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# Taphonomic effects in Archaelogical contexts: An analytical experimental protocol to improve archaeomalacology research

*Effets taphonomiques dans les contextes archéologiques : un protocole expérimental analytique pour améliorer la recherche en archéomalacologie*

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# TAPHONOMIC EFFECTS IN ARCHAEOLOGICAL CONTEXTS: AN ANALYTICAL EXPERIMENTAL PROTOCOL TO IMPROVE RESEARCH IN ARCHAEOMALACOLOGY

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## ABSTRACT

Today, it is clear that the study of malacological remains in archaeology has a great potential to reconstruct techno-economic, social, and territorial patterns in the past. In recent years, pioneering research has set a methodological basis for the study of shells from a behavioural perspective. However, taphonomic bias is still poorly understood. In this paper, we present the results of the first phase of the ArchaeoENHANCE project developed within the International Research Network of Taphen (CNRS). A long-term experimental protocol was designed and implemented to improve the systemic comprehension of the malacological collections in archaeological contexts, especially focusing on taphonomic causes and effects in macro and microscopic analyses. The results of the analysis after eighteen months of shell burial show an unequal development of alterations among the different taxa selected for the project (*Patella*, *Mytilus*, *Glycymeris* and *Callista chione*). Among taphonomic alterations, mechanical processes are significant, as is dissolution. Although the experimental protocol is still in its first phase, the results show the need for similar long-term projects. We expect that the extension of the experimental protocol will improve the understanding of the effects of taphonomic modifications on archaeomalacological assemblages, which is of interest for elucidating assemblage formation processes and their interpretation.

**HORS-SÉRIE**
**Colloque hommage à Émilie Campmas (1983-2019)**
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RÉSUMÉ

**Effets taphonomiques en contextes archéologiques : un protocole expérimental analytique pour améliorer la recherche en archéomalacologie.**

Il est désormais démontré que l'étude des vestiges malacologiques présente un grand potentiel pour la reconstitution des aspects techno-économiques, sociaux et territoriaux des communautés préhistoriques. Ces dernières années, des recherches pionnières ont posé les bases méthodologiques de l'étude des coquillages pour la compréhension des aspects comportementaux des communautés anciennes. Cependant, les aspects taphonomiques sont encore peu compris. Dans cet article, nous présentons les résultats de la première phase de réalisation du projet ArchaeoENHANCE, développé dans le cadre du Réseau International de Recherche de Taphen (CNRS). Un protocole expérimental a été créé et réalisé dans l'objectif d'améliorer la compréhension systémique des collections malacologiques dans les contextes archéologiques, en se concentrant notamment sur les causes et les effets taphonomiques dans l'analyse macro et microscopique. Les résultats de l'analyse après dix-huit mois d'enfouissement ont montré un développement inégal des altérations parmi les différents taxons sélectionnés pour le projet (*Patella*, *Mytilus*, *Glycymeris* et *Callista chione*). Parmi les altérations taphonomiques, les processus mécaniques et la dissolution sont les plus fréquemment attestés. Bien que le protocole expérimental soit encore dans sa première phase, les résultats ont montré la nécessité de projets similaires sur le long terme. Nous espérons que le développement du protocole expérimental améliorera la compréhension des effets des modifications taphonomiques sur les assemblages archéomalacologiques, qui est de première importance pour la compréhension des processus de formation des séries et leur interprétation.

MOTS-CLÉS Archéomacologie, taphonomie, traces fonctionnelles, méthodes de recherche, archéologie expérimentale, outils en coquillage.

## INTRODUCTION

The presence of shells in archaeological contexts is usually interpreted in the sphere of subsistence (e.g., Colonese *et al.* 2011; Cortés-Sánchez *et al.* 2011; Dupont 2012; Jerardino and Marean 2010; Steele 2010) and symbolic behaviours, including ornaments (e.g. Balme *et al.* 2018; Bar-Yosef Mayer and Bosch 2019; Cristiani and Borić 2017; Hohmann *et al.* 2018; Hutterer *et al.* 2021; Kurzawska *et al.* 2020; Manca *et al.* 2018; Perlès and Rigaud 2020; Vanhaeren *et al.* 2019; Wei *et al.* 2017), other non-functional unspecified elements (Peresani *et al.* 2013; Zilhão *et al.* 2010), and objects attesting to complex social interactions (Mitchell 1996; Paulsen 1974). Beyond their value as a source of subsistence, rituality, symbolism, and currency, shells can also be an effective resource for shaping tools and undertaking daily activities, as supported by a rich body of evidence in ethnographical studies (see bibliography in Cuenca Solana *et al.* 2011). Shell has most probably been used as raw material for approximately 400,000 years (Joordens *et al.* 2015) and became frequent in Mediterranean Neanderthal sites, where retouched shell tools have been identified in several coastal sites (Romagnoli *et al.* 2015, 2016; Villa *et al.* 2020). Moreover, shell tools have been clearly identified in Holocene archaeological contexts (e.g., Davidson *et al.* 2011; Lucero and Donald 2005; Pawlik *et al.* 2015; Perttula 2020; Szabó 2019).

Whereas modified valves, as is the case of retouched artefacts, are easily identified as tools, unmodified specimens (e.g., Theler and Hill 2019), also referred to as expedient tools (O'Day and Keegan 2001), are not easily distinguishable from any other malacological remain that is preserved in an archaeological layer because they were a source of subsistence. The vast majority of archaeological shell tool assemblages have been identified only through the systematic application of the use-wear microscopic approach and experimental archaeology (Cuenca-Solana *et al.* 2016, 2017, 2021; Manca 2013, 2016; Manca *et al.* 2018). This research line is fairly new, and although it has clearly shown great potential to improve knowledge of past technological and social behaviours, it is still in an early stage, and several methodological issues must be properly and deeply addressed.

One relevant aspect that is still poorly investigated is the characterisation of how taphonomic processes can alter anthropogenic traces of modification and the use of shell tools. The term taphonomy was coined in the 1940s to identify a branch of paleontological studies aimed at understanding the physical, chemical, and biological patterns that affect the processes of fossilisation (Efremov 1940). The discipline has grown significantly since then. Currently, it includes many different topics and methods and is an essential part not only in the study of archaeozoological and bioanthropological remains (e.g., Blasco *et al.* 2020; Campmas *et al.* 2018a; Fernández-Jalvo and Andrews 2016; Gutiérrez *et al.* 2021; Maureille *et al.* 2017; Saladié *et al.* 2021; Souron *et al.* 2019; Stiner *et al.* 2022; Yeshurun and Meier 2021) but also of other archaeological records (e.g. Bordes 2003; Borrazzo 2016, 2020; Mallol and Bertran 2010; Mallol *et al.* 2019; Romagnoli and Vaquero 2016, 2018), as it allows the understanding of the processes that affect the formation of sites and assemblages beyond organic materials. Actualistic taphonomy, frequently applied in recent studies, as shown in the literature cited above, is the study of alterations in contemporary settings to understand the relationships between taphonomic processes and effects and thus improve the interpretation of archaeological contexts. This approach has made archaeologists much more aware of the importance of local and regional differences in taphonomic processes and the need to build solid experimental references to investigate different sedimentary contexts and categories of archaeological remains.

Malacological actualistic taphonomy has mainly been developed to distinguish processes and effects between the natural and anthropogenic formation of shell accumulations in archaeological contexts. This is especially informative in interpreting shell middens (e.g., Jerardino 2016; Ruiz *et al.* 2020) and is a research line particularly developed in southern America (see the bibliography in Beovide and Martínez 2020; De Francesco *et al.* 2020). However, experimental actualistic projects aimed at investigating taphonomic processes and effects on shell tools are lacking. This is especially due to two main factors. One is the need for long-term controlled experiments to achieve reliable data useful for interpreting archaeological contexts. Today, it is extremely difficult for archaeologists to start such long-term projects, at least in Europe, because of the usually short-term research contracts, the difficulties in professional stabilisation, and the challenges of planning research funding during several consecutive years for cyclical and regular analyses needed to accomplish the experimental goals. Furthermore, international research policies and evaluation systems are forcing researchers to prioritise projects that can quickly result in publications; thus, exploratory investigations and projects that require several years of observations are most frequently neglected. A second factor is the limited development of studies focused on shell tools from a technological and functional perspective, which has until now give emphasis on the study of archaeological malacological assemblages to paleoclimate reconstruction (e.g., Escobar *et al.* 2010; García-Escárzaga *et al.* 2020), seasonal studies (e.g., Branscombe *et al.* 2020; Colonese *et al.* 2012, 2017; García-Escárzaga *et al.* 2019; Padilla Vriesman *et al.* 2022), and subsistence (e.g., Campmas 2017; Campmas *et al.* 2018b; Jerardino 2021; Zilhão *et al.* 2020).

In this paper, we present a novel experimental taphonomic project (ArchaeoENHANCE) aimed at systematising the characterisation and degree of post-depositional processes and effects that could affect shell items. In particular, the project is focused on the investigation of the development of taphonomic alterations on fracture planes and natural edges of unused shells and on understanding the possible effects of these alterations of use-wear traces on shell tools. The project will allow researchers to better understand the effects of taphonomic processes on shells and the influence of different processes on the preservation of shells in archaeological contexts, including sediment pressure, bioturbation, and fragmentation. It is designed to cyclically and regularly perform macro- and microscopic analyses of shells after three 18-month periods of burial to describe the progress modifications on four marine mollusc specimens. The taxa were selected because they are frequently attested in archaeological deposits in coastal sites, both in Pleistocene and Holocene chronologies. In this paper, we present the experimental and analytical protocols, as well as the results after the first burial period. The data are discussed in the framework of malacological and use-wear analyses to improve methodological issues in archaeomalacological research.

## 1. | MATERIAL AND METHODS

The experimental protocol was organised in six different phases (**fig. 1**): 1) selection and preparation of the experimental corpus of shells; 2) macroscopic and microscopic description of the selected shells (natural surfaces and edges); 3) use of some of these shells as tools for processing different materials; 4) use-wear analysis of the experimental shell tools; 5) burial of all the experimental pieces and excavation after eighteen months; and 6) macro- and microscopic analyses of the taphonomic alterations on the shells after burial (shell surfaces, natural edges, and use-wears). Observations during each phase of the experimental protocol were recorded in a single database for data comparison.

### 1.1 | Selection and preparation of the shells

Four taxa were selected for the project, including bivalves and gastropods, which are frequently identified in archaeological deposits throughout prehistory, both as food debris and also as tools: *Patella* sp., *Mytilus* sp., *Callista chione*, and *Glycymeris* sp. All the shells of *Patella* sp., *Mytilus* sp. and *Callista chione* were collected alive (the state of shells was fresh), while the *Glycymeris* shells were collected as *postmortem* beach drift (the state of shells was dry) (**table 1**). These species have various mechanical and physic properties that affect their density, resistance to deformation, rigidity and hardness (e.g., Barthelat *et al.* 2009; Li *et al.* 2017; Taylor and Layman 1972) and therefore, could have influenced their response to different post-depositional agents. The shell's properties are related to the internal microstructure and the type and organisation of the crystal. *Patella* sp. shells are composed of a variable number of layers with different composition and structure (calcite or aragonite) and different orientation and arrangement, including prismatic and lamellar arrangements of crystal units (Ortiz *et al.* 2015). *Mytilus* sp. shell microstructure consists of aragonite nacre and prismatic fibrous calcite layers with a ragged interface zone between the polymorphs (Griesshaber *et al.* 2013). *Callista chione* shell, principally consisting of aragonite and secondary calcite (Keller *et al.* 2002), has a microstructure composed of prismatic and cross-lamellar layers. *Glycymeris* sp. shell includes four different microstructures and textures from outer to inner shell surfaces: crossed-lamellar, myostracal, complex crossed-lamellar and fibrous prismatic (Crippa *et al.* 2020a, 2020b). These shells are made of aragonite crystals.

Twenty shells were buried to be monitored for taphonomic modifications during the running of the project (**table 1**). The presence, abundance, and widespread presence of *Mytilus* sp. and *Glycymeris* sp. in numerous Pleistocene


— FIGURE 1 —

Phases of the ArchaeoENHANCE project: 1) selection and preparation of the shells; 2) macroscopic and microscopic description of the shells; 3) analytical experimentation; 4) use-wear analysis of experimental shell tools; 5) burial and excavation after eighteen months; 6) analysis and documentation of the taphonomic modifications after burial.

*Phases du projet ArchaeoENHANCE : 1) sélection et préparation des coquilles ; 2) description macroscopique et microscopique des surfaces naturelles des coquilles ; 3) expérimentation analytique avec les outils en coquille ; 4) analyse de l'usure de ces outils en coquille ; 5) enfouissement et excavation après dix-huit mois ; 6) analyse et documentation des modifications taphonomiques après cette période d'enfouissement.*

| Id | Taxa | State of shells | Fracturing | Weight (gr) | Length (mm) | Width (mm) |
|---|---|---|---|---|---|---|
| 1 | *Patella* sp. | fresh | | 3.13 | 33.1 | 29.6 |
| 4 | *Patella* sp. | fresh | x | 0.53 | 22.1 | 11.1 |
| 11 | *Callista chione* | fresh | | 11.62 | 61.1 | 46.2 |
| 14 | *Callista chione* | fresh | x | 2.23 | 37.5 | 21.7 |
| 21 | *Mytilus* sp. | fresh | | 9.18 | 85.9 | 45.9 |
| 23 | *Mytilus* sp. | fresh | x | 1.67 | 43.2 | 29.6 |
| 25 | *Mytilus* sp. | fresh | | 10.98 | 96.5 | 46 |
| 26 | *Mytilus* sp. | fresh | | 10.69 | 96.4 | 46.5 |
| 27 | *Mytilus* sp. | fresh | | 7.98 | 95.3 | 46.3 |
| 28 | *Mytilus* sp. | fresh | x | 4.03 | 6.93 | 33 |
| 29 | *Mytilus* sp. | fresh | x | 3.31 | 73.2 | 21.1 |
| 30 | *Mytilus* sp. | fresh | x | 3.14 | 67.6 | 35.4 |
| 32 | *Glycymeris* sp. | dry | | 14 | 48.9 | 46.8 |
| 34 | *Glycymeris* sp. | dry | x | 5.85 | 47 | 31.2 |
| 35 | *Glycymeris* sp. | dry | | 20.27 | 53.7 | 50.5 |
| 36 | *Glycymeris* sp. | dry | | 9.95 | 45.6 | 43.4 |
| 37 | *Glycymeris* sp. | dry | | 11.59 | 46.5 | 42.9 |
| 38 | *Glycymeris* sp. | dry | x | 5.29 | 45.3 | 33.4 |
| 39 | *Glycymeris* sp. | dry | x | 7.77 | 45.2 | 30.7 |
| 40 | *Glycymeris* sp. | dry | x | 3.34 | 31.8 | 27 |

— TABLE 1 —

Experimental pieces buried during the development of the project.

*Pièces expérimentales enterrées pendant le projet.*

and Holocene archaeological sites justified the main selection of these taxa to develop this first phase of the experimental protocol. Prior to the experimental sessions, all the pieces were photographed using a Nikon D5500 camera equipped with a Nikon DX AF-S NIKKOR 105 mm 1:3.5-56G ED objective. The photographic documentation was performed using EOS Utility and Helicon Focus 7.5.6 software.

## 1.2 | Documentation and description of the experimental corpus of shells before and after burial

The macroscopic and microscopic analyses were conducted with magnifications between 10× and 200×. A Stemi305-N ZEISS stereoscopic microscope equipped with an AxioCam ERc5s ZEISS camera was used for the analyses. We also used a Leitz DMRX Leica microscope equipped with an AxioCam 208 colour camera. In both cases, ZEN 2 Core V2.7 software was used to produce the photographic documentation. Several points along the natural edge and the fracture planes of the shells were photographed, as well as the prominent area of the external convex surface and the concave part of the internal surface of each experimental piece. The photographic documentation was oriented towards registering the state of preservation of each shell before the experimental protocol to enable the later discrimination of the post-depositional alterations produced on these pieces during the burial period. All documented alterations on the shell surfaces were registered photographically at both the macroscopic and microscopic scales before the experimental protocol.

## 1.3 | The use of shell tools

Six shells of each taxon (3 fragments and 3 complete shells; 24 shells in total) were used for 30 minutes to scrape dry pine wood, soften tanned skins[1] for conversion into leather, and to separate fresh meat from bone. Although shells of each taxon were used, only those of *Mytilus* sp. and *Glycymeris* sp. were described and subsequently buried in this first phase of the experimental protocol (**table 2**) being the taxa more frequently and abundantly attested in archaeological contexts in Late Pleistocene and Holocene.

## 1.4 | Use-wear analysis

During the functional experiments, we monitored (i) the kinematic action (transverse, oblique, or longitudinal), (ii) the inclination of the active edge during the action, (iii) the working time, and (iv) the state of the material (dry and fresh). In scraping dry pine wood (**fig. 4a**), softening tanned skins (**fig. 4b**), and separating fresh meat from bone (**fig. 4 c**), the tool movement was bidirectional, and the inclination of valves in relation to the worked surface was oblique (45° to 90°). Although shells of each taxon were used, only those of *Mytilus* sp. (**fig. 4d-l**) and *Glycymeris* sp. (**fig. 5**) were described and subsequently buried in this first phase of the experimental protocol (**table 2**).

After processing each worked material, the tools were cleaned using an ultrasonic cleaning bath, JP Selecta. The pieces were cleaned in a solution of water (50 %), alcohol (50 %), and TWEEN 20 (neutral pH cleaner). The shell tools used to process meat were kept in this mixture for twenty minutes, while those used to process hides and wood were kept for ten minutes. After cleaning, the use-wear traces developed on the active zones of the tools were observed and photographed both at macroscopic and microscopic scales (magnification between 10× and 200×). The same equipment was used as in the previous phase (Section 1.2). Use-wear traces were described and recorded in the database by applying the terminology and variables well known in the literature and developed in the framework of previous studies (see Cuenca-Solana 2013; Cuenca-Solana *et al.* 2017; Manca 2013, 2016). Thus, the database included the characterisation of the micro and macro use-wear traces, mainly the micro-polish, the macro and micro-striations, scars, and rounding of the active edge.

## 1.5 | Natural surfaces before anthropic transformation

Except for the *Glycymeris* sp. valves, which were collected beached in a rounded state, all other shells (*Patella* sp., *Mytilus* sp., and *Callista chione*) were processed, used, and then buried in fresh forms. Therefore, they did not show any important changes of natural origin, except for tiny detachments in the edges (**fig. 2a**) and the classical rounding of the most elevated portions of the shells, such as the apex in the limpets (**fig. 2b**). Beached *Glycymeris* showed rare long and isolated macro-striations with a U-shaped bottom (**fig. 2c**), and areas pockmarked by dissolution and characterised by rounded depressions (**fig. 2d**). All these modifications have already been described as characteristics of *thanatocoenosis* on beached *Glycymeris* (Manca 2013, 2016, 2018). During the present study, several new observations of macro removals of non-anthropic origin on *Callista chione* valves were made to distinguish them from anthropic retouching (Romagnoli *et al.* 2016). A single author systematically described the natural surface of the shells before experiments (*Ostrea* sp., *Patella* sp., and *Mytilus* sp.; Cuenca-Solana 2013; Cuenca-Solana *et al.* 2010), as well as the traces due to the post-excavation treatment of archaeological finds (sieving), which can hinder the reading of anthropogenic functional traces (Cuenca-Solana 2010). This information, together with other data obtained from the scientific literature about fragmentation due to anthropogenic activities (*fracturation* in French literature) or to other mechanical and chemical taphonomic agents (*fragmentation* in French literature) (e.g., Driscoll and Weltin 1973; Kotzian and Simoes 2006; Manca 2018; Parsons and Brett 1991; Weston *et al.* 2015), was taken into account during the observation of technical stigmata, use-wear and post-depositional analyses.

## 1.6 | Anthropic macro- and micro-traces before burial

As shown earlier, part of the experimental corpus was buried after fracturing the shell valve (NR 10; **table 1; fig. 3**) and processing the different materials (NR 12; **table 2; fig. 4**).

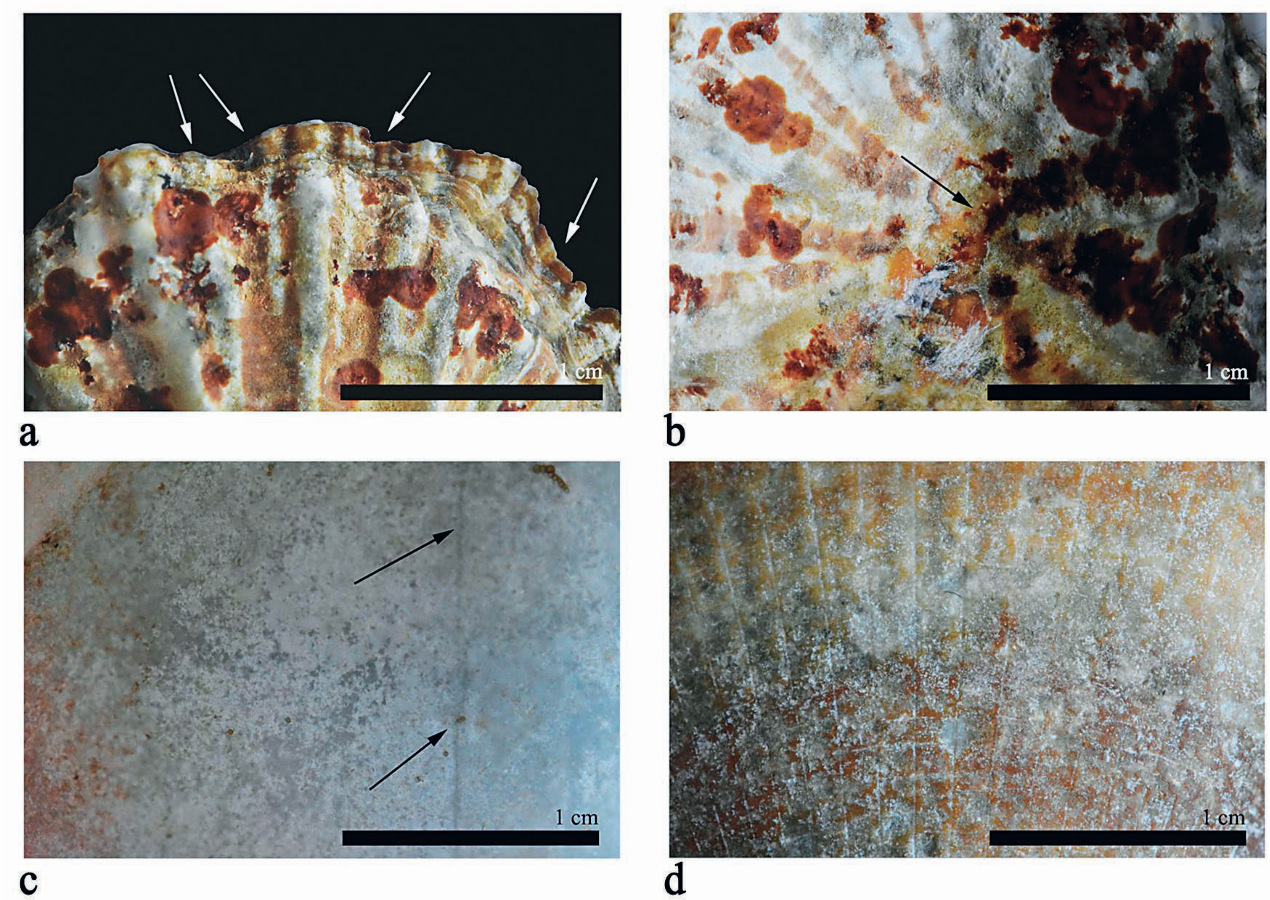
[1] The leather was recovered already tanned by an Iranian craftsman who does not use any chemicals products.

| Id. | Taxa | State of shells | Use | Worked material | State of material | Time of use (minutes) |
|---|---|---|---|---|---|---|
| 25 | *Mytilus* sp. | fresh | scraping | wood | dry | 30 |
| 26 | *Mytilus* sp. | fresh | scraping | leather | dry | 30 |
| 27 | *Mytilus* sp. | fresh | sawing | meat | fresh | 30 |
| 28 | *Mytilus* sp. | fresh | scraping | wood | dry | 30 |
| 29 | *Mytilus* sp. | fresh | scraping | leather | dry | 30 |
| 30 | *Mytilus* sp. | fresh | sawing | meat | fresh | 30 |
| 35 | *Glycymeris* sp. | dry | scraping | wood | dry | 30 |
| 36 | *Glycymeris* sp. | dry | scraping | leather | dry | 30 |
| 37 | *Glycymeris* sp. | dry | sawing | meat | fresh | 30 |
| 38 | *Glycymeris* sp. | dry | scraping | wood | dry | 30 |
| 39 | *Glycymeris* sp. | dry | scraping | leather | dry | 30 |
| 40 | *Glycymeris* sp. | dry | sawing | meat | fresh | 30 |

— TABLE 2 —

*Shell tools used and buried.*

Outils sur coquille utilisés et enterrés.




— FIGURE 2 —

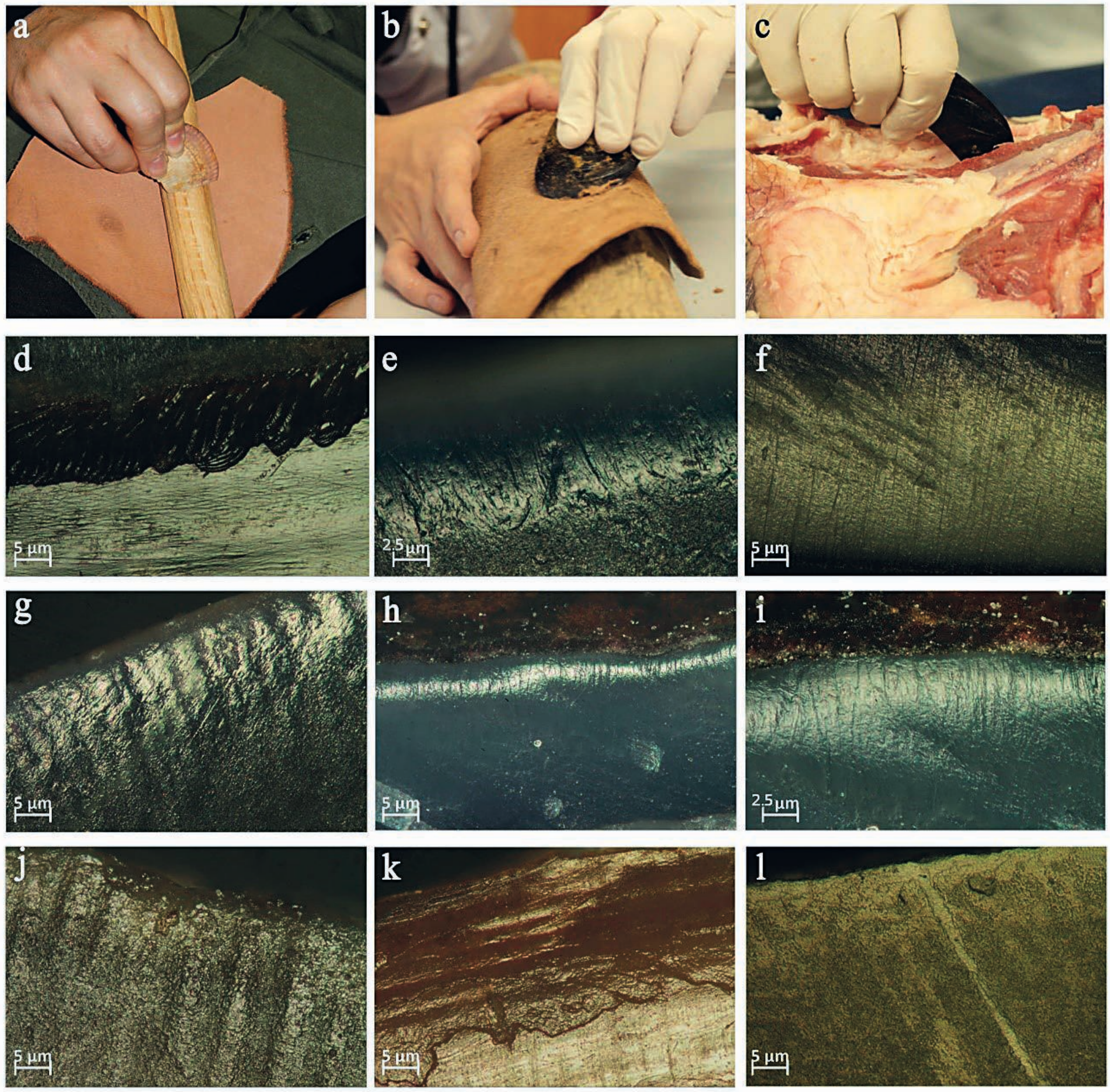
Natural surfaces before anthropic transformation: a) detachments, edge of *Patella* sp. (#id 1); b) rounding, apex of *Patella* sp. (#id 1); c) macro-striations, ventral side of *Glycymeris* sp. (#id 31); d) dissolution area, dorsal face of *Glycymeris* sp. (#id 35).

*Surfaces naturelles avant transformation anthropique : a) enlèvements sur les bords de* Patella *sp. (# id 1) ; b) arrondissement apex de* Patella *sp. (# id 1) ; c) macro-stries sur la face ventrale de* Glycymeris *sp. (# id 31) ; d) zone de dissolution sur une face dorsale de* Glycymeris *sp. (# id 35).*


— FIGURE 3 —

The fracturing of the shells and the technical marks obtained: a) pebble used for fracturing shells; b–e) fracture planes and impact points on the valves of *Patella* sp. (b; #id 4 and 9), *Mytilus* sp. (c; #id 30 and 23), *Glycymeris* sp. (d; #id 33 and 34), and *Callista chione* (e; #id 14 and 20). #IDs are described from left to right.

*La fracturation des coquilles et les stigmates techniques obtenus : a) galet utilisé pour la fracturation des coquilles ; b-e) pans de fracture et points d'impact sur les valves de* Patella *sp. (b ; # id 4 et 9),* Mytilus *sp. (c ; # id 30 et 23),* Glycymeris *sp. (d ; id 33 et 34) et* Callista chione *(e ; # id 14 et 20). #IDs sont décrits de gauche à droite.*




— FIGURE 4 —

*Mytilus* sp., experimental activities and use-wear traces: a) scraping of dry pine wood; b) scraping of soften tanned skins; c) cutting fresh meat; d–f) use-wear traces due to scraping of wood (#id 25, 25, and 28); g–i) use-wear traces due to scraping soften skin (#id 26, 26, and 29); j–l) use-wear traces due to cutting fresh meat (#id 27, 27, and 30). #IDs are described from left to right.

*Activités expérimentales et traces d'usure obtenues sur* Mytilus *sp. : a) raclage de bois de pin sec ; b) raclage de peaux tannées pour leur transformation en cuir ; c) découpe de viande fraîche ; d-f) traces d'usure produites par le raclage du bois (# id 25, 25 et 28) ; g-i) traces d'usure produites par le raclage de la peau (# id 26, 26 et 29) ; j-l) traces d'usure produites par la découpe de viande fraîche (# id 27, 27 et 30). #IDs sont décrits de gauche à droite.*

#### 1.6.1 | Fracturing

The fracturing of the shells (**table 1**) was carried out by direct percussion on the dorsal face using a 410.3 gr pebble 93 mm long, 62 mm wide, and 53 mm thick (**fig. 3a**). The fracture planes had sharp edges with a straight, more or less segmented profile (**fig. 3c-e**). In *Patella* sp., fractures developed along the growth lines of the shells (**fig. 3b**). Their orientation with respect to the main axis of the shells (in the anatomical position) was transverse, oblique, or longitudinal, and their cross-sections were straight, oblique, flap-shaped, or hinge-shaped. The impact points, marked by concavities and radial flexures, were associated with V-shaped edges or the presence of striations, and in many cases, were accompanied by micro-fissures (**fig. 3b-d**).

#### 1.6.2 | Use-wear traces

As explained in section 1.3, different activities were done during the experimental phase such as scraping dry pine wood (**fig. 4a**), softening tanned skins (**fig. 4b**), and separating fresh meat from bone (**fig. 4c**).

**_Mytilus_ sp.**

Wood (#id 25 and 28; **table 2, fig. 4d-f**). The observation at 30× to 40× magnification showed the presence of rounding and flattening of the surface with marginal extension and a vertical to oblique incidence on the active part of the shell. The disappearance of the natural asperities of the valve in the active zone was also documented. Short, fine striations were visible at 30×. The microscopic use-wear traces (observation 100× to 200×) were micro-polish, striations, and micro-removals visible in the bifacial position.

Leather (#id 26 and 29; **table 2, fig. 4g-i**). The rounding of the edge and erasure of the natural striations of valves were observed at 20× magnification. These macro-traces were visible in the bifacial position, with a vertical incidence and a marginal extension. The micro-traces were located on the ventral face and on the edge.

Fresh meat (#id 27 and 30; **table 2, fig. 4j-l**). Small removals were visible in the active part of one valve (#id 27) at 40× magnification. These macro-traces were marginal with a vertical to oblique incidence. Scraping fresh meat resulted in the formation of a micro-polish that was localised along the edge and extended slightly onto the lower face.

**_Glycymeris_ sp.**

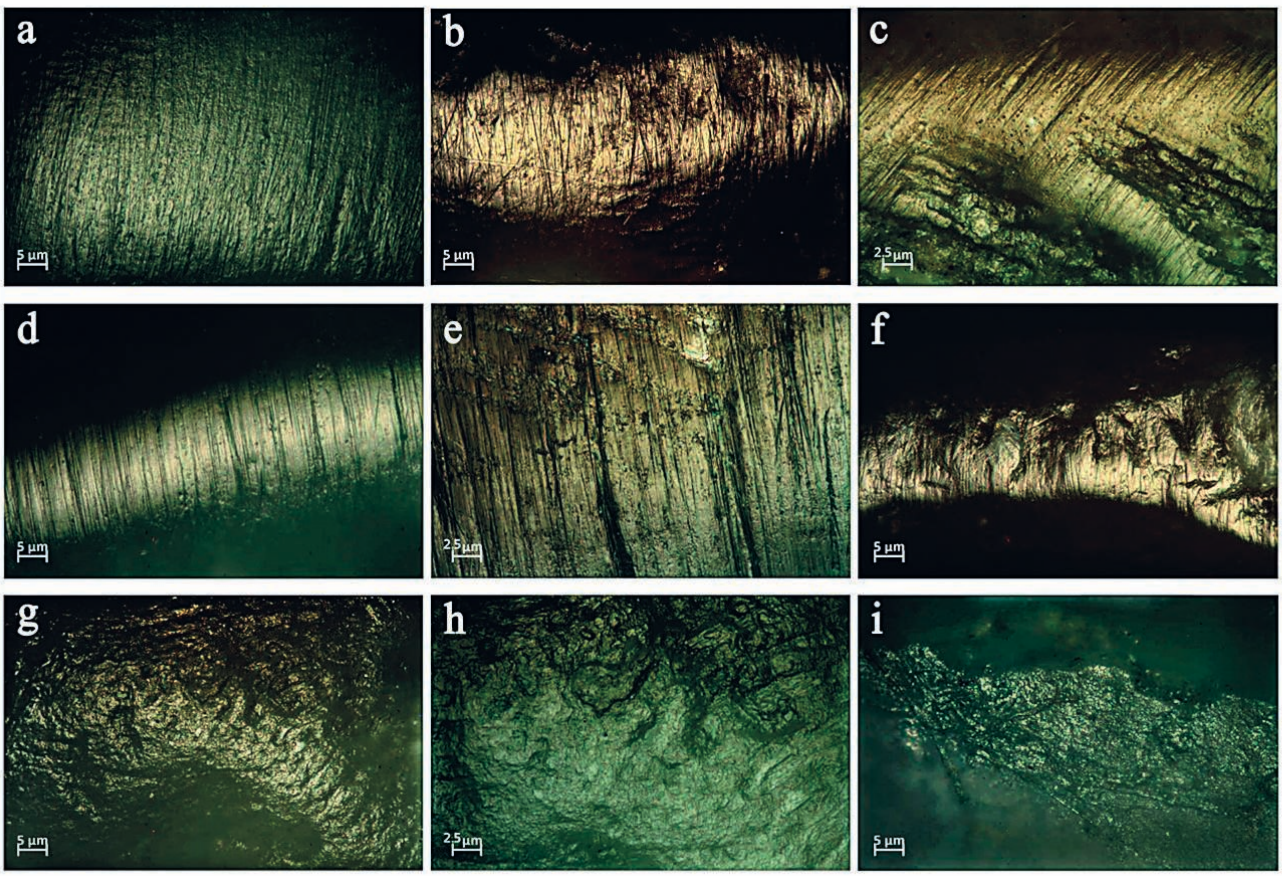
Wood (#id 35 and 38; **table 2, fig. 5a-c**). The observation of the surface at 20× and 30× allowed for the identification of the rounding and flattening of the edge. The extension of micro-traces (micro-polishes and scratches) was marginal, with a vertical to oblique incidence. Short and fine scratches, localised on elevations, were visible at 40×.

Leather (#id 36 and 39; **table 2, fig. 5d-f**). The rounding and flattening of the surface were visible at 20× to 40× magnification. The scratches, observed at 40×, were short and fine. The micro-polish, which developed on the edge and partially on the dorsal face, was localised in a in a marginal area of the edge.

Fresh meat (#id 37 and 40; **table 2, fig. 5g-i**). The polish of the surface was observed at 30× in one valve (#id 37). The use-wear traces were the polish, but very poorly developed, and scratches, with absence of striations.

## 1.7 | Burial, soil analysis, and excavation

After the description and photographic documentation, twenty used and unused shells and shell fragments were buried in an open space at the Universidad Autónoma de




— FIGURE 5 —

_Glycymeris_ sp., experimental activities and use-wear traces: a–c) use-wear traces due to scraping of wood (#id 35, 35, and 38); d–f) use-wear traces due to scraping soften skin (#id 36); g–i) use-wear traces due to cutting fresh meat (#id 37, 37, and 40). #IDs are described from left to right.

_Activités expérimentales et traces d'usure obtenues sur_ Glycymeris _sp. : a-c) traces d'usure produites par le raclage du bois (# id 35, 35 et 38) ; d-f) traces d'usure produites par le raclage de la peau (# id 36) ; g-i) traces d'usure produites par la découpe de viande fraîche (# id 37, 37 et 40). #IDs sont décrits de gauche à droite._

Madrid (UAM) (**table 1**). The spatial distribution was recorded using a Leica TS06 Plus total station. During the shell burial period, analyses of the sediment were performed using X-ray fluorescence spectrometers in the PACEA-Transfert Sédimentologie & Matériaux-UMR5199 laboratory (presence and quantity of organic material, measurement of pH, and granulometry). The experimental corpus of shells was buried in sediments with a pH of 7.996, which corresponds to slightly alkaline soils. After an eighteen month burial period, the entire set of experimental pieces was dug up using microstratigraphic archaeological methodology and applying wood digging tools to avoid possible alterations on the shells due to contact with metal instruments.

### 1.8 | Documentation and description of taphonomic alterations

After excavation, the experimental shells were cleaned using the same equipment and methodology described in Section 1.4. In this case, ten minutes of cleaning enabled the correct observation of the surface. We then analysed the same variables that were registered in the database before burial (see section 1.2). Thus, for each shell, we observed and characterised the same points on the edge and the fracture planes, along with the most prominent area on the external convex surface and the most concave part on the internal surface. This analytical protocol enabled us to monitor the taphonomic alterations after eighteen months of burial. The alterations were described, photographed macro- and microscopically, and recorded in the database. For this observation and documentation of the shells, the same equipment and methodology were used as in the previous phases of the experimental protocol.

## 2 | RESULTS: TAPHONOMIC ALTERATIONS AFTER BURIAL

#### Patella *sp.*

Macroscopic observation of the shells showed the formation of isolated, long, and thick scratches located in the lower face of the shell and scratches and fissures accompanying the detachments already present in the edge of the shell (#id 4; **fig. 6a-b**). Microscopic observations attested to the formation of polished portions of the surface located in the elevations of the shells on the ventral face. The micro-traces were characterised by a homogeneous microtopography, a regular and flat micro-relief with a soft texture, and a compact to united fabric (**fig. 6c-d**).

#### Callista chione

These valves retained the outer protein layer (conchiolin), which is the part of the shell most affected by dissolution. At a macroscopic level, striations located on the dorsal face were observed. They had the classic appearance of alterations caused by roots, described in the literature for other organic materials, such as bone (Fernández-Jalvo and Andrews 2016). The striations had an elongated shape with a sinuous profile, irregular edges, and a bottom characterised by fissures (**fig. 6 e-f**). The surface alterations visible microscopically were localised on the dorsal face. In one shell, a superficial cracking appeared (**fig. 6g**). Scratches of random morphology were also present in the same area but were not likely to be caused by the same phenomenon because they formed posteriorly. Abrasion spots characterised by fine parallel striations were observed on the higher parts of the shells (**fig. 6h**). Their nature (natural or post-depositional) will be clarified as the experiment proceeds.

#### Mytilus *sp.*

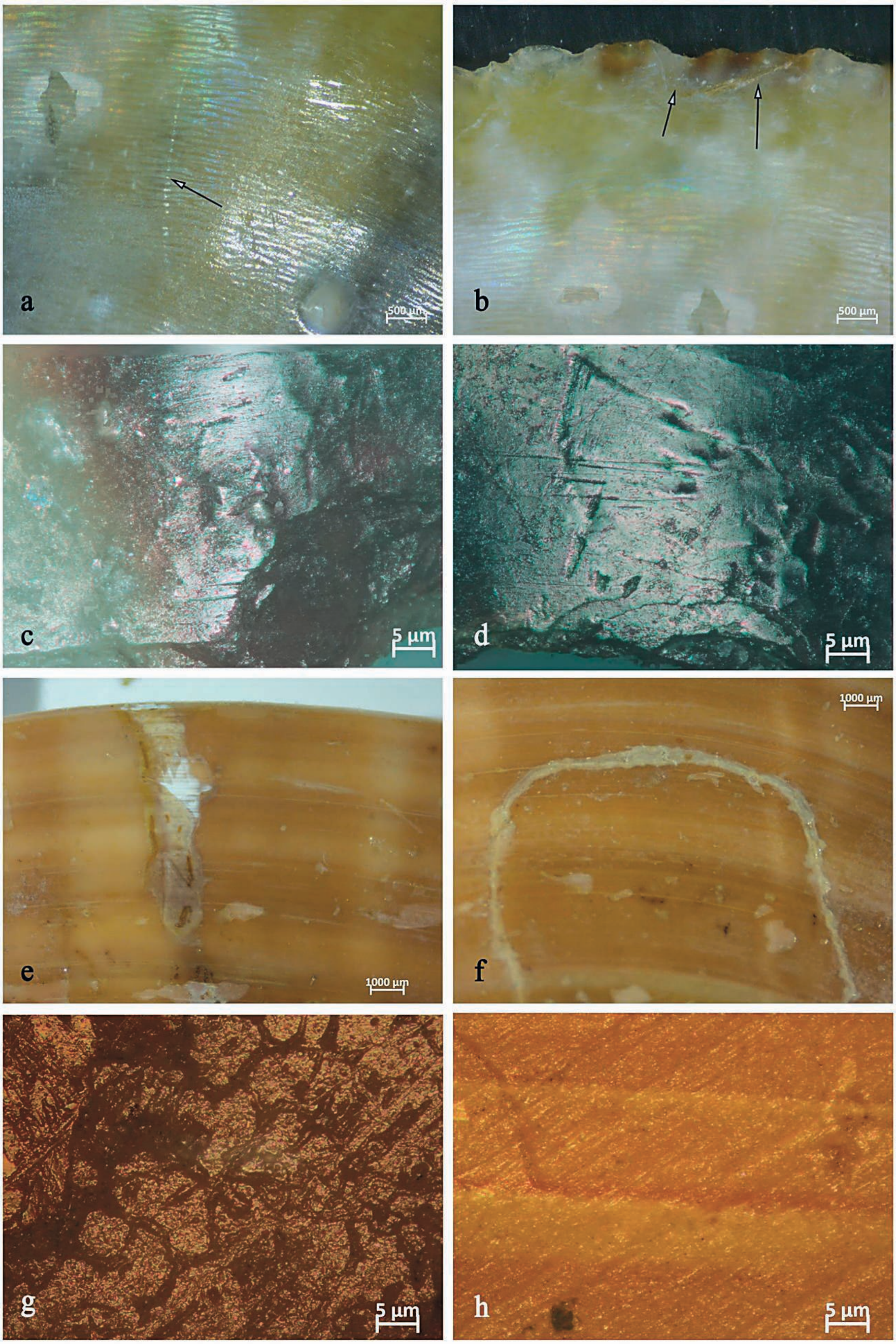
The outer protein layer of the *Mytilus* sp. valves underwent the most invasive modification due to the loss of organic material and consequent shrinkage of the matter or dissolution caused by the roots. Macroscopic observation showed the presence of fissures (#id 23; **fig. 7a-b**), sometimes resulting in the loss of whole portions of conchiolin or in detachments (#id 25 and 26; **fig. 7c**). Striations (#id 21, 23 and 29; **fig. 7d**) or larger areas of dissolution (#id 21, 23 and 29; **fig. 7e**) by roots were also present on the surface. During the microscopic observation of the surfaces, we noted that, overall, there were no substantial changes. The presence of wide, rectilinear striations with irregular edges and a black, rough background, probably due to rubbing against the ground, was noteworthy (#id 27; **fig. 7g**). A portion of the active part in one valve suffered detachments with partial preservation of previously documented traces of use (#id 26; **fig. 7 g-h**). These detachments probably occurred on a portion of the rim already fragilised during use.

#### Glycymeris *sp.*

*Glycymeris* valves showed striations and larger areas affected by root dissolution (#id 32, 37, 39–40; **fig. 8a-c**). These macro-traces, located on the dorsal and ventral faces of the valves, had a weak density and a small extension. The burial and subsequent excavation of the shells caused the detachment of some portions of the shells at the impact points caused by fracturing (#id 32, 37–38; **fig. 8d-e**). One valve showed an increase in the dissolution phenomenon already present on the ventral face before burial. This was visible by observing the alterations on the detachment negatives that were developed during the eighteen-month period of burial (#id 38; **fig. 8e**). One valve was fractured during the excavation. The observation of the surfaces used at the macroscopic level did not reveal any changes. At the microscopic level, the surfaces appear unaltered. Of note, however, was the appearance of micro-areas of abrasion associated with striations, which was not observed prior to digging (#id 37; **fig. 8f**).

## 3 | DISCUSSION AND CONCLUSIONS

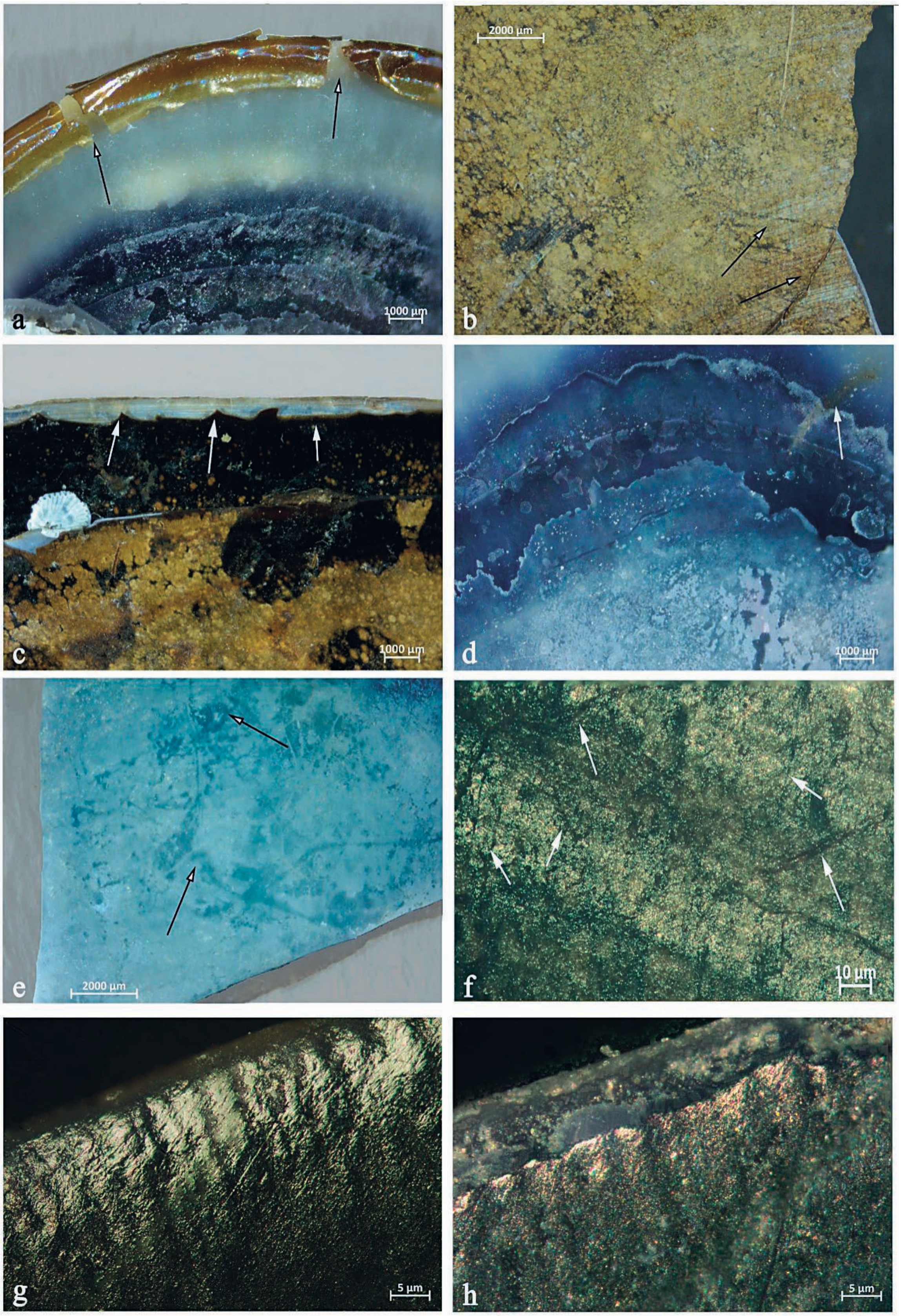
After eighteen months of burial, taphonomic alterations in the shells were poorly developed. Two types of alterations were identified at the macroscopic level: (i) striations and grooves caused by the growth of roots and soil abrasion, and (ii) fragmentation due to the mechanical action of the sediment and human intervention during the exhumation of the shells. In *Mytilus* sp. and *Callista chione* shells, the most significant alteration was the loss of theouter protein layer.




— FIGURE 6 —

Post-depositional alterations after burial: a) and b) isolated scratches on the lower face of *Patella* sp. (#id 4); c) and d) striations and fissures on the edge of *Patella* sp. (#id 4); e) and f) striations caused by the action of roots on a *Callista chione* valve (#id 11); g) polished and cracked area on the dorsal face of *Callista chione* (#id 11); h) abrasion zones associated with striations on the dorsal face of *Callista chione* (#id 11).

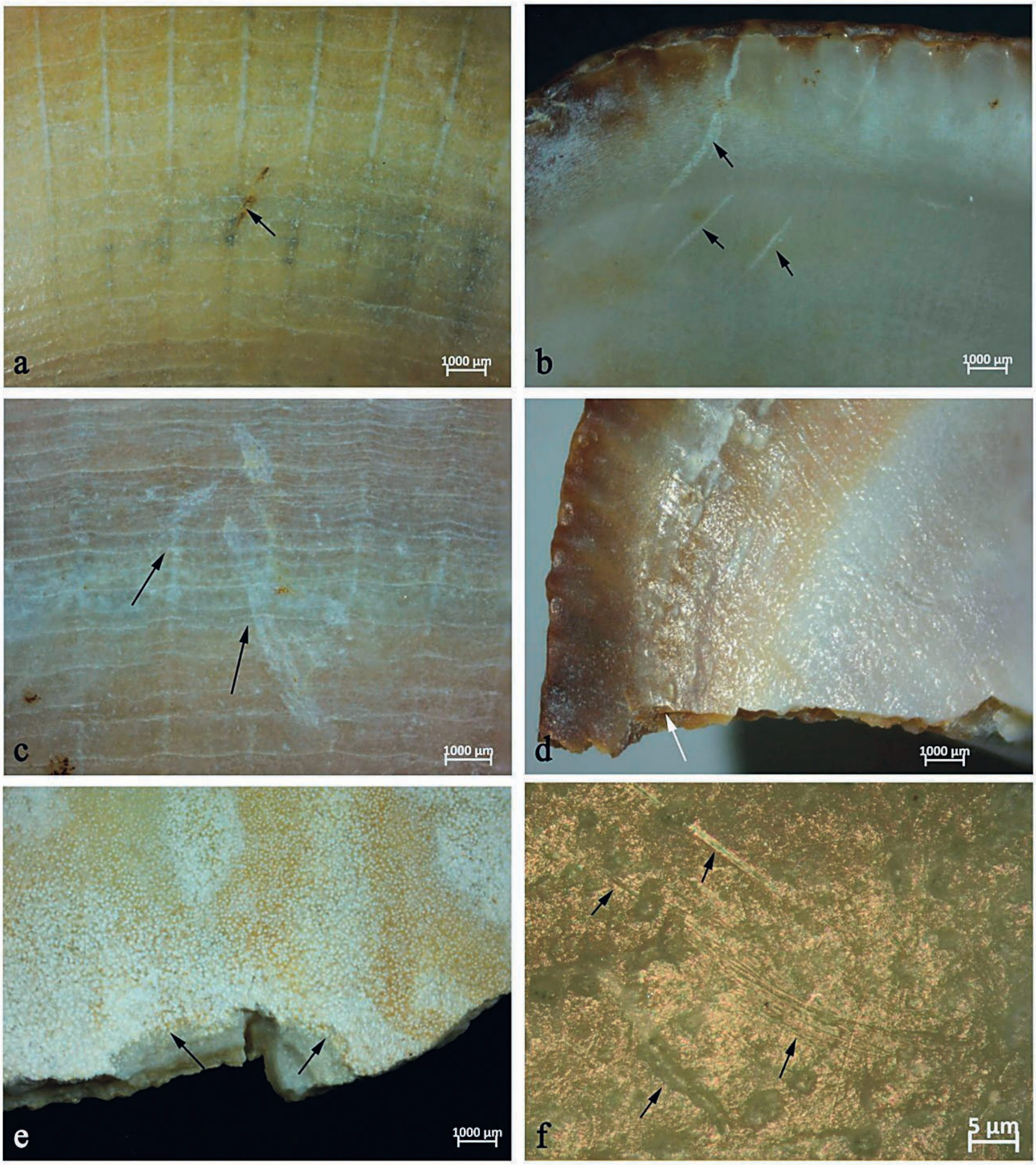
*Altérations post-dépositionnelles des coquilles après un an et demi d'enfouissement : a) et b) stries isolées sur la face inférieure de* Patella *sp. (# id 4) ; c) et d) stries et fissures sur le bord de* Patella *sp. (# id 4) ; e) et f) stries causées par l'action des racines identifiées sur une valve de* Callista chione *(# id 11) ; g) zone polie et craquelée sur la face dorsale de* Callista chione *(# id 11) ; h) zones d'abrasion associées à des stries sur la face dorsale de* Callista chione *(# id 11).*




— FIGURE 7 —

Post-depositional alterations of *Mytilus* sp. after burial: a and b) fissures of conchiolin in the edge (#id 23); c) detachments of conchiolin (#id 25); d) striations due to roots dissolution on the ventral face (#id 21); e) area of dissolution (#id 25); f) striations on the dorsal face (#id 27); g) and h) detachment on the active part of a valve (#id 23), the same surface after utilisation (g) and after burial (h).

*Altérations post-dépositionnelles des coquilles de* Mytilus *sp. après un an et demi d'enfouissement : a et b) fissures de la conchioline sur le bord (# id 23) ; c) détachements de conchioline (# id 25) ; d) stries dues à la dissolution des racines situées sur la face ventrale (# id 21) ; e) zone de dissolution (# id 25) ; f) stries sur la face dorsale (# id 27) ; g) et h) enlèvement sur la partie active d'une valve (# id 23), la même surface après utilisation (g) et après enfouissement (h).*




— FIGURE 8 —

Post-depositional alterations of *Glycymeris* sp. after burial: a–c) striations and more large areas caused by roots dissolution (#id 32 and 37); d) detachments near the impact point due to fracturing (#id 32); e) detachments near the impact point due to fracturing and dissolution process (#id 38); f) striations on the dorsal face (#id 37).

*Altérations post-dépositionnelles des coquilles de* Glycymeris *sp. après un an et demi d'enfouissement : a-c) stries et portions de surface affectées par la dissolution des racines (# id 32 et 37) ; d) négatifs d'enlèvement près d'un point d'impact dus à la fracturation (# id 32) ; e) négatifs d'enlèvement près d'un point d'impact dus à la fracturation et au processus de dissolution (# id 38) ; f) stries sur la face dorsale (# id 37).*

In some *Glycymeris* sp., striations and small isolated fractures were more frequently identified. At the microscopic level, the presence of small polished areas, striations, scratches, and some small edge fractures were documented. In addition to these alterations of mechanical origin, chemical dissolution of surfaces was also documented, probably related to growing roots.

Regarding the different taxa, *Patella* sp. shells showed a low level of alteration. The limpets were only externally affected by the dissolution that damaged their surfaces. This could be due to the location of these shells in the soil in an area less affected by growing roots. *Mytilus* sp. valves showed the highest degree of alteration after eighteen months of burial: they showed a loss of organic material, edge fractures, dissolution surfaces, and striations.

With regard to the shell tools, the presence of alterations was very similar to the rest of the experimental pieces, except for the presence, in some cases, of small fractures on the active edge, probably due to the weakening of the active area during use. The use-wear traces were well identifiable on both macroscopic and microscopic observations. Overall, the post-depositional striations and polishing did not disturb the functional reading. They were clearly distinguished from anthropogenic traces by their location, contour, and morphology. The only problem encountered during functional interpretation after burial was related to the detachments located in the active part of a *Mytilus* valve (#id 26; **fig. 7, 7-8**). In this case, the post-depositional alterations made it impossible to correctly interpret the use-wear traces.

The degree of taphonomic alterations was found to be very similar in fragmented valves and complete shells. The only distinctive alterations between fragments and complete shells were the presence of some small fissures and fractures developed after burial from the point of impact generated by percussion during the experimental protocol to fracture the shells. These alterations were most probably due to the development of zones of brittleness during the experimental percussion, which were progressively extended by sediment pressure. Nevertheless, the presence of these alterations to the surface made it possible to clearly identify the technical stigmata produced by fracturing; the edges did not show post-depositional rounding, and the impact points remained generally intact. Despite the low degree of post-depositional modifications of the sample, the mechanical processes were the main agents generating alterations compared with the chemical processes. According to previous studies (Denys 2002; Fernández-Jalvo 1992), highly alkaline sediments (pH 9–14) and primarily acidic soil attack buried organic materials (bones and teeth) and produce different alterations. In particular, acid attacks have been shown to be very rapidly effective in generating alterations (Fernández-Jalvo *et al.* 2002). The experimental corpus of shells was buried in sediments with a pH of 7.996, which corresponds to slightly alkaline soils. It is possible that the low degree of chemical alterations in the experimental sample was due, at least partially, to soil pH. Possibly, as the experimental protocol progresses, the effects of chemical processes will be enhanced by the extended burial of the specimen, with temperature variations playing a role.

After completing the first phase of the experimental protocol, and considering the degree of alterations of the buried specimens, we estimate that it will be necessary to significantly extend the burial time of the sample, as planned in the ArchaeoENHANCE project. The progress of the experiments will be necessary to document the most significant changes in the conservation state of the shells and possible alterations in the anthropogenic traces that could limit the archaeological interpretation of the sample. Thus, we expect that the development of this research during the next years will contribute to show a greater evolution of the taphonomic processes in our experimental sample and contribute to improve the understanding of the causes and effects of post-depositional alterations in archaeomalacological assemblages. In the next phases of the research, we plan to monitor the changes in the chemical composition of the shells and alterations related to biostratinomic agents (weathering and trampling) during the time of exposure. Finally, we want to emphasise the effort involved in this type of protocol, since it requires rigorous and exhaustive macroscopic and microscopic analyses and documentation of the experimental sample every time the shells undergo a burial process, and the need for a scientific policy that supports such a long-term protocol. The understanding of site and assemblage formation processes is now essential in archaeology and palaeontology, and it should be imperative to devote efforts to improve this research line and related methodologies.

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