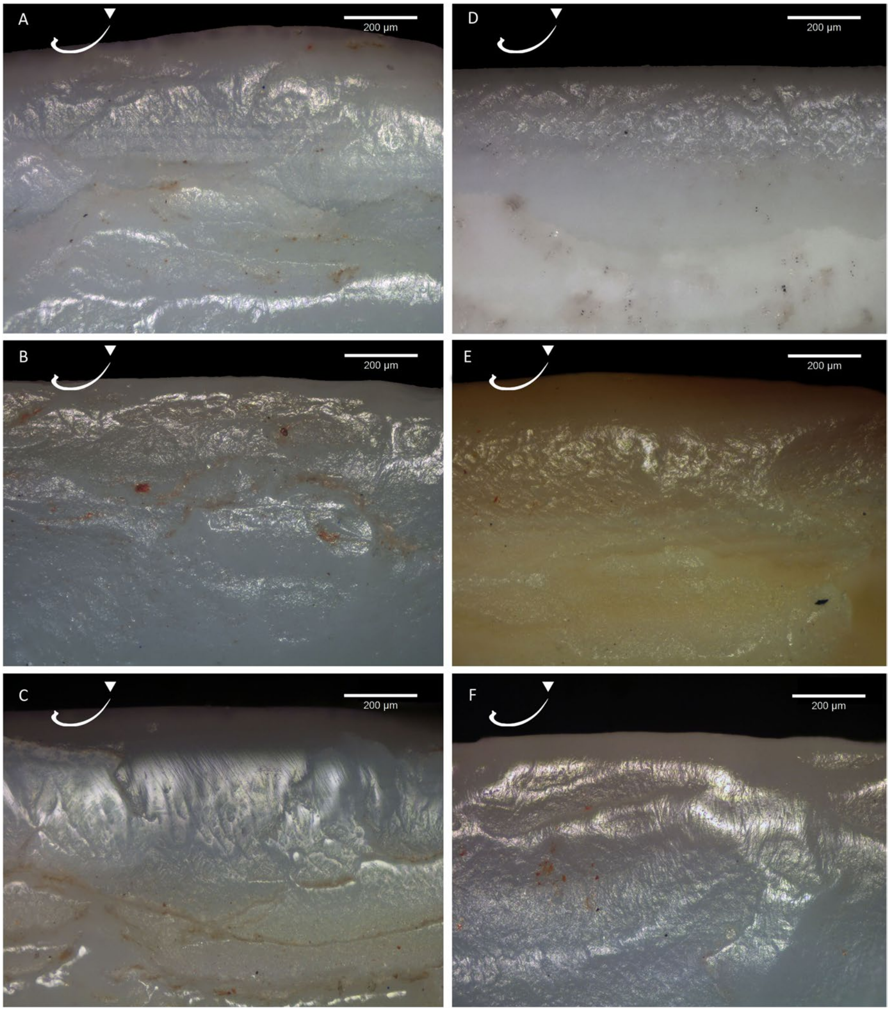


Fig. 10 Use-wear produced by the processing of animal skins, at 100×. **A** Cleaning and softening a wet sheep skin on a hard wood support, 60 min (ref. ML.03). **B** Softening a half-dry sheep skin on a hard wood support, 60 min (ref. CU.22). **C** Softening a dry roe deer skin on a hard wood support, 30 min (ref. CU.36). **D** Softening a wet sheep skin on a frame, 20 min (ref. CU.70). **E** Softening a half-dry sheep skin on a frame, 20 min (ref. CE.13). **F** Cleaning and treating a sheep skin using an emulsified solution of lamb brain mixed with ochre powder, on hardwood support, 35 min (ref. CU.27)

quite greasy and grainy (Cuenca Solana et al., 2010: 218–219, fig. 3). The relief tends to show more roundings and a matter brightness through time as much the skin is dry and rigid (Fig. 10C)—also observed on lithic tools by Keeley and Newcomer (1977: 42). The edge would also show a certain attrition, progressively developing in a more regularly rounded profile with a unified micro-polish. When visible, striations develop on the high points of the micro-topography: they are regular, short, thin, shallow, arranged in parallel, and oriented transversally (or obliquely) to the edge, confirming a scraping action. They are much better developed and visible when the skin has been worked over a long duration on a hard surface (*e.g.* on the ground or a table) than when laid on a frame (see Fig. 10D, E). Similarly, dry skins are reported to produce more abraded surfaces and striations on lithic and bone tools as well (Peltier & Plisson, 1986: 73, figs. 5–6; Gauvrit Roux & Beyries, 2018: 655–656, figs. 6–7;). The active area is frequently reported to show numerous sub-circular micro-holes, especially when the skin is dry (González Urquijo & Ibáñez Estévez, 1994: 51; Cuenca Solana, 2013: 178, fig. 3.30.8). The residual presence of abrasive material such as ochre on the skin would also induce a greater rounding of the micro-relief and the formation of striations.

Ochre has antibacterial and antifungal properties that favour the preservation of animal skins (Audouin & Plisson, 1982; Philibert, 1995; Rifkin, 2011; Tributsch, 2016)—its ancient use has been previously highlighted in functional analyses (*e.g.* Cuenca Solana et al., 2021; Rios Garaizar et al., 2002; fig. 3). When a mineral material is added to a skin, it produces a stronger abrasivity: the edge and the relief of the tool are distinctively rounded and show many transversal striations (Brink, 1978; Mansur-Franchomme, 1983: 229). These striations are invasive, long, deep, and of various thicknesses (Cuenca Solana, 2013: 167) (Fig. 10F)—however, it depends greatly on the grain size of the ochre powder used. The striations frequently intersect when the movement is bidirectional (also visible on the outer side of the valve). The reliefs tend to flatten because of the strong abrasivity associated with the skin's elasticity, creating wide surfaces with a unified micro-polish. The brightness is generally higher than when the skin is worked without ochre. The texture remains grainy and greasy, especially on the relief's lower points and the active area's periphery.

Vegetal Materials

Vegetal materials that have been processed include wood and non-woody fibres at different stages of dryness. Woodworking tasks have consisted in debarking and planing tree branches. Regarding non-woody fibres, activities have focused on relaxing and cutting leaflets and leaf sheath. Further experiments that are not documented in the present study include gathering wild halophyte shrubs (*Arthrocnemum macrostachyum* and *Zygophyllum qatarense*) and peeling of bulbs of the desert broomrape (*Cistanche tubulosa*).

Woodworking

In the case of debarking and planing wood, the action involves a transversal or oblique movement. Therefore, the use-wear develops mainly when the valve is inclined on the microscope stage, indicating a small contact with the material worked—limited to the edge. It differs from grooving, for which the action is longitudinal: the micro-polish is thus visible when the valve is set almost flat and its axis perpendicular to the incident light.

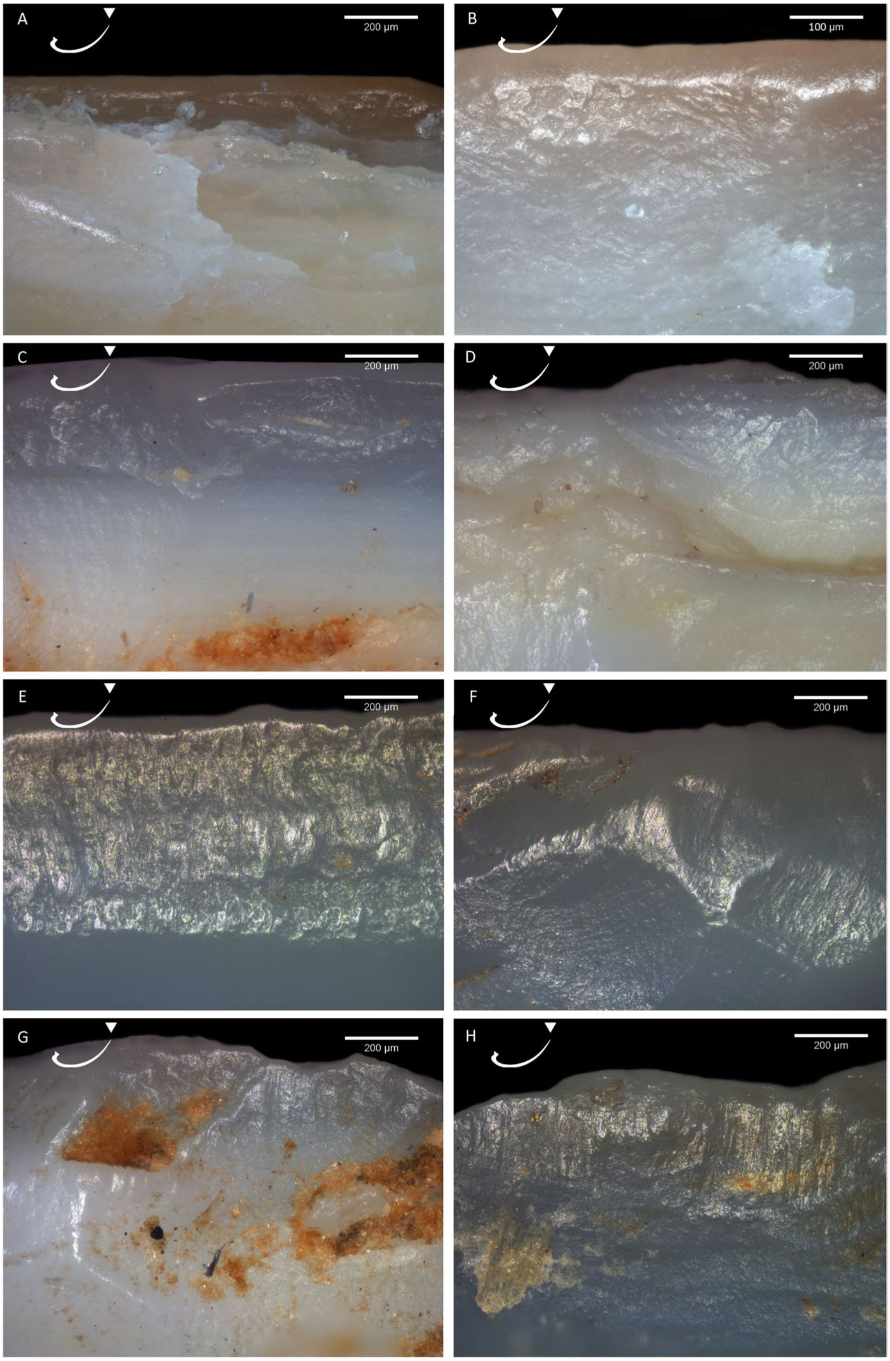
The removal of a fresh and thin bark produces a slightly rounded facet on the edge of the valve. There, the micro-polish shows a fairly closed pattern with a

Fig. 11 Use-wear produced by woodworking, at 100× (at 200× for **B**). **A**, **B** Debarking a branch of fresh false acacia, 20 min (ref. CE.04). **C** Debarking a branch of fresh false acacia, 10 min (ref. CU.59). **D** Debarking a branch of fresh mangrove, 10 min (ref. CU.53). **E**, **F** Debarking a branch of dry false acacia, 20 min (ref. CU.16). **G** Planing a branch of half-dry false acacia, 20 min (ref. CU.34). **H** Planing a branch of dry false acacia, 20 min (ref. CU.19)

fine-grained texture (better visible at 200×) (Fig. 11B) and a dull brightness (Cuenca Solana, 2013: 130). It tends to form a continuous band along the edge of the active area (Fig. 11A, C). Farther toward the inner valve, the relief shows some roundings as well, but they remain little developed and do not result in an extensive flattening of the microtopography. The micro-polish shows a loose pattern with a more grainy texture—frequently looking varnished (it might be produced by the natural 'hydration' of the green wood or its bark) (Fig. 11D). A similar texture is observed on valves used for gathering fresh wild plants or peeling bulbs. Vegetal materials are expected to create various use-wear traces depending on the fibres' hardness, ductility, and texture. Experiments with bone tools have shown that the scraping of a soft bark (such as from the birch, *Betula* sp.) produces a use-wear more or less similar to those obtained when processing fresh animal skins (Peltier & Plisson, 1986: 73). But the extension of the micro-polish would be further restricted and irregular for wood than for animal skins which are more pliant materials. Some areas showing a closer pattern could also indicate contact surfaces with wood nodes. It is also to note that striations remain rare and little visible.

Conversely, when removing a dry and smooth bark, the edge and the reliefs are extensively abraded. The micro-polish shows a closed pattern with a scratchy texture, moderately bright. It develops on the contours of the reliefs, resulting in a distinctive domed and angular aspect (Fig. 11F)—also observed on lithic tools by Keeley and Newcomer (1977: 39). Wide domed facets are even appearing on some parts of the edge (Fig. 11E). Striations are visible: they are invasive, short, of various depths and thicknesses. They are broadly parallel and oriented transversally to the edge, sometimes obliquely (Cuenca Solana et al., 2021: figs. 5, 6.c). Oblique striations tend to be thicker and deeper than transversal ones. They might result from a certain resistance of the wood to the back-and-forth motion associated with a bidirectional movement.

Planing wood produces a distinct use-wear. The edge of the valve generally shows light and more or less discontinuous roundings. Indeed, working hard or dry wood would result in the frequent renewal of the active area, creating many isolated semi-circular and half-moon-shaped fractures (Fig. 11G, H). Therefore, the main active area would be located preferentially on the extremities of the ventral margin, where the shell is thicker and more resistant to fracture. Nevertheless, the efficiency of mussel (*Aulacomya* sp. and *Mytilus* sp.) valves has been confirmed for debarking and pruning southern beech (*Nothofagus* sp.) wood in the context of the study of Aboriginal cultures from Tierra del Fuego (Argentina). However, the latter are also reported as being quite fragile when the impact force is little controlled (Mansur & Clemente Conte, 2009: 364). Conversely, the roundings are more accentuated when the wood is soft or green, especially on the edge. The further the wood is rough, hard, and dry, the more the contacts with the active area are isolated. Therefore,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the micro-polish develops more on high reliefs, showing a closed pattern and creating domed surfaces. It is moderately bright and has a slightly lumpy texture. Striations are concentrated on the edge and oriented transversally to it. They are short, thick, deep, and arranged in parallel. According to its state of hydration, the wood would also produce an extensive varnished-like micro-polish on the active area (see Fig. 11G). It generally has a loose pattern and develops well in relief. Debarking and planing wood are distinct activities that can be conducted one after another using the same tool. It would result in a combination of their respective use-wear traces.

Vegetal Fibres

Leaves of date palm have been cut using shell tools. The micro-polish is well developed when the valve is almost flat on the stage, indicating a wide contact with the material processed. The micro-polish shows a very wide extension on the active area; its pattern is closed and very bright (Cuenca Solana, 2013: 136, fig. 3.17.5–6). It develops following the relief and shows a strong abrasivity—the relief is sometimes totally disappearing, creating wide and flat surfaces with a unified micro-polish (Fig. 12A, B). The working surface is thus obviously fluent. It is worth noting that the texture is not remarkably smooth but appears slightly lumpy in some areas. Striations are numerous, very long, deep, and of various thicknesses (Cuenca Solana et al., 2021: fig. 6.b)—they look to cut through the reliefs without rounding them like a knife. They are parallel and oriented longitudinally to the edge of the valve, confirming a cutting action (Cuenca Solana et al., 2010: 217–218, fig. 2). Shorter and intersected striations would indicate a bidirectional movement. The use-wear is visible on the outer face of the valve as well.

Other vegetal fibres worked include the leaf sheath of palm trees. The edge and the relief are quite rounded here, which shows a certain abrasivity. However, we do not observe the formation of wide flat surfaces, such as for the cutting of leaves described above (Fig. 12C, D). The micro-polish is less bright and develops more moderately in relief. Indeed, the pattern is more gradual: close on high points, more open on lower points. It shows that the working surface is less fluent and, somehow, more comparable to what it is documented for wood. It, however, differs from the presence of invasive striations oriented longitudinally to the edge: they evidenced a cutting action. These striations are shallower, thinner, and more regular than those observed for tools used to process leaves. The micro-polish shows a wide extension when the action consists of processing the leaf sheath in bulk. Conversely, it is much more limited when cutting a rope or a thread in vegetal fibres (Fig. 12E).

Mineral Materials

Activities involving the process of mineral materials include scraping ochre (used for treating and colouring animal skins, in particular). The micro-polish is organised in small and discontinuous areas concentrated on the edge of the valve. It is visible mainly when inclining the valve on the microscope stage, indicating a small contact

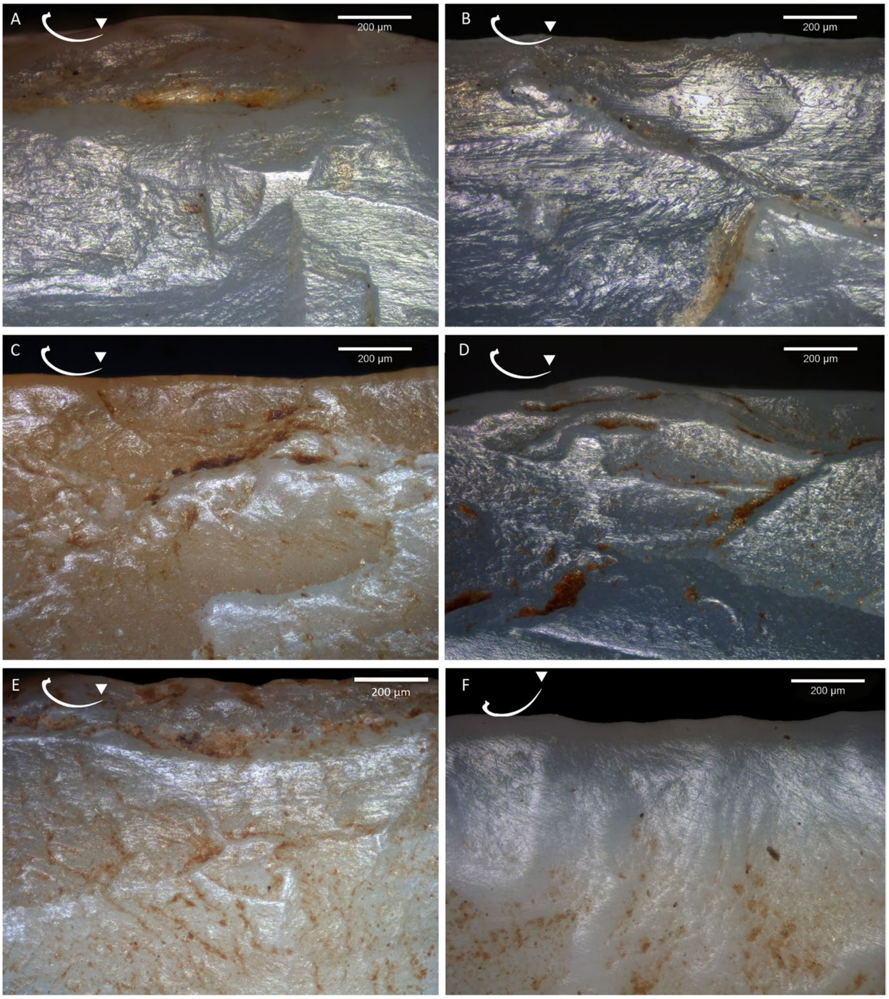

Fig. 12 Use-wear produced by the processing of vegetal fibres, at 100×. **A** Cutting half-dry date palm leaves, 10 min (ref. CU.08). **B** Cutting dry date palm leaves, 10 min (ref. CU.18). **C** Cutting date palm leaf sheath, 10 min (ref. CE.10). **D** Cutting coconut palm leaf sheath, 10 min (ref. CU.39). **E** Cutting threads of date palm leaf sheath, 5 min (ref. CE.19). **F** Stretching date palm leaf sheath, 10 min (ref. CU.74)

with the material worked. It has a completely closed pattern and it is very bright. In some areas, the roundness of the edge indicates a strong abrasivity (Fig. 13A). The relief can also be completely abraded and rounded: striations are long, thin, parallel, and variously deep (Cuenca Solana et al., 2016: figs. 2, 5.4–9). They indicate a transversal or an oblique movement. A bidirectional motion can be evidenced by the distinctive pointed-arch shape of the edge (Fig. 13B) and the development of the use-wear on the outer side of the valve.

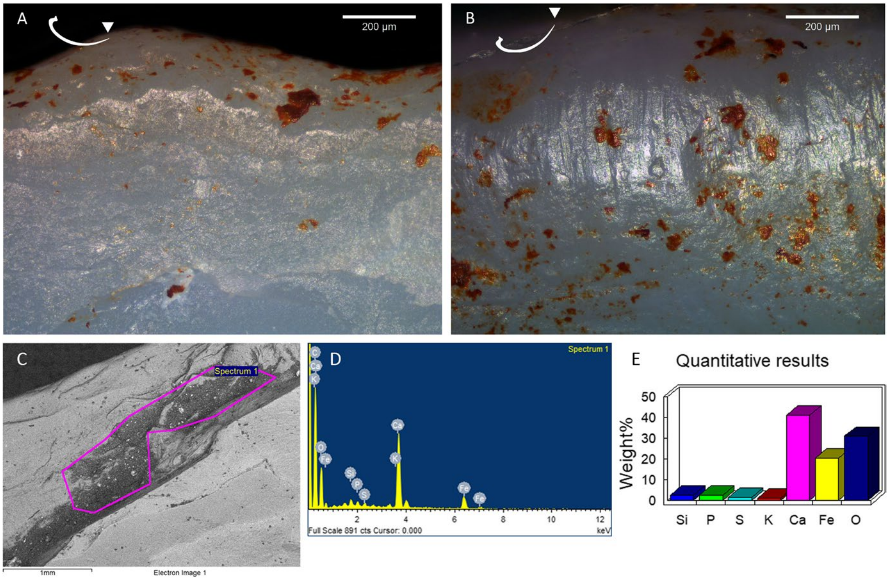

Fig. 13 **A**, **B** Use-wear produced by the hard nodule of haematite (ochre), 10 min (ref. CU.05) (at 100×). **C** One of the two sampling areas selected for residue analysis on CU.05 (image by scanning electron microscopy). **D** Energy-dispersive X-ray spectroscopy (EDX) spectrum **E** Bar chart of the elemental composition performed on the selected sampling area

Ochre is an iron oxide-rich pigment that can be either prepared from haematite and goethite, which are classified as medium-hard rocks (5–6.5 on the Mohs hardness scale) or obtained from softer earthy materials such as shale and mudstone (2–3 on the Mohs scale) (see for instance Henshilwood et al., 2014). Mollusc shells are expected to be more efficient for scraping soft minerals—whereas massive haematite would cause more fracture. It would result in a frequent renewal of the active area, showing a less developed use-wear at the end of the experiment. Conversely, the edge and the reliefs would show more roundings as much as the ochre nodule that has been worked is ductile (Cuenca Solana et al., 2013b: 374). Residue analyses can confirm the processing of ochre or other mineral materials—in the case of ochre, it can be evidenced by the residual presence of iron oxides on the surface of the active area (Cuenca Solana et al., 2016). An EDX analysis has been undertaken on two clusters of ochre present at the surface of a (not cleaned) reference shell valve (ref. CU.05 illustrated in Fig. 13C–E) used for scraping a hard block of haematite coming from Northern Spain: iron oxide (FeO) is comprised between 26.15 and 40.44%—intrusive compounds include sulfur trioxide (SO3) (3.82–6.94%), silica (SiO2) (5.74%), and phosphorus pentoxide (P2O5) (5.56%).

Discussion

The Efficiency of the Shell Valve Tools

The experiments confirmed the great efficiency of the retouched shell valves for butchering activities, particularly for slicing and scraping meat from bones and for fish scaling. These activities do not significantly affect the sharpened edge over time. Similarly, retouched valves consist of good tooling for processing animal skins, especially for scraping tasks, but only as long as the worked edge does not cause perforation or tearing because it is too irregular or toothed. In this sense, previous experimental protocols have already shown the great effectiveness of carrying out this activity using shells without retouching (Cuenca Solana, 2013). The edge tends to blunt faster when the skin is dry or when an abrasive material is added, such as ochre. Although not illustrated in the present study, other experiments have consisted of sharpening bone points. The latter have proved to be ineffective.

The retouched shell valves are effective for tasks conducted on vegetal fibres, such as for relaxing and cutting leaves or leaf sheath. However, the great abrasivity of the vegetal fibres—particularly leaves—causes a fast blunting of the working edge (in about 10 min, according to experiments). The fibres' flexibility prevents the shell from fracturing and obliges the artisan to deliberately re-sharpen the working edge to restore its effectiveness. It would appear as a significant reduction in the valve shape over time.

The efficiency of the valve tools is more contrasted regarding woodworking tasks. Activities affecting the surface of the wood, such as debarking, planing, smoothing, and shallow grooving have been successfully conducted during the experiments but sometimes lead to the fracture of the valve after several minutes of work—the fracture observed is systematically longitudinal and follows the growth lines. The edge is frequently fracturing, causing the automatic renewal of its sharpness and reducing the use-wear's readability. The use-wear is thus heterogeneously preserved all along the edge. The shell valves used for the present study are not strong enough for carving or logging wood effectively. However, further experiments must be conducted on wood of various densities to more accurately assess the durability and effectiveness of the shell tools.

Scraping ochre with a retouched valve tool was not significantly effective but, as already mentioned, it would depend on the relative great hardness of the haematite nodule that has been worked. It is expected that obtaining ochre from a softer material (*e.g.* shale and mudstone) would be more successful and would produce a better-developed use-wear.

Resuming and Comparing the Use-Wear

For butchering activities, the use-wear is characterised by a polish showing a greasy aspect and produces relatively few roundings and striations. The use-wear has a loose pattern in a general way but can show closer areas when the surface has been in contact with bones or fish bony scales. Contacts with bones are more isolated, while when the valve has been used for scaling, areas of contact are multiple and distributed on wide surfaces.

The processing of animal skins produces a polish showing a pattern from narrow to closed and a greasy-grainy texture. Unlike for butchering tasks, we observe the production of distinctive roundings on the reliefs and the edge of the valve. Dry skins are more abrasive, producing more rounding and numerous subcircular micro-holes and striations. The latter are thin, long, parallel, and arranged transversally or obliquely to the edge. Striations are also better developed when the skin has been worked on flat and hard supports rather than when laid on a frame. When an abrasive mineral powder such as ochre is added for cleaning, treating, or colouring the skin, it produces greater rounding and deep striations of various thicknesses.

The use-wear traces produced by woodworking tasks show significant variations according to the state of matter of the material worked. Experiments on fresh bark produce a distinctive use-wear: a continuous facet forms along the edge. It has a domed profile and shows a fairly closed pattern with a fine-grained texture and a dull brightness. Farther in the inner valve, the relief is significantly less affected, showing a more opened pattern and a varnished-like texture. When the bark is dry, discontinuous domed facets are produced on the edge. The texture appears scratchier and the brightness is stronger. The reliefs on the inner valve are more affected, showing a domed and angular aspect. Numerous striations are also visible, evidencing a transversal motion—they are short, showing various depths and thicknesses. Planing wood produces more or less discontinuous roundings along the edge but not properly facets such as for debarking. The roundings are more apparent when the wood is green or soft. Conversely, the further the wood is dry and hard, the more the edge would fracture, creating isolated areas where the use-wear is better preserved. The micro-polish is moderately bright and develops on high points of the reliefs close to the edge. The reliefs are slightly domed and affected by a micro-polish showing a narrow-to-closed pattern that bears numerous striations—the latter are short, thick, deep, and parallel. The texture is a bit lumpy and sometimes looks varnished.

The use-wear associated with the processing of vegetal fibres is highly distinctive, showing a closed pattern, a strong abrasion of the relief, and many striations. Cutting leaves produces a bright micro-polish and extensive flat surfaces on the working edge. Indeed, leaves are quite abrasive, and their processing produces long and deep striations that cut through the reliefs (knife-like striations) without properly rounding them. It differs from leaf sheath, which is a less abrasive vegetal fibre and produces a use-wear showing rounded and slightly domed reliefs. In the latter case, the striations are less developed and visible, thinner and shorter than those observed when cutting leaves. The pattern is closed and pretty unified on valves used for cutting leaves, while more gradual and closer areas are restricted on the high points of the relief when processing leaf sheath.

In the experiments conducted, the hardness of haematite has caused frequent fractures of the valve edge. The use-wear is not equally preserved on the working edge despite the great abrasivity of the mineral material worked—as it is shown by distinctive striations and rounding on areas that have not been fractured. Therefore, the use-wear is organised in isolated areas on the edge of the valve where the micro-polish has a closed pattern and is crossed by distinctive striations. The latter are long, thin, and variously deep. As the worked material is hard, the contact with the working area is limited, and the use-wear is not developing farther on the inner valve.

Documenting the Ancient Productive Activities

The absence of other functional analyses conducted on lithic and bone material from Late Prehistoric Arabia is a great lack for the study of shell tooling and its specificities. A single published use-wear analysis concerns Late Paleolithic (c. 12–8 kyBP) implements from Southern Oman (Hilbert & Clemente Conte, 2021). The results highlight the use of burins for transversal woodworking tasks, which could have been planing or scraping.

So far, the ancient exploitation of wood has been mainly documented as fuel through anthracological analyses. Results indicate the preferential use of locally available mangrove wood on the coast, whereas acacia-related trees and the Christ's thorn jujube were exploited in the hinterlands (Tengberg, 1998, 2005). Woodworking tasks are expected to produce shafts and handles used for tooling and weaponry—including those used for fishing and hunting (spears, bows, arrows, *etc.*). Indeed, experiments show that retouched shell valves are suitable tools for debarking, planing, and carving wood branches. On the other hand, wood can have been exploited for making furnishings (including frames for processing animal skins) and architectural elements for housing or boating. For instance, imprints on bitumen from Ra's al-Jinz (Sultanate of Oman) show the use of sewn wood planks for building boats by 2200 BCE (Cleuziou & Tosi, 2020: 294–295). However, the shell valves used for the present study are not strong enough to support the greater physical restraints induced by logging wood or shaping planks. Notably, the localisation of the use-wear produced by woodworking activities is often hard on shell valves, especially when the motion is transversal. Because of the hardness of the wood, the use-wear is restricted on the edge, not developing farther on the inner valve surface. The observation of this area requires inclining the valve almost vertically (80–90°) on the microscope stage—with this inclination, the valve sometimes does not fit within the maximal subject distance allowed by the microscope.

Direct evidence of crafting vegetal fibres is reported not only from imprints left on bitumen coatings but also from mineralised fragments of baskets, mats, and ropes—including at Ra's al-Jinz RJ2 and Ra's al-Hadd HD6 (Sultanate of Oman) for the Bronze Age (Cleuziou & Tosi, 2020: fig. 168, 179–180), and at Salut (Sultanate of Oman) for the Iron Age (Bellini et al., 2011). Until recently, date palm fibres were traditionally used for basketry and making ropes in Eastern Arabia (Crocker Jones, 1991): analyses from Salut tend to confirm its ancient use. The use of fibres from other vegetal taxa is little documented in both ethnographical and archaeological sources in this region. Shell valves have shown great effectiveness for processing vegetal fibres despite a tendency to blunt quite fast. Their use would have involved either a frequent renewal of the retouched working area or the replacement of the whole valve. On this basis, shell valves used for processing vegetal fibres are theoretically expected to be more numerous among archaeological tooling. However, experiments conducted on vegetal fibres have provided very distinctive and easily readable use-wear, which can lead to an overestimation of their importance within the assemblages.

In coastal Eastern Arabia, the animal economy was based essentially on fishing and herding during the Neolithic—on hunting as well to a lesser degree (Mashkour et al., 2016). The consumption not only of terrestrial and marine mammals, as well as of some large fish (including tuna, sharks, and rays), would have involved butchering processes for obtaining pieces of meat ready for cooking—for being stored, dried, or salted. Cutting tools can consist of either lithic or shell specimens, but, so far, no functional analysis has been conducted on the material of the region to document it. The morphological study of cut marks observed on some mammal bones could help partly to solve this issue. Conversely, up to now, no fish remains have shown cut marks within faunal assemblages retrieved from Neolithic contexts: whole fish could have been grilled on coals without beheading, scaling, or filleting processes (Lidour, 2023). Nevertheless, cut marks are sometimes observed on material from Bronze Age and Iron Age assemblages, allegedly associated with preparing preserved fish for regional trade (Lidour et al., 2023). Experiments have confirmed the effectiveness of retouched shell valves for cutting soft animal materials, including for slicing mammal meat and filleting fish. Paradoxically, butchering activities would have been one of the main uses of domestic tooling but are expected to be less documented. It is due to the little development of the use-wear and the low probability for the latter to be preserved enough on archaeological specimens to allow observations and descriptions. Therefore, there is a distinctive bias between evidence of shell tooling use for butchering tasks in ethnographic studies and its documentation within functional analyses conducted on archaeological material.

Herding and hunting provide edible animal meat and craft materials such as bones, horns, furs, and skins. Animal skins were globally exploited for producing a great variety of garments, bags (water bags, churning bags, pouches, *etc.*), and for making tents and drums (Crocker Jones, 1991). Furthermore, strips made of leather can be used for sewing or as threads for making necklaces and bracelets. Therefore, the exploitation and the use of animal skins are highly expected in Eastern Arabia since the Neolithic despite the lack of direct evidence. The present study has experimented the use of retouched shell valves for various tasks associated with the processing of animal skins: scouring, treating, and softening. The exploitation of ochre (or in the form of raw haematite) is documented on several Neolithic sites, while no study has been conducted to precise its uses so far (see Drechsler et al., 2018 for a review). The production and use of ochre powder to treat animal skins have been documented in other functional analyses (*e.g.* Cuenca Solana et al., 2016) and thus have been experimented with following a prospective approach.

Conclusion

This paper constitutes the first contribution to the functional analysis of shell tools in Eastern Arabia. The reference collection that has been built allows the description of a variety of use-wear traces associated with the processing of animal, vegetal, and mineral materials. For the present paper, it has been decided to detail the description of use-wear only for a selection of reference specimens made according to the most recurrent activities documented in the other functional analyses—especially those conducted on shell tools. It includes butchering, the processing of animal skins, woodworking, the cutting of vegetal fibres, and the scraping of ochre. This prospective initiative is aimed to provide detailed methodological support for the analysis and the interpretation of use-wear produced on Late Prehistoric shell tools of Eastern Arabia. This research not only shows that use-wear analysis can be efficiently conducted in this geographical area but also provides a better understanding of the management of marine shell as raw material and the retouching processes related to the manufacture of shell tools.

In that respect, the description of experimental use-wear allows us documenting new techno-economical aspects of the Late Prehistoric societies in this study area. Furthermore, the methods and results provided in the present study would also be helpful for functional analyses intended to concern other shell tools, particularly specimens made of the valves of other Veneridae species—including *C. chione* in Southern Europe. In this sense, the information provided here is also a relevant contribution since these taxa have barely been analysed from use-wear analysis (Cristiani et al., 2005), despite the existence of numerous tool specimens related to the Middle Palaeolithic chronologies (Romagnoli et al., 2015, 2016, 2017; Villa et al., 2020).

One of the particularities of the present reference collection is being composed of shell tools that have been deliberately worked before to be used. We have seen that the need for an effective cutting edge drives this action. It causes an important modification of the micro-topography on the active area, creating peaks and crevasses on which the use-wear develops thereafter. It differs greatly from the use of unworked shells that has been documented so far in most previous functional analyses based on reference collections. Somehow, specimens that have been worked tend to show better how a micro-polish can develop in relief.

On the occasion of the present study, it has been shown that the valves of *C. erycina* were more than likely directly collected when washed up on the shore, whereas specimens of *C. umbonella*, *A. violascens*, and *Meretrix* sp. were potentially available in intertidal substrates. Large valves were preferentially selected, providing a suitable size to be gripped in hand and a robust ventral margin intended for being worked. The retouch could have followed different schemes, including the 'Quina retouch' documented by Romagnoli et al. (2016) and the 'flat retouch' and the 'block-on-block' techniques. Although the latter retouching processes remain relatively simple, worked shell tools do not consist of expedient (versus curated) productions according to the definition given by Binford (1977). First observations on archaeological specimens have shown that shell tools were not 'task-specific', that they were frequently reworked and reused, and that some examples have been documented on sites located by tens of kilometres inland (*i.e.* by the Late Bronze Age, at Masafi 5) showing anticipation of the tool needs in a geographical context where they are not locally available. It is conceivable that marine shells would have been frequently more accessible than suitable lithic resources for most groups living more or less isolated on the coast. However, it remains to be investigated under what circumstances shell tools could have been potentially used as a substitute for lithic specimens such as flint 'tile knives'. In this sense, Cuenca Solana et al. (2013b: 378) have suggested the use of *Patella* shells for highly damaging tasks (scraping ochre) in order to save more valued lithic or bone tooling in the case of the Gravettian occupation at Fuente del Salín (Cantabria, Spain).

For this reason, further works have to be promoted in the future in this study area, including on use-wear made on lithic and bone tooling. Further experiments would be conducted taking more into account the gradual development of the micro-polish according to the duration of the activities—on the model of Cuenca Solana (2013). Variations of the working angle during the experiments would be documented more easily with the systematic use of video recordings. Furthermore, a wider range of activities associated with the processing of animal skins (or hides) and leather should be experimented with not only regarding the different stages of cleaning and treating but also regarding the differences induced by the use of a frame by opposition to an action completed on the ground or other hard supports. It would be preferable to conduct new experiments not only on sheep skins but also on those of goats, cattle (*Bos* sp.), gazelles (*Gazella* sp.), donkeys (*Asinus* sp.), and even oryx (*Oryx leucoryx*), which counted as other terrestrial mammals consumed in Late Prehistoric Arabia. Further experiments of butchering activities should also be conducted on fish species (among others, tuna and sharks) encountered in the study area. Compiling ethnographic records would allow a more complete assessment of the variety of locally available vegetal fibres that could have been processed and used in the past. Finally, pottery and plaster vessel production processes must be reconstructed and experimented with using shell tools.

This first methodological development constitutes a significant advance in the knowledge of shell tools in this area—a geographic space where these tools played an essential role within the technological assemblages of ancient fisher-herder populations.

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Authors' contributions KL has conducted the experiments and the analyses. Interpretations are discussed by both KL and DCS. KL wrote the manuscript and designed the figures. DCS provided critical feedback and helped shape the research. All authors read and approved the final manuscript.

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Code Availability Not applicable.

Declarations

Ethics Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Competing interests The authors declare no competing interests.

References

Akerman, K. (1975). Baler Shell Implements from North West Australia. *Mankind*, *10*, 16–19.

Akerman, K., & Bindon, P. (1984). The edge-ground stone adze and modern counterparts in the Kimberley region, Western Australia. *Records of the Western Australia Museum, 11*(4), 357–437.

Allen, M. S. (1996). Style and function in East Polynesian fish-hooks. *Antiquity, 70*(267), 97–116. https://doi.org/10.1017/S0003598X00082922

Allen, H. (2009). Native companions: Blandowski, Krefft, and the Aborigines on the Murray River Expedition. *Proceedings of the Royal Society of Victoria, 121*(1), 129–145. https://doi.org/10.1071/RS09129

Anderson-Gerfaud, P. C. (1980). A testimony of Prehistoric tasks: Diagnostic residues on stone tool working edges. *World Archaeology, 12*(2), 181–194. https://doi.org/10.1080/00438243.1980.9979791

Ardhana, I. P. G., Rimbawan, I. M. G. S., Cahyo, P. N., Fitriani, Y., & Rohani, S. (2018). The distribution of vertical leaves and leaves biomass on ten mangrove species at Ngurah Rai Forest Park, Denpasar, Bali. *Indonesia. Biodiversitas, 19*(3), 918–926. https://doi.org/10.13057/biodiv/d190322

Armitage, S. J., Jasim, S. A., Marks, A. E., Parker, A. G., Usik, V. I., & Uerpmann, H.-P. (2011). The southern route of "Out of Africa": Evidence for an early expansion of modern humans into Arabia. *Science, 331*(6016), 453–456. https://doi.org/10.1126/science.1199113s

Armstrong, D. V. (1979). Scrap or tools: A closer look at *Strombus gigas* Columella Artifacts. *Journal of the Virgin Islands Archaeological Society, 7*, 27–34.
Audouin, F., & Plisson, H. (1982). Les ocres et leurs témoins au Paléolithique en France : Enquête et expériences sur leur validité archéologique. In H. Plisson (Ed.), *Cahier du centre de recherches préhistoriques – Section 33* (pp. 33–80). U.E.R. d'Art et d'Archéologie.
Barton, H., & White, P. J. (1993). Use of stone and shell artifacts at Balof 2, New Ireland. *Papua New Guinea. Asian Perspectives, 32*(2), 169–181.
Beech, M. J., & Glover, E. (2005). The environment and economy of an Ubaid-related settlement on Dalma Island. *United Arab Emirates. Paléorient, 31*(1), 97–107.
Beech, M. J., Cuttler, R. T., Khalfan al-Kaabi, A., Abdalla el-Faki, A., Martin, J., Hamad al-Hameli, N., Roberts, H. M., Spencer, P., Tomasi, D., Brunet, O., & Crassard, R. (2020). Excavations at MR11 on Marawah Island (Abu Dhabi, UAE): New insight into the architecture and planning of Arabian Neolithic settlements and early evidence for pearling. *Arabian Archaeology and Epigraphy, 31*(1), 19–31. https://doi.org/10.1111/aae.12148
Beech, M. J., Hamad al-Hameli, N., Cuttler, R. T., Lidour, K., Roberts, H. M., Crassard, R., Yalman, N., & Davies, T. (2022). Neolithic settlement patterns and subsistence strategies on Marawah Island, Abu Dhabi Emirate, United Arab Emirates. *Proceedings of the Seminar for Arabian Studies, 51*, 7–24.
Beech, M. J. (2004). *In the land of the Ichthyophagi. Modelling fish exploitation in the Arabian Gulf and Gulf of Oman from the 5th millennium BC to the Late Islamic period.* Abu Dhabi Island Archaeological Survey Monograph 1. BAR International Series 1217. Archaeopress.
Bellini, C., Condoluci, C., Giachi, G., Gonelli, T., & Mariotti Lippi, M. (2011). Interpretative scenarios emerging from plant micro- and macroremains in the Iron Age site of Salut, Sultanate of Oman. *Journal of Archaeological Science, 38*(10), 2775–2789. https://doi.org/10.1016/j.jas.2011.06.021
Berger, J.-F., Guilbert-Berger, R., Marrast, A., Munoz, A., Guy, H., Barra, A., López Sáez, J. A., Pérez Díaz, S., Mashkour, M., Debue, K., Lefèvre, C., Gosselin, M., Mougne, C., Bruniaux, G., Thorin, S., Nisbet, R., Oberlin, C., Mercier, N., Richard, M., … Béarez, P. (2020). First contribution of the excavation and chronostratigraphic study of the Ruways 1 Neolithic shell midden (Oman) in terms of Neolithisation, palaeoeconomy, social-environmental interactions and site formation processes. *Arabian Archaeology and Epigraphy, 31*(1), 32–49. https://doi.org/10.1111/aae.12144
Bernard, F. R., Cai, Y. Y., & Morton, B. (1993). *Catalogue of the living marine bivalve molluscs of China*. Hong Kong University Press.
Binford, L. R. (1977). Forty-seven trips: A case study in the character of archaeological formation processes. In R. V. S. Wright (Ed.), *Stone Tools as Cultural Markers* (pp. 24–36). Humanities Press.
Bocquenet, J.-P. (1998). Les ateliers de perles en coquillages marins des Pyrénées méditerranéennes. L'exemple de l'atelier de perles du Moulin à Durban-Corbières (Aude). In G. Camps (Ed.), *L'homme préhistorique et la mer. Actes du 120ème congrès des sociétés savantes d'Aix en Provence, 23-26 oct. 1995* (pp. 259–272). Editions du Comité des travaux historiques et scientifiques.
Bordes, F. (1947). Etude comparative des différentes techniques de taille du silex et des roches dures. *L'anthropologie, 51*, 1–29.
Bordes, F. (1988). *Typologie du Paléolithique ancien et moyen (5th ed.).* Presses du CNRS.
Bosch, D. T., Dance, S. P., Moolenbeek, R. G., & Oliver, P. G. (1995). *Seashells of Eastern Arabia*. Motivate Publishing.
Bowdler, S. (1976). Hook, line and dilly bag: An interpretation of an Australian coastal shell midden. *Mankind, 10*(4), 248–258. https://doi.org/10.1111/j.1835-9310.1999.tb01453.x
Bradfield, J. (2015). Use-trace analysis of bone tools: A brief overview of four methodological approaches. *South African Archaeological Bulletin, 70*(201), 3–14.
Bretzke, K., Preusser, F., Jasim, S. A., Miler, C., Preston, G., Raith, K., Underdown, S. J., Parton, A., & Parker, A. G. (2022). Multiple phases of human occupation in Southeast Arabia between 210,000 and 120,000 years ago. *Scientific Reports, 12*(1600). https://doi.org/10.1038/s41598-022-05617-w
Brink, J. W. (1978). *An experimental study of microwear formation on endscrapers.* Mercury Series, Archaeological Survey of Canada Paper 83. University of Ottawa Press. https://doi.org/10.2307/j.ctv16w5v
Brown, S. (1997). *Estimating biomass and biomass change of tropical forests: A primer.* FAO Forestry Paper 134. FAO.
Cade, C. (1998). Les coquillages marins dans les gisements préhistoriques du midi méditerranéen français. In G. Camps (Ed.), *L'homme préhistorique et la mer. Actes du 120ème congrès des sociétés*

savantes d'Aix en Provence, 23-26 oct. 1995 (pp. 339–349). Editions du Comité des travaux historiques et scientifiques.

Cesari, P., & Pellizzato, M. (1990). Biology of Tapes Philippinarum. In D. Agostini & G. Alessandra (Eds.), *Tapes Philippinarum: Biologia e Sperimentazione* (pp. 21–46). Centre Scientifico Didattico.

Charpentier, V., Angelucci, D. E., Méry, S., & Saliège, J.-F. (2000). Autour de la mangrove morte de Suwayh, l'habitat VIe-Ve millénaires de Suwayh SWY-11, Sultanat d'Oman. *Proceedings of the Seminar for Arabian Studies, 30*, 69–85.

Charpentier, V., Marquis, P., & Pellé, E. (2003). La nécropole et les derniers horizons Ve millénaire du site de Gorbat al-Mahar (Suwayh, SWY-1, Sultanat d'Oman): Premiers résultats. *Proceedings of the Seminar for Arabian Studies, 33*, 11–19.

Charpentier, V., Méry, S., & Phillips, C. (2004). Des coquillages… outillages des Ichtyophages ? Mise en évidence d'industries sur Veneridae, du Néolithique à l'âge du Fer (Yémen, Oman, E.A.U.). *Arabian Archaeology and Epigraphy, 15*, 1–10. https://doi.org/10.1111/j.1600-0471.2004.00019.x

Cheynier, A. (1949). *Badegoule, station solutréenne et proto-magdalénienne.* Archives de l'Institut de Paléontologie Humaine, Mémoire 23. Institut de Paléontologie Humaine (IPH).

Clemente Conte, I. (1997). *Los instrumentos líticos de Tunel VII: una aproximación etnoarqueológica.* Treball d'etnoarqueológica 2. Consejo Superior de Investigaciones Científicas de Barcelona.

Clemente Conte, I., Cuenca Solana, D., Oliva Poveda, M., Rosilla Turrà, R., & Palomo Pérez, A. (2015). Comparative analysis of shell tools from two Neolithic sites in NE Iberia: La Draga and Serra del Mas Bonet (Girona). In J. Marreiros, J. Gibaja Bao, & N. Bicho (Eds.), *International Conference on Use-Wear Analysis. Use-Wear 2012* (pp. 607–618). Cambridge Scholars Publishing.

Cleuziou, S., & Tosi, M. (2020). *In the shadow of the ancestors. The Prehistoric foundations of the early Arabian civilization in Oman (second edition expanded).* Ministry of Heritage and Tourism, Sultanate of Oman.

Cleyet Merle, J.-J. (1990). *Préhistoire de la pêche*. Editions Errance.

Cortés Sánchez, M., Morales Muñiz, A., Simón Vallejo, M. D., Lozano Francisco, M. C., Vera Peláez, J. L., Finlayson, C., Rodríguez Vidal, J., Delgado Huertas, A., Jiménez Espejo, F. J., Martínez Ruiz, F., Martínez Aguirre, M. A., Pascual Granged, A. J., Bergadà Zapata, M. M., Gibaja Bao, J. F., Riquelme Cantal, J. A., López Sáez, J. A., Rodrigo Gámiz, M., Sakai, S., Sugisaki, S., … Bicho, N. F. (2011). Earliest known use of marine resources by Neanderthals. *PLoS ONE, 6*(9), e24026. https://doi.org/10.1371/journal.pone.0024026

Courtin, J., & Vigié, B. (1987). Le problème des coquillages à bord dentelé dans la Préhistoire du midi de la France. *Mesogee, 47*, 93–98.

Craib, J. (1977). *A typological investigation of Western Micronesian Adzes*. M.A. dissertation. California State University.

Cristiani, E., Lemorini, C., Martini, F., & Sarti, L. (2005). Scrapers of Callista chione from Grotta del Cavallo (Middle Palaeolithic cave in Apulia): Evaluating use-wear potential. In H. Luik, A. M. Choyke, C. E. Batey, & L. Lõugas (Eds.), *From Hooves to Horns, from Mollusc to Mammoth: Manufacture and Use of Bone Artefacts from Prehistoric Times to the Present* (pp. 319–324). Oxbow Books.

Crocker Jones, G. (1991). The crafts. In P. M. Costa (Ed.), *Musandam. Architecture and material culture of a little known region of Oman* (pp. 145–90). IMMEL Publishing.

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*. Editorial de la Universidad de Cantabria (PUbliCan).

Cuenca Solana, D., & Clemente Conte, I. (2017). Pasado, presente y futuro del análisis funcional aplicado al estudio de los instrumentos de concha prehistóricos. In F. Molina González (Ed.), *Cuadernos de Prehistoria y Arqueología de la Universidad de Granada 27* (pp. 293–314). Universidad de Granada.

Cuenca Solana, D., Clemente Conte, I., & Gutiérrez Zugasti, I. (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 huellas de uso en materiales malacológicos. *Trabajos De Prehistoria, 67*(1), 211–225. https://doi.org/10.3989/tp.2010.10037

Cuenca Solana, D., Gutiérrez Zugasti, I., & Clemente Conte, I. (2011). The use of mollusc shells as tools by coastal human groups: The contribution of ethnographical studies to research on Mesolithic and Early Neolithic technologies in Northern Spain. *Journal of Anthropological Research, 67*(1), 77–102.

Cuenca Solana, D., Cantillo Duarte, J. J., Vijande Vila, E., Montañés Caballero, M., Clemente Conte, I., & Villalpando 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 dela Frontera, Cádiz). *Zephyrus, 72*, 95–111. https://doi.org/10.14201/zephyrus20137295111

Cuenca Solana, D., Gutiérrez Zugasti, I., González Morales, M. R., 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. *Current Anthropology, 54*(3), 370–380.

Cuenca Solana, D., Clemente Conte, I., Oliva Poveda, M., & Gutiérrez Zugasti, I. (2014). Estudio de la manufactura y/o uso de instrumentos de trabajo y elementos de adorno de concha desde la metodología del análisis funcional. *Archaeofauna, 23*, 9–24.

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. In I. Gutiérrez Zugasti, D. Cuenca Solana, & M. R. González Morales (Eds.), *La Investigación Arqueomalacológica en la Península Ibérica: Nuevas Aportaciones* (pp. 101–111). Actas de la IV Reunión de Arqueomalacología de la Península Ibérica. Nadir Ediciones.

Cuenca Solana, D., Gutiérrez Zugasti, I., Ruiz Redondo, A., González Morales, M. R., Setién, J., Ruiz Martínez, E., Palacio Pérez, E., de Las Heras Martín, C., Prada Freixedo, A., & Lasheras Corruchaga, J. A. (2016). Painting Altamira Cave? Shell tools for ochre-processing in the Upper Palaeolithic in northern Iberia. *Journal of Archaeological Sciences, 74*, 135–151. https://doi.org/10.1016/j.jas.2016.07.018

Cuenca Solana, D., Clemente Conte, I., Lloveras, L., García Argüelles, P., & Nadal, J. (2021). Shell tools and productive strategies of hunter-gatherer groups: Some reflections from a use-wear analysis at the Balma del Gai site (Barcelona, Spain). *Journal of Archaeological Science: Reports, 37*, 102955. https://doi.org/10.1016/j.jasrep.2021.102955

Dacal Moure, R. (1978). *Artefactos de concha en las comunidades aborígenes cubanas.* Publicaciones del Museo Antropológico Montané 5. Universidad de la Habana.

Dacal Moure, R., & Rivero de la Calle, M. (1984). *Arqueología aborigen de Cuba*. Editorial Gente Nueva.

Davidson, J. (1967). An archaeological assemblage of simple fishhooks from Nukuoro Atoll. *Journal of the Polynesian Society, 76*(2), 177–196.

Delagnes, A., Jaubert, J., & Leignen, L. (2007). Les technocomplexes du Paléolithique moyen en Europe Occidentale dans leur cadre diachronique et géographique. In B. Vandermeersch & B. Maureille (Eds.), *Les Néandertaliens, Biologie et cultures* (pp. 213–229). Editions du CTHS.

D'Errico, F., Vanhaeren, M., Barton, N., Bouzouggar, A., Mienis, H., & Richter, D. (2009). Additional evidence on the use of personal ornaments in the Middle Palaeolithic of North Africa. *PNAS, 106*(38), 16051–16056. https://doi.org/10.1073/pnas.0903532106

Douka, K. (2011). An Upper Palaeolithic shell scraper from Ksar Akil (Lebanon). *Journal of Archaeological Science, 38*(2), 429–437. https://doi.org/10.1016/j.jas.2010.09.026

Douka, K., & Spinapolice, E. (2012). Neanderthal shell tool production: Evidence from Middle Palaeolithic Italy and Greece. *Journal of World Prehistory, 25*, 45–79. https://doi.org/10.1007/s10963-012-9056-z

Drechsler, P. (2018). *Dosariyah: Reinvestigating a Neolithic coastal community in eastern Arabia.* British Foundation for the Study of Arabia Monograph 19. Archaeopress.

Drechsler, P., Berthold, C., & Kainert, C. (2018). Hematite Objects and the Use of Red Pigments. In P. Drechsler (Ed.), *Dosariyah: Reinvestigating a Neolithic coastal community in eastern Arabia (British Foundation for the Study of Arabia Monograph 19)* (pp. 302–309). Archaeopress.

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*. PhD dissertation. Université Paris 1 Panthéon-Sorbonne.

Dupont, C., & Cuenca Solana, D. (2014). Outil ou parure sur coquille marine. In I. Praud (Ed.), *Nord-Pas-de-Calais Escalles, Mont d'Hubert : Une enceinte du Néolithique Moyen II, des fosses du Néolithique Moyen I et du Bronze final sur le littoral de la Mer du Nord (INRAP, Rapport de fouille préventive)* (pp. 138–159). Editions CD.

Edens, C. (1982). Toward a definition of the western ar-Rub' al-Khali « Neolithic ». *Atlal, 6*, 109–124.

Edens, C. (1988). The Rub' al-Khali "Neolithic" revisited: The view from Nadqan. In D. Potts (Ed.), *Araby the Blest: Studies in Arabian Archaeology* (pp. 15–43). Carsten Niebuhr Institute Publications 7. Museum Tusculanum Press.

Emory, K. P., Bonk, W. J., & Sinoto, Y. H. (1959). *Hawaiian Archaeology: Fishhooks.* Bernice P. Bishop Museum special publication 47. Bishop Museum Press.

Emperaire, J. (1958). *Los nómades del mar*. Lom Ediciones.

Erlandson, J. M. (2001). The archaeology of aquatic adaptations: Paradigms for a new millennium. *Journal of Archaeological Research, 9*(4), 287–350. https://doi.org/10.1023/A:1013062712695

Gauvrit Roux, E., & Beyries, S. (2018). Le travail de la peau au Magdalénien moyen ancien. Analyse techno-fonctionnelle des grattoirs de la Marche (Lussac-les-Châteaux, Vienne). *Bulletin de la Société préhistorique française, 115*(4), 647–675.

Ghalehno, M. D., Sheshkal, B. N., Humar, M., & Bahmani, M. (2021). Characterization of anatomical, morphological, physical and chemical properties of Konar (*Ziziphus spina-christi*) wood. *Wood Research, 66*(6), 912–920. https://doi.org/10.37763/wr.1336-4561/66.6.912920

González Urquijo, J. E., & Ibáñez Estévez, J. J. (1994). *Metodología de análisis funcional de instrumentos tallados en sílex.* Cuadernos de Arqueología 14. Universidad de Deusto.

Grace, R. (1989). *Interpreting the Function of Stone Tools: The quantification and computerization of microwear analysis.* BAR International Series 474. BAR Publishing.

Gruet, M., Lemonnier, L., & Gruet, Y. (1999). Les coquilles marines. In C. Burnez & P. Fouéré (Eds.), *Les enceintes néolithiques de Diconche à Saintes (Charente-Maritime)* (Vol. 1, pp. 139–146). Association des Publications Chauvinoises & Société Préhistorique Française.

Gusinde, M. (1986). *Los Indios de Tierra de Fuego: Los Yámana.* Centro Argentino de Etnología Américana.

Gutiérrez Zugasti, F. I., Cuenca Solana, D., Clemente Conte, I., González Sainz, C., & López Quintana, J. C. (2011). Instrumentos de trabajo y elementos de adorno en conchas de molusco de la cueva de Santimamiñe (Kortezubi, Bizkaia). In J. C. López Quintana (Ed.), *La cueva de Santimamiñe: revisión y actualización (2004-2006)* (pp. 155–170). Bizkaiko Arkeologi Indusketak 1. Argitarazlea.

Harold, L., Fossat, J., & Pelletier, D. (2010). Les indicateurs de la biodiversité marine et côtière: état des lieux institutionnel. *Vertigo, 10*(2). https://doi.org/10.4000/vertigo.9893

Henshilwood, C., & Sealy, J. (1997). Bone artefacts from the Middle Stone Age at Blombos Cave, Southern Cape. *South Africa. Current Anthropology, 38*(5), 890–895.

Henshilwood, C. S., van Niekerk, K. L., Wurz, S., Delagnes, A., Armitage, S. J., Rikkin, R. F., Douze, K., Keen, P., Haaland, M. H., Reynard, J., Discamps, E., & Mienies, S. S. (2014). Klipdrift Shelter, southern Cape, South Africa: Preliminary report on the Howeiesons Poort layers. *Journal of Archaeological Science, 45*, 284–303. https://doi.org/10.1016/j.jas.2014.01.033

Hilbert, Y. H., & Clemente Conte, I. (2021). Stone tool use and rejuvenation at the Late Palaeolithic site of TH.413 Wadi Ribkout, southern Oman. In S. Beyries, C. Hamon, & Y. Maigrot (Eds.), *Beyond Use-Wear Traces: Going from tools to people by means of archaeological wear and residue analyses* (pp. 129–142). Sidestone Press.

Hoffmann, D. L., Angelucci, D. E., Villaverde, V., Zapata, J., & Zilhão, J. (2018). Symbolic use of marine shells and mineral pigments by Iberian Neandertals 115,000 years ago. *Science Advances, 4*(2), eaar5255. https://doi.org/10.1126/sciadv.aar5255

IDEAS Consultancy Services. (2013). Preparation of Baseline Data Mangrove Ecosystem Management in Binland Island. Indonesia.

Jensen, H. J. (1988). Functional analysis of prehistoric flint tools by high-power microscopy: A review of West European research. *Journal of World Prehistory, 2*, 53–88. https://doi.org/10.1007/BF00975122

Johnson, P. J. (1978). Patwin. In R. E. Heizer (Ed.), *Handbook of the North American Indians* (Vol. 8, pp. 350–360). Smithsonian Institution.

Joordens, J. C. A., d'Errico, F., Wesselingh, F. P., Munro, S., de Vos, J., Wallinga, J., Ankærgaard, C., Reimann, T., Wijbrans, J. R., Kuiper, K. F., Mücher, H. J., Coquegniot, H., Prié, V., Joosten, I., van Os, B., Panuel, M., van der Haas, V., Lustenhouwer, W., Reijmer, J. J. G., & Roebroeks, W. (2015). *Homo erectus* at Trinil on Java used shells for tool production and engraving. *Nature, 518*, 228–231. https://doi.org/10.1038/nature13692

Kamminga, J. (1982). *Over the Edge: Functional Analysis of Australian Stone Tools.* Occasional papers in Anthropology 12. Anthropology Museum, University of Queensland.

Kapel, H. (1967). *Atlas of the Stone-Age Cultures of Qatar*. Aarhus Universitetforlag.

Keeley, L. H. (1974). Technique and methodology in microwear studies: A critical review. *World Archaeology, 5*, 323–336. https://doi.org/10.1080/00438243.1974.9979577

Keeley, L. H., & Newcomer, M. H. (1977). Microwear analysis of experimental tools: A test case. *Journal of Archaeological Science, 4*, 29–62. https://doi.org/10.1016/0305-4403(77)90111-X

Lammers Keijsers, Y. M. J. (2008). *Tracing Traces from Present to past. A funtional analysis of Pre-columbian shell and stone artefacts from Anse à la Gourde and Morel, Guadaloupe, French West Indies*. Leiden University Press.

Lampert, R. J., & Turnbull, G. E. (1970). The manufacture of shell fish hooks on the south coast of New South Wales. *Mankind, 7*, 312–313.

Laplace, G. (1968). Recherches de typologie analytique 1968. *Origini, 2*, 7–64.

Leontarakis, P. K., & Richardson, C. A. (2005). Growth of the smooth clam, *Callista chione* (Linnaeus, 1758) (Bivalvia: Veneridae) from the Thracian Sea, northeastern Mediterranean. *Journal of Molluscan Studies, 71*(2), 189–192. https://doi.org/10.1093/mollus/eyi022

Leroi-Gourhan, A. (1945). *Evolution et techniques vol. II : Milieu et technique*. Editions Albin Michel.

Lidour, K. (2018). *Stratégies et techniques de pêche dans le Golfe persique au Néolithique (VIème-IVème millénaire av. n.-è.). Etude des assemblages ichtyologiques des sites néolithiques d'Akab, de Dalma et de Marawah MR11 (Emirats Arabes Unis).* PhD dissertation. Université Paris 1 Panthéon-Sorbonne. https://doi.org/10.13140/RG.2.2.16426.54729

Lidour, K. (2023). Thoughts on Neolithic fishing-based economies in coastal Eastern Arabia. *Journal of Anthropological Archaeology, 70*, 101489. https://doi.org/10.1016/j.jaa.2023.101489

Lidour, K., Pellegrino, M. P., & Charbonnier, J. (2023). Coastal-hinterland exchange during the Late Bronze Age and the Early Iron Age across the northern Ḥajar mountains: The case of marine shells at Masāfī 5 (Emirate of Fujairah, United Arab Emirates). *Archaeological and Anthropological Sciences, 15*, 29. https://doi.org/10.1007/s12520-023-01732-5

Lidour K., Beech, M. J., & Hamad al-Hameli, N. (in press). Fishing strategies and adaptation to maritime environments during the Neolithic on Marawah Island, United Arab Emirates. In *Archaezoology of the Near East XIV Proceedings of the 14th International Symposium of the ICAZ Archaeozoology of Southwest Asia and Adjacent Areas Working Group. 3rd to 7th of June 2019, Barcelona (Spain)*. Barkhuis Publishing.

Magee, P. (2014). *The Archaeology of Prehistoric Arabia*. Cambridge University Press. https://doi.org/10.1017/CBO9781139016667

Maigrot, Y. (1997). Tracéologie des outils tranchants en os des Ve et IVe millénaires av. J.-C. en Bassin parisien. Essai méthodologique et application. *Bulletin de la Société Préhistorique française, 94*(2), 198–216.

Maigrot, Y. (2003). *Étude technologique et fonctionnelle de l'outillage en matières dures animales, la station 4 de Chalain (Néolithique final, Jura, France).* PhD dissertation. Université Paris 1 Panthéon-Sorbonne.

Manca, L. (2013). *Fonctionnement des sociétés de la fin du Néolithique au début de l'âge du cuivre en Sardaigne. Une approche inédite à partir de l'étude des productions en matières dures animales*. PhD dissertation. Université de Provence Aix-Marseille.

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. https://doi.org/10.5252/az2016n2a6

Mansur, M. E., & Clemente Conte, I. (2009). ¿Tecnologías invisibles? Confección, uso y conservación de instrumentos de valva en Tierra del Fuego. In F. Olivia, N. de Grandis, & J. Rodríguez (Eds.), *Arqueología Argentina en los inicios de un nuevo siglo. XIV Congreso Nacional de Arqueología Argentina (Tome II)* (pp. 359–367). Universidad Nacional de Rosario.

Mansur-Franchomme, M. E. (1983). Scanning electron microscopy of dry hide working tools: The role of abrasives and humidity in microwear polish formation. *Journal of Archaeological Science, 10*, 223–230. https://doi.org/10.1016/0305-4403(83)90005-5

Mansur-Franchomme, M. E. (1980). *Las estrías coma microrastros de utilización: clasificación y mecanismos de formación.* Antropología y Paleoecología Humana vol. 2. Universidad de Granada.

Marcucci, L. G., Badel, E., Genchi, F., Munoz, O., Todero, A., & Tosi, M. (2014). New investigations at the prehistoric shell midden of Ra's al-Hamra 6 (Sultanate of Oman): Results of the 2012 and 2013 excavation seasons. *Proceedings of the Seminar for Arabian Studies, 44*, 235–256.

Marcucci, L. G., Badel, E., & Genchi, F. (2021). *Prehistoric fisherfolk of Oman. The Neolithic village of Ras al-Hamra RH5.* The Archaeological Heritage of Oman, vol. 6. Archaeopress.

Marean, C. W., Bar-Matthews, M., Bernatchez, J., Fisher, E., Goldberg, P., Herries, A., Jacobs, Z., Jerardino, A., Karkanas, P., Minichillo, T., Nilssen, P. J., Thompson, E., Watts, I., & Williams, H. M. (2007). Early human use of marine resources and pigment in South Africa during the Middle Pleistocene. *Nature, 449*, 905–908. https://doi.org/10.1038/nature06204

Marquardt, W. H. (1992). Shell artifacts from the Caloosahatchee area. In W. H. Marquardt & C. Payne (Eds.), *Culture and Environment in the Domain of the Calusa* (pp. 191–227). Institute of Archaeology and Paleoenvironmental Studies.

Martin, C. (2004). La consommation de mollusques marins sur les sites de Suwayh 1 et Ra's al-Jinz 2 (Néolithique, âge du Bronze, sultanat d'Oman). In J.-P. Brugal & J. Desse (Eds.), *Petits animaux et sociétés humaines. Du complément alimentaire aux ressources utilitaires. XXIVe rencontres internationales d'archéologie et d'histoire d'Antibes* (pp. 47–67). Editions APDCA.

Martin, C. (2005). Stratégies et statut de la collecte des mollusques marins sur les sites côtiers d'Oman du Néolithique à l'âge du Bronze: Apport des sites de Suwayh 1, Ra's al-Khabbah 1 et Ra's al-Jinz 2. *Paléorient, 31*(1), 169–175.

Mashkour, M., Beech, M. J., Debue, K., Yeomans, L., Bréhard, S., Gasparini, D., & Méry, S. (2016). Middle to Late Neolithic animal exploitation at UAQ2 (5500–4000 cal BC): An Ubaid-related coastal site at Umm al-Quwain Emirate, United Arab Emirates. *Proceedings of the Seminar for Arabian Studies, 46*, 195–210.

Méry, S. (2015). Mobilité et interculturalité en Arabia orientale durant la Protohistoire ancienne : la formation d'un ensemble culturel et d'entités régionales. In N. Naudinot, L. Meignen, D. Binder, & G. Guerré (Eds.), *Les systèmes de mobilité de la Préhistoire au Moyen Âge. XXXVe rencontres internationales d'archéologie et d'histoire d'Antibes* (pp. 353–368). Editions APDCA.

Méry, S., & Charpentier, V. (2012). Akab Island, a Neolithic sanctuary in the gulf. In D. T. Potts & P. Hellyer (Eds.), *Fifty Tears of Emirates Archaeology. Proceedings of the Second International Conference on the Archaeology of the United Arab Emirate* (pp. 69–77). Motivate Publishing.

Méry, S., & Charpentier, V. (2013). Neolithic material cultures of Oman and the Gulf seashores from 5500–4500 BCE. *Arabian Archaeology and Epigraphy, 24*(1), 73–78. https://doi.org/10.1111/aae.12010

Moss, E. H. (1983). Some comments on edge damage as a factor in functional analysis of stone artifacts. *Journal of Archaeological Science, 10*, 231–242. https://doi.org/10.1016/0305-4403(83)90006-7

Moss, E. H., & Newcomer, M. H. (1982). Reconstruction of tool use at Pincevent: Microwear and experiments. *Studia Praehistorica Belgica Leuven, 2*, 289–312.

Odell, G. H. (1977). *The implication of microwear analysis to the lithic component of an entire prehistoric settlement: Methods, problems and functional reconstructions*. PhD dissertation. Harvard University.

Odell, G. H. (1980). Butchering with stone tools : Some experimental results. *Lithic Technology, 9*(2), 39–48. https://doi.org/10.1080/01977261.1980.11754469

Parkington, J. E. (2001). Milestones : The impact of the systematic exploitation of marine foods on human evolution. In P. V. Tobias, M. A. Raath, J. Moggi-Cecchi, & G. A. Doyle (Eds.), *Humanity from African Naissance to Coming Millennia* (pp. 327–336). Witwatersrand University Press.

Pascual Benito, J. L. (2008). Instrumentos neolíticos sobre soporte malacológico de las comarcas centrales valencianas. In M. S. Hernandez Perez, J. A. Soler Diaz, & J. A. Lopez Padilla (Eds.), *IV Congreso del Neolítico Peninsular (tomo II)* (pp. 290–297). Museo Arqueológico de Alicante.

Peltier, A., & Plisson, H. (1986). Micro-tracéologie fonctionnelle sur l'os. Quelques résultats expérimentaux. In *Outillage peu élaboré en os et en bois de cervidés* (Vol. 2, pp. 69–90). Editions du Centre d'Etudes et de Documentation Archéologique.

Petraglia, M. D., al-Sharekh, A., Breeze, P., Clarkson, C., Crassard, R., Drake, N., Groucutt, H. S., Jennings, R., Parker, A. G., Parton, A., Roberts, R.G., Shipton, C., Matheson, C., al-Omari, A., & Veall, M.-A. (2012). Hominin dispersal into the Nefud Desert and Middle Palaeolithic settlement along the Jubbah Palaeolake, Northern Arabia. *PLoS ONE, 7*(11), e49840. https://doi.org/10.1371/journal.pone.0049840

Philibert, S. (1995). Approche techno-fonctionnelle et territoriale de la Balma Margineda, en Andorre, durant l'occupation du mésolithique ancien. In J. Guilaine (Ed.), *Cultures i medi de la prehistoria a l'edat Mitjana : 20 anys d'arqueologia pirinenca. Xe Colloqui Internacional d'Arqueologia de Puigcerdà* (pp. 113–118). Publicacions de l'Institut d'Estudis Ceretans.

Plisson, H. (1985). *Etude fonctionnelle des outillages lithiques préhistoriques par l'analyse des micro-usures : recherche méthodologique et archéologique*. PhD dissertation. Université Paris I Panthéon-Sorbonne.

Plisson, H., & Van Gijn, A. (1989). La Tracéologie: Mode D'emploi. *L'anthropologie, 93*(3), 631–642.

Prous, A. (1990). *Os Moluscos e a Arqueologia Brasileira* (pp. 241–298). Arquivos do Museu de História Natural 11. Universidade Federal de Minas Gerais.

Rifkin, R. F. (2011). Assessing the efficacy of red ochre as a prehistoric hide tanning ingredient. *Journal of African Archaeology, 9*(2), 131–158.

Rios Garaizar, J., Ortega Cordellat, I., Ibáñez Estévez, J. J., & González Urquijo, J. E. (2002). El aporte del análisis funcional para el conocimiento del yacimiento auriñaciense de Barbas III. Primeros resultados. In I. Clemente Conte, R. Risch, J., & F. Gibaja Bao (Eds.), *Análisis Funcional: su aplicación al estudio de sociedades prehistóricas* (pp. 141–150). BAR International Series 1073. Archaeopress.

Rodríguez Rodríguez, A., & Navarro Mederos, J. F. (1999). La industria malacológica de la cueva de El Tendal (San Andrés y Sauces, Isla de La Palma). *Vegueta, 4*, 75–100.

Romagnoli, F., Martini, F., & Sarti, L. (2015). Neanderthal use of Callista chione shells as raw material for retouched tools in south-east Italy. Analysis of Grotta del Cavallo Layer L assemblage by a new methodology. *Journal of Archaeological Method and Theory, 22*, 1007–1037. https://doi.org/10.1007/s10816-014-9215-x

Romagnoli, F., Baena, J., & Sarti, L. (2016). Neanderthal retouched shell tools and Quina economic and technical strategies: An integrated behaviour. *Quaternary International, 407*(B), 29–44. https://doi.org/10.1016/j.quaint.2015.07.034

Romagnoli, F., Baena, J., Pardo Naranjo, A. I., & Sarti, L. (2017). Evaluating the performance of the cutting edge of Neanderthal shell tools: A new experimental approach. Use, mode of operation, and strength of Callista chione from a behavioural, Quina perspective. *Quaternary International, 427*(A), 216–228. https://doi.org/10.1016/j.quaint.2015.11.021

Rose, J. I. (2010). New light on human prehistory in the Arabo-Persian Gulf Oasis. *Current Anthropology, 51*(6), 849–883. https://doi.org/10.1086/657397

Rose, J. I. (2022). *An Introduction to human prehistory in Arabia: The lost world of the Southern Crescent.* Springer Textbooks in Archaeology and Heritage. Springer Cham. https://doi.org/10.1007/978-3-030-95667-7

Rosendahl, P. H. (1969). *Micronesian shell adzes: a preliminary terminology and classification*. Manuscript in Department of Anthropology, Bernice P. Bishop Museum.

Semenov, S. A. (1964). *Prehistoric technology (translated from Russian by M. W. Thompson)*. Adams & Dart.

Sheppard, C. R. C., Price, A. R. G., & Roberts, C. M. (1992). *Marine ecology of the Arabian region*. Patterns and processes in extreme tropical environments. Academic Press.

Sinoto, Y. H. (1962). Chronology of Hawaiian fishhooks. *Journal of the Polynesian Society, 71*(2), 162–166.

Skinner, H. D. (1942). A classification of the fish-hooks of Murihiku with notes on allied forms from other parts Polynesia. *Journal of the Polynesian Society, 51*(3), 208–286.

Spennemann, D. H. R. (1993). Cowrie shell tools: Fact or fiction? *Archaeology in Oceania, 28*(1), 40–49. https://doi.org/10.1002/j.1834-4453.1993.tb00312.x

Suárez Díez, L. (1974). *Técnicas prehispánicas en los objectos de concha.* Colección científica: Arqueología 14. Instituto Nacional de Antropología e Historia de México.

Suárez Díez, L. (1989). *Conchas prehispánicas en México.* BAR International Series 514. BAR Publishing.

Sydor, M., Pinkowski, G., & Jasińksa, A. (2020). The Brinell Method for Determining Hardness of Wood Flooring Materials. *Forests, 11*(878). https://doi.org/10.13390/f11080878

Szabó, K. (2008). Shell as raw material: Mechanical properties and working techniques in the tropical Indo-West Pacific. *Archaeofauna, 17*, 125–138.

Szabó, K., & Koppel, B. (2015). Limpet shells as unmodified tools in Pleistocene Southeast Asia: An experimental approach to assessing fracture and modification. *Journal of Archaeological Science, 54*, 64–76. https://doi.org/10.1016/j.jas.2014.11.022

Szabó, K., Brumm, A., & Bellwood, P. (2007). Shell artefact production at 32000–28000 BP in Island Southeast Asia. *Current Anthropology, 48*, 701–723. https://doi.org/10.1086/520131

Tengberg, M. (1998). *Paléoenvironnements e économie végétale en milieu aride. Recherches archéobotaniques dans la région du Golfe arabo-persique et dans le Makran pakistanais (4ème millénaire av. notre ère) – 1er millénaire de notre ère*. PhD dissertation. University of Montpellier.

Tengberg, M. (2005). Les forêts de la mer. Exploitation et évolution des mangroves en Arabie orientale du Néolithique à l'époque islamique. *Paléorient, 31*(1), 39–45.

Toth, N., & Schick, K. (1993). Early stone industries and inferences regarding language and cognition. In K. R. Gibson & T. Ingold (Eds.), *Tools, Language and Cognition in Human Evolution* (pp. 346–362). Cambridge University Press.

Toth, N., & Woods, M. (1989). Molluscan shell knives and experimental cut-marks on bones. *Journal of Field Archaeology, 16*, 250–255. https://doi.org/10.1179/jfa.1989.16.2.250

Tributsch, H. (2016). Ochre bathing of the bearded vulture: A bio-mimetic model for early humans towards smell prevention and health. *Animals, 6*(1), 7. https://doi.org/10.3390/ani6010007

Tringham, R., Cooper, G., Odell, G., Voytek, B., & Whitman, A. (1974). Experiment in the formation of edge damage: A new approach to lithic analysis. *Journal of Field Archaeology, 1*, 171–196. https://doi.org/10.1179/jfa.1974.1.1-2.171

Tumung, L., Bazgir, B., & Ollé, A. (2015). Applying SEM to the study of use-wear on unmodified shell tools: An experimental approach. *Journal of Archaeological Science, 59*, 179–196. https://doi.org/10.1016/j.jas.2015.04.017

Uerpmann, M., & Uerpmann, H.-P. (2003). *Stone Age Sites and Their Natural Environment. The Capital Area of Northern Oman, IIII.* Beihefte zum Tubinger Atlas des Vorderen Orients Reihe A (Naturwissenschaften) 31(3). Dr. Ludwig Reichert.

Vigié, B. (1987). Essai d'étude méthodologique d'outils sur coquillages de la grotte de Camprafaud (Ferrières-Poussarou, Hérault). *L'antropologie, 91*(1), 253–272.

Vigié, B. (1992). *Recherches sur l'exploitation des ressources aquatiques dans le midi Mediterranéen Français au Postglaciaire*. PhD dissertation. Université de Provence Aix-Marseille.

Vigié, B., & Courtin, J. (1986). Les outils sur coquilles marines dans le Néolithique du Midi de la France. *Mesogée, 46*(1), 51–161.

Villa, P., Soriano, S., Pollarolo, L., Smriglio, C., Gaeta, M., d'Orazio, M., Conforti, J., & Tozzi, C. (2020). Neandertal son the beach: Use of marine Resources at Grotta dei Moscerini (Latium, Italy). *PLoS ONE, 15*(1). https://doi.org/10.1371/journal.pone.0226690

Weston, E., Szabó, K., & Stern, N. (2017). Pleistocene shell tools from Lake Mungo lunette, Australia: Identification and interpretation drawing on experimental archaeology. *Quaternary International, 427*(A), 229–242. https://doi.org/10.1016/j.quaint.2015.11.048

Wiederhold, J. E. (2004). *Toward the standardization of use-wear studies: Constructing an analogue to Prehistoric hide work*. M.A. dissertation, Texas A&M University.

Will, M., Kandel, A. W., & Conard, N. J. (2019). Midden of molehill: The role of coastal adaptations in human evolution and dispersal. *Journal of World Prehistory, 32*, 33–72. https://doi.org/10.1007/s10963-018-09127-4

Yamada, S. (1993). The formation process of use-wear polishes. In P. Anderson, S. Beyries, M. Otte, & H. Plisson (Eds.), *Traces et function: les gestes retrouvés. Actes du Colloque international de Liège* (Vol. 1, pp. 447–458). ERRAUL 50.

Authors and Affiliations

Kevin Lidour[1,2] · David Cuenca Solana[1,3]

Kevin Lidour
lidour01@gmail.com; kevin.lidour@unican.es

David Cuenca Solana
david.cuenca@unican.es

[1] Instituto Internacional de Investigaciones Prehistóricas de Cantabria (Universidad de Cantabria, Gobierno de Cantabria, Grupo Santander), Universidad de Cantabria. Edificio Interfacultativo, Avda. Los Castros nº52. 39005, Santander, Spain

[2] Archéozoologie et Archéobotanique – Sociétés, Pratiques Et Environnement (AASPE), UMR 7209, Muséum National d'Histoire Naturelle (MNHN), Paris, France

[3] Centre de Recherche en Archéologie, Archéosciences, Histoire (CReAAH), UMR 6566, Rennes, France