Teeth as lithic raw material: Experiments and use-wear analysis

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Abstract:

This paper explores the archaeological and ethnographic evidence for use of rodent teeth as instruments, without direct modification (without manufacturing), in replacement of lithic raw materials. There are ethnographic records that describe the use of teeth, extracted from the jaw by direct manual grip or use of handles, and also used inside the jaw, which functions as a handle. Most of the teeth that appear in archaeological contexts have been studied within the framework of zooarchaeological analysis, however, there is the possibility that the dental pieces have been used as instruments, although this has rarely been considered.

The objective of this work is to present the results of a comparative study of experimental work, which we carried out with beaver (*Castor canadensis*) and capybara (*Hydrochoerus hydrochaeris*), and to discuss their similarities and differences with the traces of use of lithic material. Through macro- and microscopic analysis (Stereomicroscope and metallographic microscope), we were able to characterize and explain the natural use signs of the teeth and differentiate them from the anthropic use signs produced when they are used as instruments. These traces on a macro- and microscopic scale, have different characteristics depending on the material worked and the kinematics used, and at the same time show similarities with the traces that occur on certain lithic materials. Consequently, we believe that it is possible to develop functional analyses on teeth of different animal species, and that these analyses will contribute to our knowledge about the life forms of past societies.

Keywords: tools; tooth; beaver; capybara; microwear

1. Introduction

The archaeological and ethnographical records reveal that antler, shell, teeth and bones have been used at different moments and places of the planet, as raw materials for tool and ornament manufacturing, especially in cases when lithic raw materials may be scarce or not adapted to produce tools for specific uses. However, since the very beginnings of research in

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Prehistory, in particular in Western Europe or in the temperate regions of North and South America, these raw materials seem to have been considered less important, when compared to lithic raw materials. Because of its techno-morphological characteristics that can indicate technological traditions, because of the choice of raw materials whose proveniences may be a good reference of mobility and of many other reasons, lithic material became the mostly used reference indicator in prehistory (Mansur-Franchomme 1984, 1986; Nelson 1991; Semenov 1964). However, throughout America, Asia and Europe there are a large number of contexts of different chronologies characterized by an intensive use of bone raw materials (Anderson-Gerfaud 1985; Campana 1979; Gates St-Pierre *et al*. 2016a; Julien 1982; Julien *et al*. 1999; LeMoine 1994; Peltier & Plisson 1986; Voruz 1990; among other authors). And it is not less true that there is an extensive archaeological and ethnographic record of the use of instruments and ornaments on teeth and bones of various animal species, documented in societies of different regions, such as the inter-tropical, sub-Arctic and sub-Antarctic (Christensen 2016; Houmard 2015; Morrison 1984, 1986; Orquera & Piana 1999), to name a few examples.

Teeth have distinctive characteristics concerning their nature and their morphology, which justify their use as raw materials for ornament and tool making. However, because of their morphology, particularly the incisors, which is dependent on their biological function, unmodified teeth have been used as tools, taking advantage of their occlusal surfaces as bevels, in some cases removing them from the jaw, in others not removing them, and using the mandible as hafting (Clemente Conte *et al*. 2002; Gates St-Pierre *et al.* 2016a). However, unmodified teeth can go unnoticed in the archaeological record, where they are counted within archaeozoological remains but they are rarely given attention as potential artefacts (Gates St-Pierre *et al.* 2016a).

For this reason, a few years ago we decided to propose a long-term experimental study in which we evaluated the characteristics of some teeth that may be important for the archaeological record in general, and for the American continent in particular, as ethnographic records indicate that they were used. In a first step, we worked on beaver teeth (*Castor canadiensis*) (Parmigiani & Alvarez Soncini 2014). Then, we started to study capybara teeth (*Hydrochoerus hydrochaeris*) (Parmigiani *et al.* 2013). The same equipment and methodology of microwear analysis on lithic materials was used. However, in the case of teeth, we knew that they have traces on their surfaces produced simply by the chewing movement (striations and polished surfaces), and that these traces could mislead identification of use wear traces. Consequently, we developed a comparative study of both species. In both cases, we based our procedure on a first evaluation of the morpho-structural and functional characteristics of teeth, and on the ethnographic information about their use. The experimental program sought to evaluate the efficiency of these teeth when they are used as tools for different tasks, to identify and characterize the natural microwear traces on their surfaces, and to evaluate the formation of anthropic microwear traces as a consequence of different uses. In this paper we present our two principal hypotheses and the results about the characteristics of natural and functional microwear traces recorded in microscopic analysis on teeth, which are comparable to those produced on heterogeneous lithic materials.

1.1. Characteristics of capybara and beaver teeth

Capybaras and beavers are the largest rodents in the world. Both species have large incisor teeth. The ethnographic and archaeological records show that these species were not only consumed for their flesh or skin, but also to use their teeth as tools.

Capybaras (*Hydrochoerus hydrochaeris*) live in the tropical wetlands of South America, from Panama to Buenos Aires, Argentina (Schivo *et al.* 2010). Individuals can measure more than 1 m long and 0.60 m high and weigh about 60 kilograms. They have high biological and cultural value and they are still an important source of protein for many native and peasant communities (Ballesteros Correa & Jorgenson 2009).

Beavers are native to North America (*Castor canadensis*) and Eurasia (*Castor fiber*). They reach up to 0.75 m long and 0.30 m high and can weigh up to 40 kilograms. In the past, due to the important use of their skins, the population was reduced in Europe at the end of the 19th century (Halley & Rosell 2002) and was introduced in the extreme south of South America (Tierra del Fuego, Argentina). In 1946, six couples of Canadian beavers were introduced into the Tierra del Fuego ecosystem; there they progressed and colonized different environments, as they found no predators and extensive water resources such as rivers, lakes, streams, ponds, and peatlands (Lizarralde *et al.* 2008)

In order to analyse the natural traces produced on the teeth surfaces by the chewing motion, the type of bite and the feeding habits of these rodents were considered. Normally, a tooth has three sections: the crown, the neck, and the root. The crown is the extra-alveolar sector, generally covered with enamel, sometimes with cement. This is where the occlusal surface of the tooth is located. The crown shape varies: conical, cylindrical, prismatic, laminar (Mones 1979). Young capybara specimens have conical incisors, without a median furrow, characteristics that disappear progressively with age (Mones 1975). The enamel generally covers the entire surface of the crown, but there are cases where discontinuous bands are formed. Sometimes, due to wear of the occlusal surface, the enamel only covers the sides of the crown.

The enamel is formed by hydroxyapatite, a biological mineral formed by calcium phosphate and hydrogen (Ca5 (PO4) 3 (OH)). Its surface can be smooth or scratched, with grooves that sometimes are filled with cement. The colour of the enamel may vary from white to yellow (*Hidrochoerus hidrochaeris)* or even orange (*Castor canadensis* and *Castor fiber)* (Mones 1979).

Koenigswald (2011) takes up the definition proposed by Mones (1982) to define teeth with continuous growth as Euhypsodonts, this category is within the broader category of hypsodontia. Enamel-banded hypsodontia includes those teeth with enamel on only one side or two sides, the dentin covering more than 1/3 of the circumference of the tooth, for the entire life of the animal. A typical example of hypsodontia with enamel bands includes the large incisors of rodents and lagomorphs and within this category the upper and lower incisors are classified as euhypsodontia where the enamel covers the anterior face and part of the mesial face. The length of these teeth is strictly controlled by a balanced wear.

The dental growth of rodents´ incisors is continuous (euhypsodonts) and lasts throughout the animal's life. Teeth that have this type of growth are characterized by high crowns and roots that are open and very small. The implantation of the incisors in the alveoli, especially the lower incisors, is very deep in the jaw (*thecodontia*). With regard to occlusion, beavers and capybaras have a mechanism called crushing, which basically has two movements: lateral and forward.

Stefena *et al.* (2011) studied the movements of chewing and food processing of *Castor fiber* by means of biplanar X-ray. They observed that during the cutting movement, the incisors of the lower jaw move up and down as well as back. The authors point out that they did not detect lateral movements in cutting action. When the interaction of the incisors with the object begins, the lower incisors are brought to an anterior position to the upper incisors; then they move upwards to cut the food and after occlusion they move backwards sliding down the lingual bevel of the upper incisors (Stefena *et al.* 2011) (Figure 1). They demonstrated that the incisors do not participate in the food chewing process, which is carried out by the cheek teeth. The lower jaw moves upwards, to put into occlusal contact, then it scrolls forward and then laterally, alternating left and right sides (Figure 2). The authors can distinguish between the interaction of the incisors involved in ingestion and the interaction of the cheek teeth involved in chewing activity.

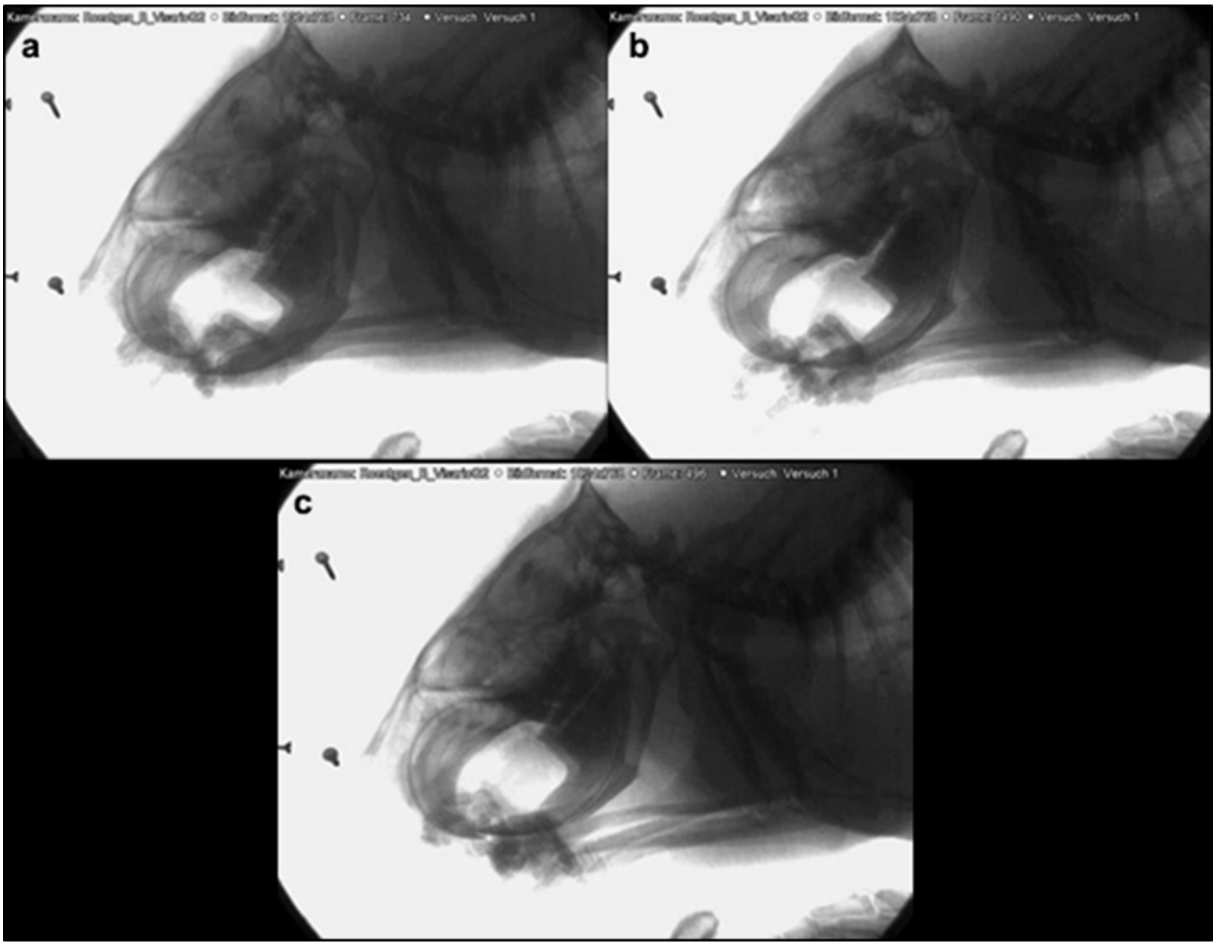

Figure 1. Movements of incisors of *Castor fiber,* according to Stefena *et al.* (2011:535). a) X-ray image in lateral view, showing lower incisor tip far anterior to upper incisor tip during action of incisors. b) X-ray image in lateral view showing upper and lower incisor tip to tip during action of incisors. c) X-ray image in lateral view showing lower tip in end position before the mouth is opened again.

Beavers are rodents with semi-aquatic habits. They use their incisors to reduce plant foods to small particles, but they also use them to peel the bark from the branches or to cut wood. The beaver is able to modify the structure and dynamics of the environment where it lives, in order to build ponds where it constructs its burrow. It builds dams that cross the valley to stop the flow and raise the water level. To do this, it uses its powerful incisors to cut trees (branches and trunks), which it then scoops up to the dam construction site.

Capybaras also have semi-aquatic habitats that lead them to occupy more humid environments, with semi-aquatic and tender food sources. This habitat is shared with another group of related rodents, the Myocastoridae. In the case of the capybaras, they have a strongly oblique bite and powerful incisors; their preferred foods are grass sprouts (Becerra 2015).

These different characteristics will be considered in the discussion section in relation with the natural traces observed in our experiments.

Therefore, this work was structured on the basis of two main hypotheses:

- There will be differences between the natural traces that appear on beaver and capybara teeth.

• Since the mastication movement is determined by the biological function of the teeth, the traces that it produces will have standard characteristics, unlike those produced by subsequent anthropic use.

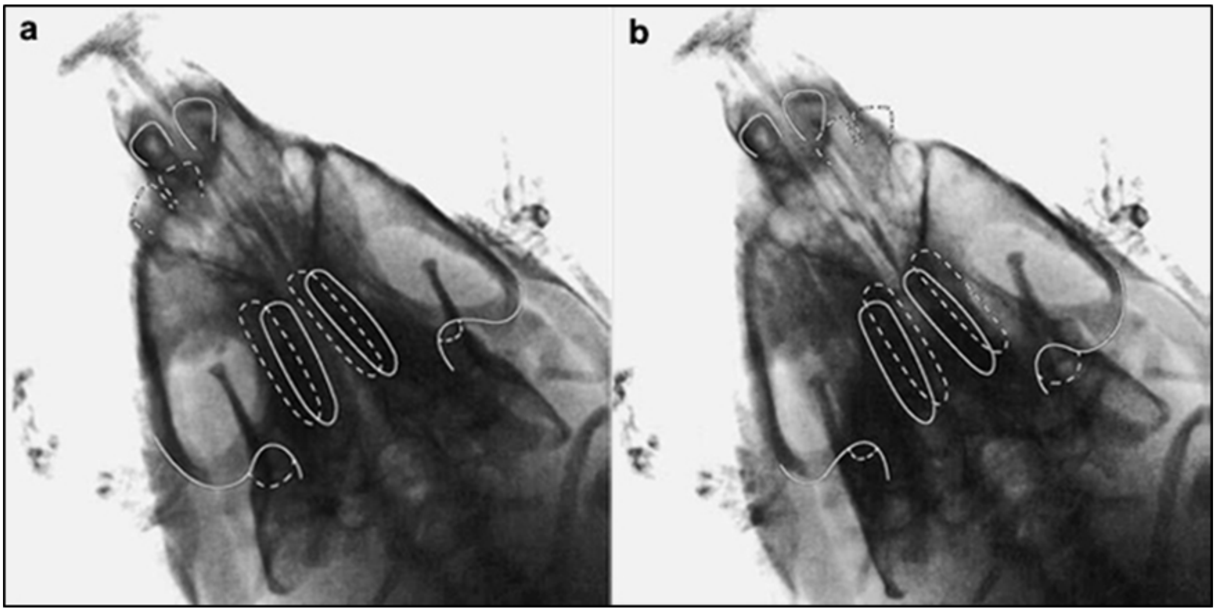

Figure 2. X-ray image of *Castor fiber* showing maximal lateral transition of the lower jaw to the left (a) and right (b) in dorsal view and indicating the approximate positions of teeth rows and mandibular condyles. The continuous lines indicate maxillary teeth and position of distal orbital rim, the dotted lines indicate mandibular teeth and condyle. Taken from Stefena *et al.* (2011:537).

2. Teeth in the archaeological and ethnographical record

Ethnographic and archaeological studies frequently mention the use of teeth as raw materials, parts of ornaments or body decorations (Álvarez Fernández & Jöris 2007; Choyke 2010; Hasselin 1986; Kuhn *et al.* 2001; Sidéra 1989; White 2007; Zilhão 2007). However, there are also mentions of the use of teeth as tools. Maigrot (2001) summarizes information from several ethnographic studies, for example in Indonesia, where boar incisors and canines were used as tools, and in New Guinea, where people used marsupial teeth. In both cases teeth were still in the jaw, which was used as handle. This author also mentions cases in North America, where different ethnographers recorded the use of beaver teeth by local populations (Figure 3) (Maigrot 2001).

In South America, there is also a record of teeth used as tools. Capybara teeth were used by the Bororó societies in Brazil. The incisors, which are naturally curved, were attached laterally to a handle by a ligature and used as burins, especially for preparation of bows and arrows of hard wood (Figure 3) (Lévi-Strauss 1995).

Investigations on teeth from archaeological contexts usually concern the taxonomic and anatomical determination in the zooarchaeological study. There are also publications concerning bone, antler and teeth tools and ornaments; in these cases, most of the studies include a more or less detailed analysis of the manufacturing techniques. Functionality is frequently inferred from morphology or from direct ethnographic analogy. For the use of teeth, it is assumed that they were used to work wood (Pétrequin & Pétrequin 1988; Zhilin 1997). The interpretation of function of teeth tools on the basis of microscopic analysis is very recent, however it starts to give clues to recognise other uses for this tool (Clemente Conte *et al.* 2002; Clemente Conte & Lozovskaya 2011; Maigrot 2001).

Beaver teeth have been recovered in sites with different chronologies located in the northern hemisphere, in an area coinciding with the habitat of this rodent. One of the most interesting archaeological sites is Zamostje 2, located on the Russian plain, which has a maximum age of 7400-7300 BP, but it also has occupation levels that go from the Mesolithic to the Neolithic (Lozovski *et al.* 2013). The site has levels with peat, which has allowed an excellent conservation of the archaeological materials, not only the bone and dental records, but also woods and other plant material. Among the faunal material, the most relevant correspond to beaver (*Castor fiber*) and moose (*Alces alces*), which appear not only as faunal remains, but also as raw material for the making of bone instruments. At this site, Zamostje 2, there is evidence of the use of the upper and lower incisors as tools, and even the latter were used while still attached to the jaws (Clemente Conte *et al*. 2002).

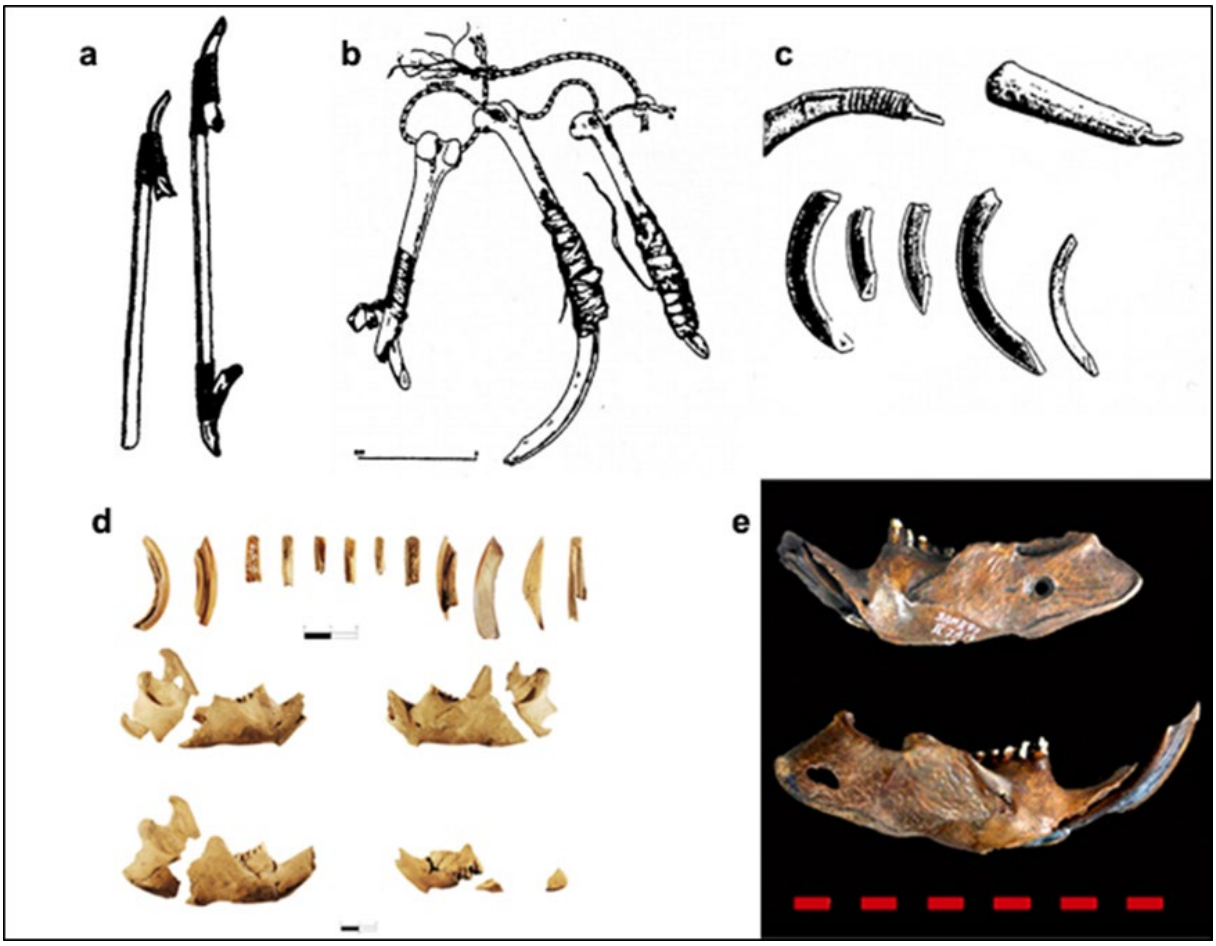

Figure 3. Ethnographic records of instruments made from teeth: a) Capybara tooth knives, Brazil, (Levi Strauss 1995:242); b) Capybara incisors from Southern America recorded by Clastres (1972), images taken from Maigrot (2001:60); c) Beaver incisors from Northern America recorded by Albright (1984), Stewart (1973), images taken from Maigrot (2001:60). Archaeological records of instruments made from teeth: d) Tools made from rodent incisors, including beaver and beaver jaws possibly fractured for incisor extraction, from the McDonald site, Canada (Gates St-Pierre & Boisvert 2018:130,131); e) Beaver jaws used as instruments, originating from the Zamostje 2 site, Russia (Clemente Conte & Lozovskaya 2011:229). The scale bars are 1 cm wide (1 cm for each segment).

The beaver teeth used have been modified: the jaws are usually fractured in the area of the ascending branch, possibly to facilitate hand holding, since they functioned as handles (Figure 3); the enamel of the incisors has been eliminated, in order to enlarge the active surface of the tool (Clemente Conte *et al.* 2002; Clemente Conte & Lozovskaya 2011). The microscopic study revealed traces of use on wood; however, these were distributed differently in the distal and lateral areas. The authors interpreted the possible kinematics of these instruments, which would have worked in multiple ways as burins, gouges, scrapers and planers, for the manufacture of both large objects such as canoes and oars, as well as smaller objects such as spoons and plates (Clemente Conte & Lozovskaya 2011).

In North America, the studies carried out by Gates St-Pierre on sites in south-eastern Canada provide abundant information on the use of beaver teeth (*Castor canadensis*). The sites correspond to Iroquoian villages dated to the fourteenth and sixteenth century (Gates St-Pierre *et al.* 2016a). Many bone instruments were recovered from habitation structures; among them, many beaver incisors, some with modifications, as well as fractured jaws (Gates St-Pierre & Boisvert 2015; Gates St-Pierre *et al.* 2016a, b). At the McDonald site, they recovered many jaws fractured in the ascending branch area, which would indicate a systematic processing to remove the incisors, that were later modified by longitudinal fracturing (Figure 3) (Gates St-Pierre & Boisvert 2018). The study of these teeth included experimentation and functional analysis. The majority of them were found to be used as scrapers to work on wood, though traces of other unidentified materials were discovered in some cases.

As for the remains of capybara (*Hydrochoerus hydrochaeris*), in recent years research has increased in humid and coastal environments in South America, the habitat of this species, and then the record of sites with capybara has also increased: in Brazil (*e.g.*, Perez 2005; Prous & Rocha 2011; Rosa 2009; Schmidt Dias 2004; Volkmer de Castilho & Simões-Lopes 2005), in northeast Argentina (e.g. Acosta 2005; Barboza 2014; Bastourre & Apolinaire 2017; Bonomo *et al.* 2010, 2011; Politis *et al.* 2011; Prates & Bonomo 2017) and Uruguay (Perez 2005). The archaeological remains of capybara are used for taxonomic and anatomical identification, and then to make interpretations regarding coastal populations subsistence. However, if we consider the frequency of their appearance and the ethnographic correlates on the use of teeth as instruments, it would be very important to identify these instruments among the fauna remains of the archaeological sites.

From this point of view, we believe that the analysis of use wear traces on teeth is an important part in the archaeological analysis and they should be selected from the archeofaunal assemblages and analysed separately as potential tools.

3. Materials and methods

Our investigation included an ethnographic record evaluation, followed by an experimental program where teeth were used to work different materials. The experimental program tries to cover all possible modifications by use, which is why work is carried out on various materials such as bone, wood and hide. It included two series of tools, one made with beaver teeth and another with capybara teeth.

In the series on beaver teeth, the experiment was conducted with a sample of 20 beaver skulls of *Castor canadensis*, both female and male. The skulls used in these experiments were collected in the area where beavers were first introduced in Tierra del Fuego. As for the capybara teeth, it was more difficult to obtain the specimens; we used two skulls of *Hydrochoerus hydrochaeris* from wetlands near the city of La Plata.

In the experiments with beaver teeth (Figure 4), six incisors (two upper and four lower) were used, of which four worked transversely (scraping) while the other two worked longitudinally (cutting). The kinematics are referenced to the surface of the cutting edge of the tool, in this case the occlusal surface of tooth. Two pieces were utilized with their bone support (hemi-mandibles) that worked as support handles. The other four pieces were utilized hand-held directly without intermediaries; in this case, they were the upper and lower incisors. The materials worked on were dry beaver hide (*Castor canadensis*), fresh lenga wood (*Nothofagus pumilio)*, which is a kind of wood moderately heavy and of medium density (Tortorelli 2009), and dry guanaco bone (*Lama guanicoe*). The working experiments were done at intervals of 5, 10 and 15 minutes (Figure 5), (Parmigiani & Alvarez Soncini 2014).

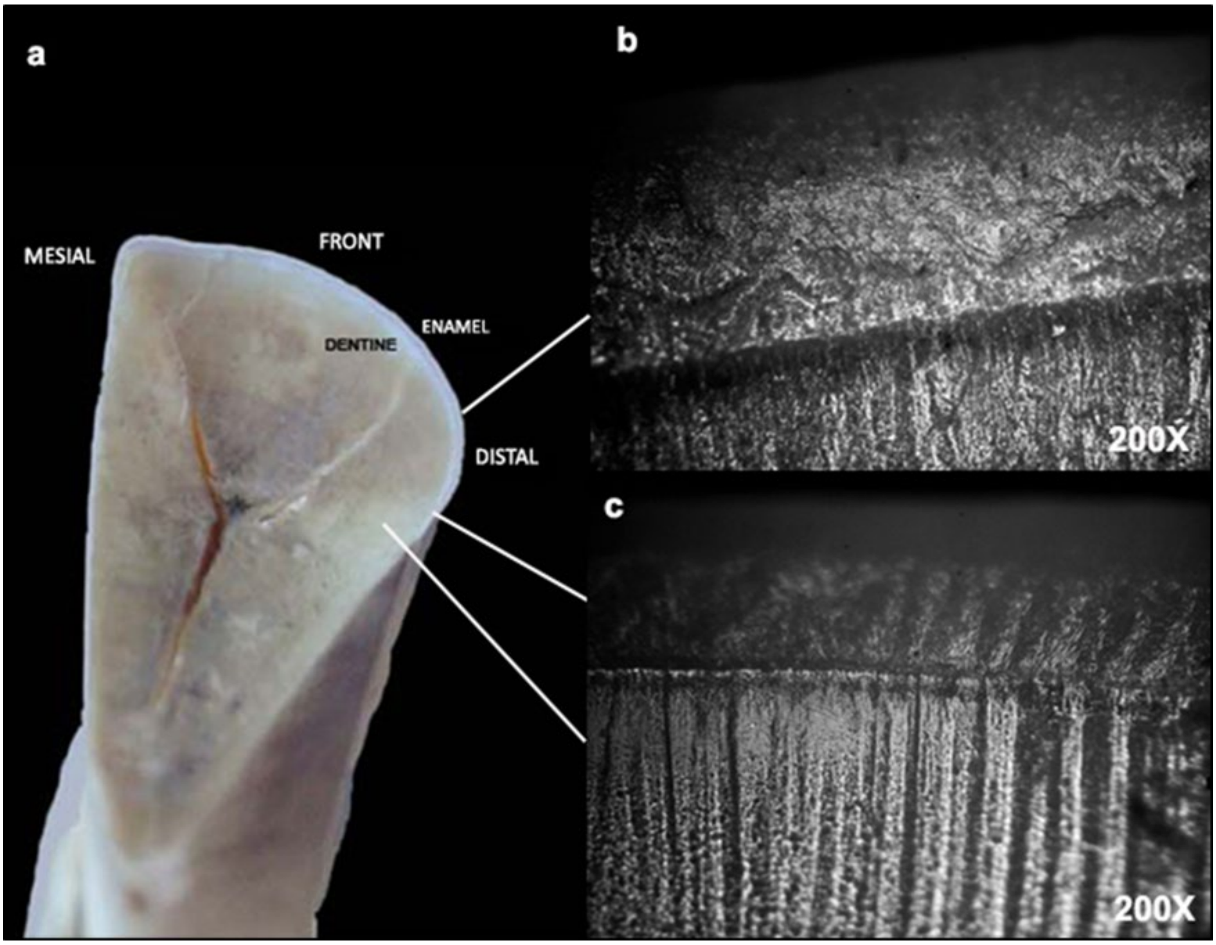

Figure 4. Unused beaver tooth. a) Stereomicroscope image: detail of different sectors on natural bevel (front, mesial and distal part, dentine and enamel); b) Microscope image: enamel detail; c) dentine and enamel detail.

In the experimentation with capybara teeth, six incisors were used, all of them transversally. One piece was used with the jaw as a support handle, while the other five were extracted from the jaw and used directly, holding them in the hand. The materials worked on were sheep hide (*Ovis aries*), lenga wood (*Nothofagus pumilio*) and guanaco bone (*Lama guanicoe*), all of them in both fresh and dry state. The working experiments were done at intervals of 5, 15 and 30 minutes (Figure 6).

The optical equipment used for this analysis includes a stereomicroscope (binocular loupe Leica S6D, with magnifications from 6X to 40X) and an incident light microscope (Leica DM2700 MH RL, 50X to 500X), with a direct system for photography and digitization. Materials were examined at different intervals during work, in order to observe, discuss, and record the process of microwear trace formation (Clemente Conte & Lozovzskaya 2011; Maigrot 2001; Mansur 1999).

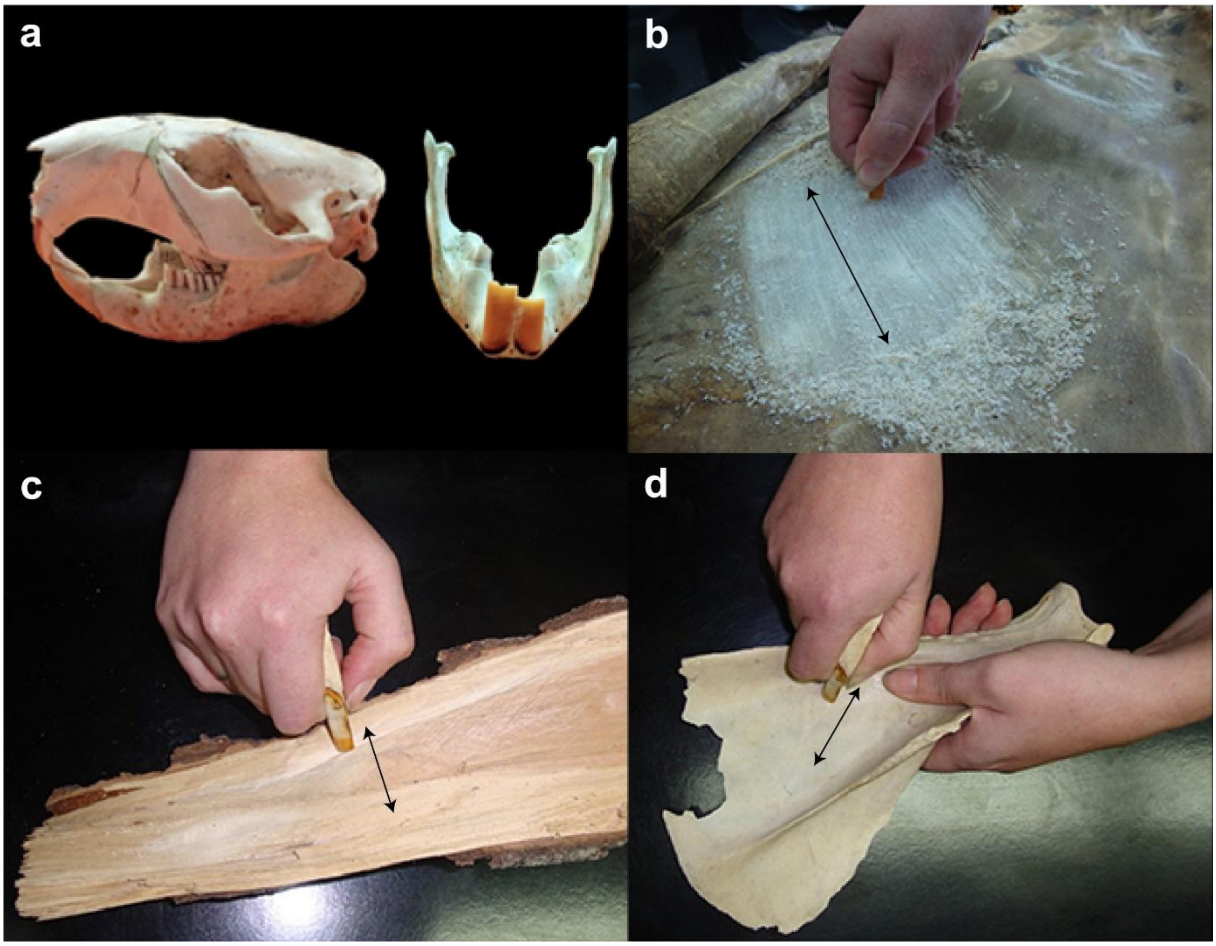

Figure 5. Experimentation with beaver teeth. a) skull and jaw; b) transversal work on hide; c) transversal work on wood; d) transversal work on bone.

The experimental protocol was the same that we normally use in all procedures in the laboratory "Grupo de Investigaciones y Análisis Tecno-Funcionales de Materiales Arqueológicos", Centro Austral de Investigaciones Científicas (GIATMA-CADIC-CONICET: https://cadic.conicet.gov.ar/antropologia/) (Parmigiani & Alvarez Soncini 2014):

1. Preparation of a specific file for each piece, in which all the events of the experiment are recorded, including user variables, artefact variables and observations made during the experience.
2. Observation at low magnification, using the binocular loupe at 6x to 40x, to analyse natural morphological characteristics of the tooth surface.
3. Observation at high magnification with a metallographic microscope at 50x to 500x, before tool utilization, to evaluate and record enamel and dentin before use.
4. Utilization of dental pieces to work. Beaver incisors were used for periods of 5, 10, and 15 minutes. Only one piece was used for up to 20 minutes, as a control piece. Periods for capybara incisors were longer, at 5, 15, and 30 minutes, because we did not find the observation at 10 minutes relevant during the beaver experiment. The difference in work duration between both species is not a problem for this study, as we are not comparing them in terms of speed of trace formation, but distinguishing natural and anthropic traces for each species.
5. Observation and analysis of the evolution in the development of microwear and the description of its characteristics as the periods of work progress.
6. Image capture at fixed points of the surface established at beginning of the experience, before utilization, and at the end of each period of use.

7. The experiments were carried out by two of the authors, Parmigiani and Alvarez Soncini, in the aforementioned laboratory (GIATMA-CADIC-CONICET). The objective was to carry out a time-based experimentation in order to compare the results with the experimental records of other raw materials such as rhyolites. Results were analysed by the other authors (Mansur, De Angelis and Franch).

Figure 6. Experimentation with capybara teeth. a) incisors and jaws; b) work on hide; c) work on wood; d) work on bone.

4. Results

The analysis of microwear trace development on dental pieces of both experimental series, beaver and capybara, showed that teeth behaved similarly. Natural teeth, before utilization, contained wear traces characterized by their distribution and orientations that depend on the mastication movements, fixed and repetitive.

In beaver teeth, we can observe a type of microwear polish that evokes traces produced by work on hard plant material, and an intense pattern of striations oriented according to teeth movement (Figure 7a).

In capybara teeth, natural traces show a lighter striation pattern, also oriented according to the direction of the chewing movement, and a slight bright polish characteristic of contact with soft plant matter. However, these traces are not as marked as on the beaver teeth (Figure 8a). These observations and the experiments were more extensively described in previous works (Parmigiani & Alvarez Soncini 2014).

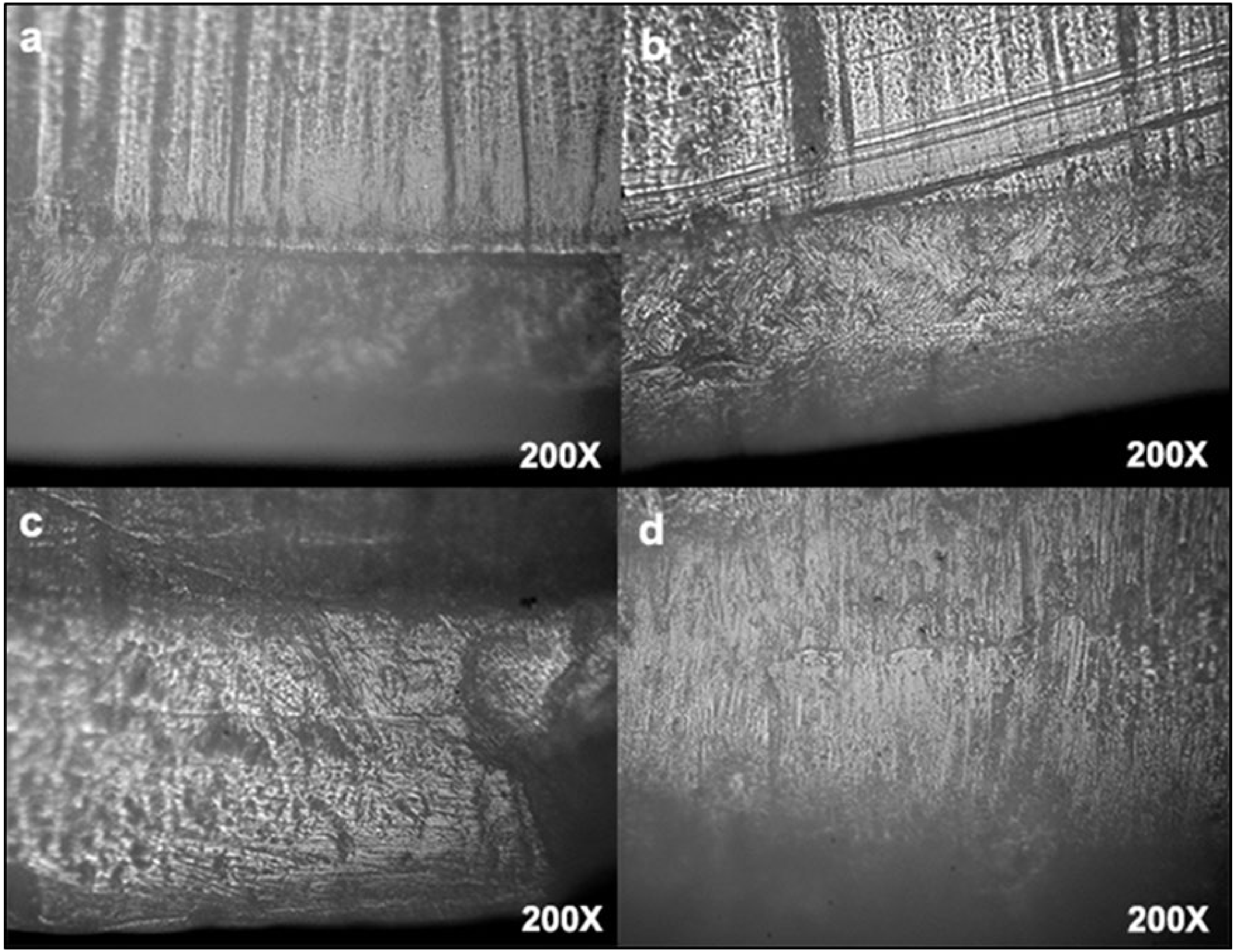

Figure 7. Microscope images: Wear traces on beaver teeth. a) natural traces of the tooth without anthropic use; b) longitudinal work on dry hide, 15 minutes; c) longitudinal work on dry wood, 15 minutes; d) transversal work on dry bone, 20 minutes.

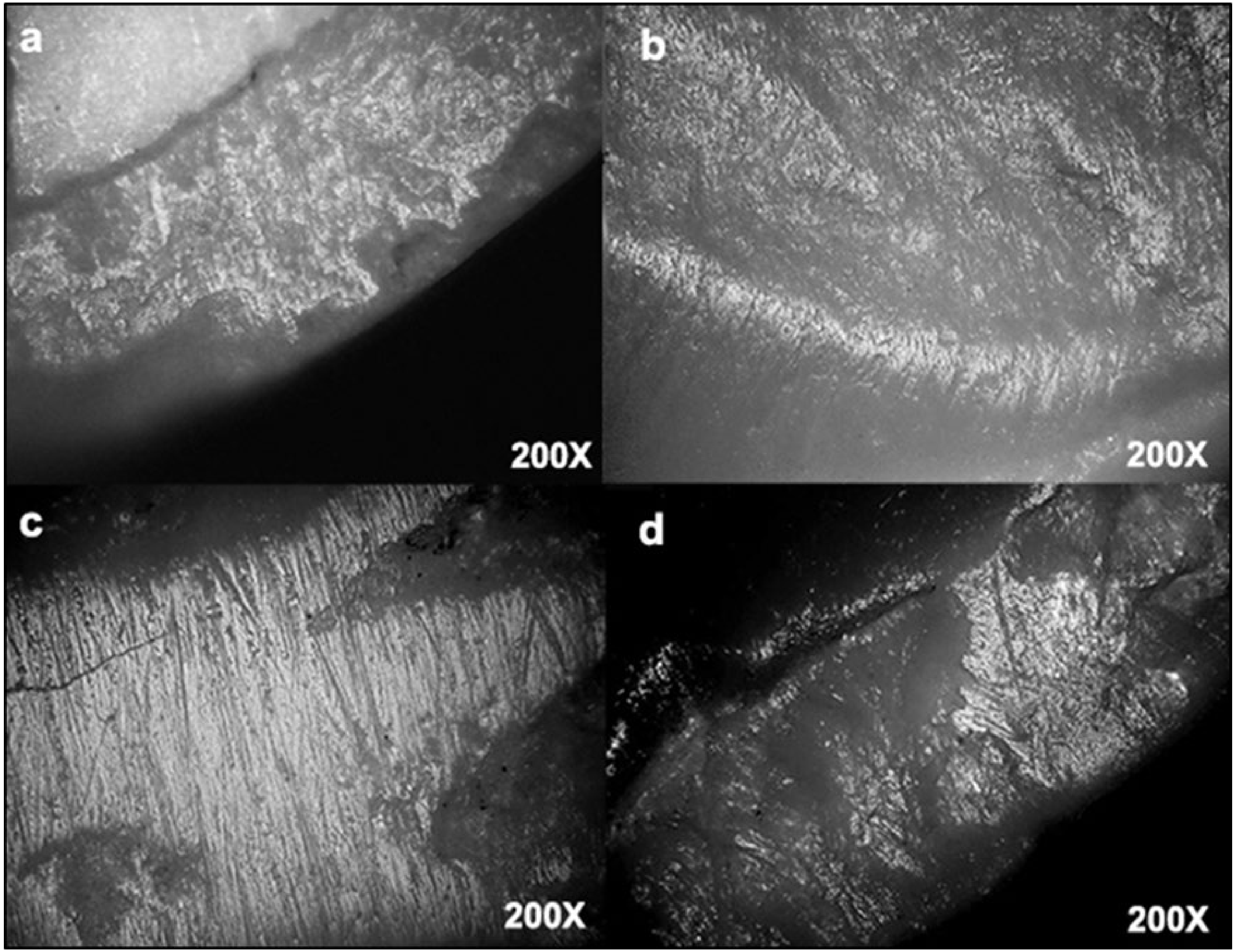

Figure 8. Microscope images: Wear traces on capybara teeth. a) natural traces of the tooth without anthropic use; b) transversal work on fresh hide, 30 minutes; c) transversal work on dry wood, 30 minutes; d) transversal work on fresh bone, 15 minutes.

4.1. Use wear on beaver teeth

Two beaver's incisors were used to work dry hide; one of them for a transversal movement (scraping) and the other for a longitudinal movement (cutting). In general terms, edges were efficient for the task. After the first 5 minutes of work, they did not show any important modifications at the macroscopic level. The main wear trace is the beginning of edge rounding that becomes accentuated as work progresses. However, at the microscopic level, modifications of the edge surface can be seen from the beginning of use, with the formation of microchipping in some sections of the edge (Akoshima 1987; Keeley 1980; Tringham *et al.* 1974; Vaughan 1985). In these sections, the use wear does not completely obliterate the natural wear traces. Microsplintering progresses as work continues. Well-developed micropolish appears when the edge is already stabilized. It varies according to the area of the tooth and the kinematics performed; in longitudinal movements, it appears first in the central part of the tooth, and in the extremities of the tooth when used in transverse movements. Traces show some differences between dentine and enamel. In the first case, they show abundant long and wide striations and a slightly shiny micropolish. In the second case, the striations are shallow, and the micropolish is more opaque (Figure 7b).

Two other incisors were used to work on wood, one of them in a longitudinal movement (cutting) and the other in transversal movement (scraping). In each case, the work performed showed no difficulty, proving that edges are efficient for scraping and cutting wood. At the macroscopic level, the most relevant trait was an irregular fracture in the distal right part of the incisor, during the scraping task after 5 minutes of work. The piece used in the cutting action did not show fractures, although microsplintering occurred in both the enamel and the dentin. At microscopic level, changes can be observed after the first 5 minutes of work, but these traces become characteristic after 10 to 15 minutes. The wear traces were a brilliant micropolish, with short, dark and deep striations (Figure 7c). As in hide work, we could observe differences in the distribution of wear traces between longitudinal and transverse actions. In longitudinal movement, edge rounding occurs more rapidly at the extremities, while large microsplintering is produced in the central part of the edge.

Finally, two incisors were used with a transverse movement (scraping) on bone. This action was also efficient and did not show any difficulty. At macroscopic level the main effect since the beginning of tool work has been microsplintering, mainly from enamel and some zones from dentine, similar to what happens in woodworking. Observation at low magnification shows that the microsplintering forms mostly at the extremities of the edge, while the rounding is principally in its central part. After this first microsplintering, the edge stabilizes and continues to be effective for the rest of the working period. At microscopic scale, we could observe that after stabilization, the edges have an intense and very brilliant microwear polish, more than on incisors working wood, with striations, long and narrow. The extension of this micropolish towards the interior of the piece is also deeper, when compared to micropolish produced on wood working pieces (Figure 7d).

4.2. Use wear on capybara teeth

Two incisors were used to work hides, one fresh and one dry. Transverse movements (scraping) were performed with both teeth. The edges were efficient for the task throughout the entire duration of work. At the macroscopic level, the main modification was a strong rounding of the edge, observed after 5 minutes of work. At the microscopic level, the modifications appear since the beginning of work, with the formation of abundant striations, in a series of parallel lines, oriented perpendicularly to the edge, according to the movement performed. As work progresses, these striations accentuate and become superimposed on the natural traces of the tooth's surface. At 15 minutes of work, an intense, opaque micropolish is observed, covering both the upper and lower parts of the topography. After 30 minutes, the micropolish is very well developed, with micropitting and thin long striations both in the enamel and the dentine (Figure 8b).

The work on wood was carried out with two incisors, one on dry wood and the other on fresh wood. In this case, the movement was transverse too. Teeth were effective for the task on both fresh and dry wood, but gave better results in debarking fresh wood. At the macroscopic level, after the first 5 minutes, splinters are observed mainly on the enamel; later the edge stabilizes. At microscopic level, after the first 5 minutes, some broad, deep and dark striations are seen, oriented according to direction of tool use. After 15 minutes, the number of striations increases and a bright micropolish begins to develop, covering the entire surface, and thus obliterating the natural traces. Micropitting can also be observed accompanying the micropolish, which deepens and remains until 30 minutes (Figure 8c).

Finally, work on bone was performed with two incisors. Both were used with transverse movements, one on a fresh bone and the other on a dry bone. At macroscopic level, after the first 5 minutes, the most important modification is the formation of intense splintering in the enamel, in the same way that occurs with beaver's teeth. In the following working periods, a slight rounding of the edge is observed, which stabilizes for periods of 15 and 30 minutes. On a microscopic scale, a slight micropolish is observed after the first 5 minutes of work, mainly as a change in surface brightness on the higher parts of the microtopography. This trace behaves differently on enamel and dentine. On enamel, microsplintering produces high areas on the microtopography that continue to have intense contact with the material being worked. On these areas, a well-developed bright micropolish is formed, accompanied by narrow striations, which can be clearly observed after 15 and 30 minutes of use. Regarding dentine, microsplintering does not occur here; the most important traces are edge rounding, and the development of a very bright micropolish with narrow striations (Figure 8d).

These results confirm that utilisation produces microwear traces on the teeth surfaces, and that there are specific criteria that allow the identification of each activity. Moreover, these microwear traces are very similar to those on lithic material. We especially observed similarities with traces on heterogeneous cryptocrystalline siliceous rocks (Mansur 1999). For that reason, we compared these traces with those on rhyolites, a kind of rock that is largely found in the archaeological record of Tierra del Fuego (Figure 9) that has already been described in previous works (Álvarez 2003; De Angelis 2015; Clemente Conte 2008; Mansur 1999; Srehnisky 1999). The question of how we explain this similarity is relevant to determining if it is possible to use the theoretical-methodological reference model of microwear traces analysis to recognize and interpret teeth used as tools in the archaeological record.

We do not want to neglect to mention here the existence of some differences when analysing the surfaces of both materials, teeth and rocks. We believe that may be due to the several differences in hardness that exist between the elements mentioned above. This, in principle, could act on a difference in the formation of grooves and the extent of polishing.

5. Discussion

The results obtained in the experimental work, using teeth as instruments to process different materials, allow us to confirm the effectiveness of the teeth edges to carry out the tasks tested in these experiments. Furthermore, the study made possible to verify and analyse the formation of microwear traces, observable on a microscopic scale.

The identification comprises two different sets of traces: natural and anthropic. The first are traces that form on the teeth due to natural use by the animal, and are indicative of movement and material with which they were in contact. They are the result of the biological function of the incisors and the interaction with the environment throughout life, which is called "natural use of the animal". The latter are those that are produced when used anthropically to work on different materials and with different kinematics.

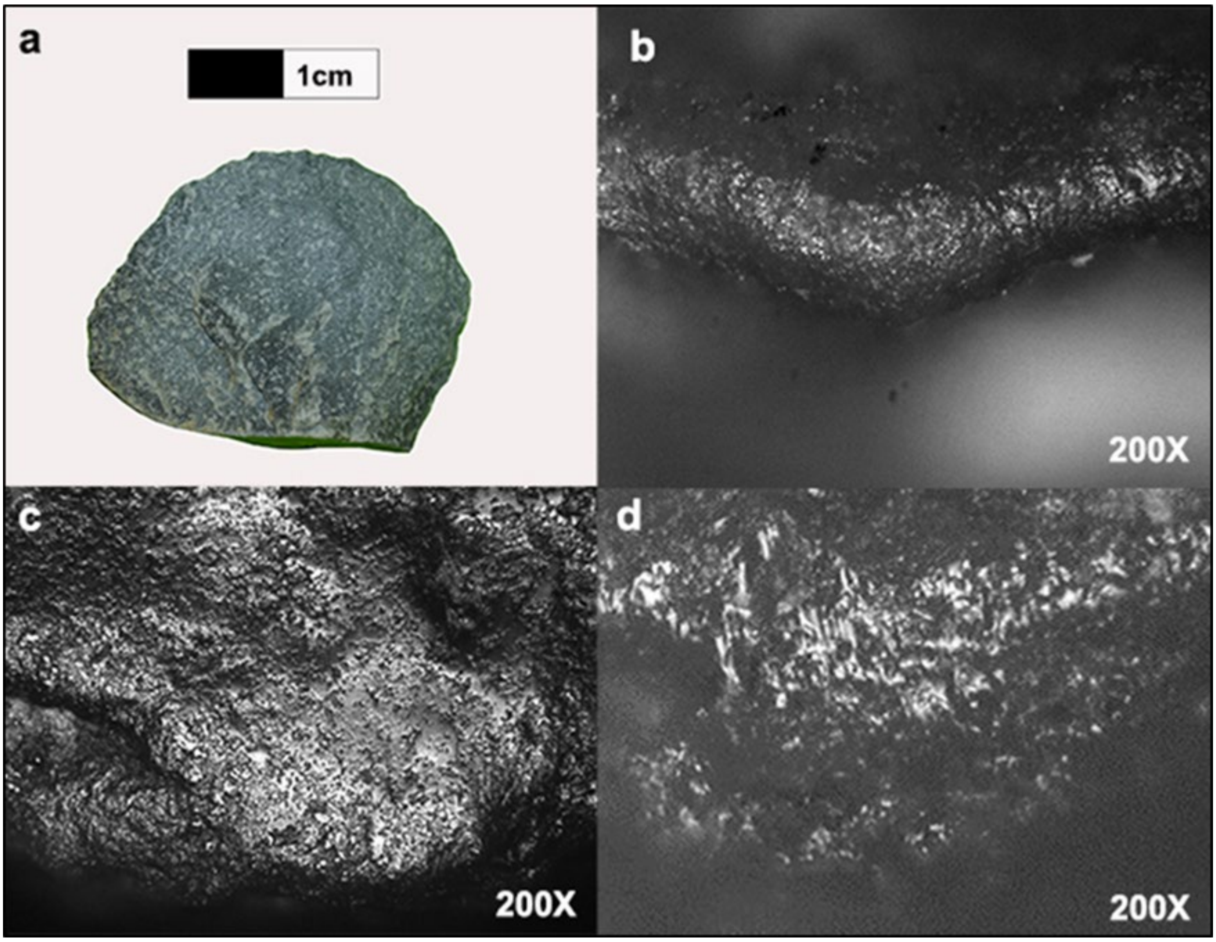

Figure 9. a) rhyolite flake. Microscope images: b) hide micropolish, experimental piece; c) Wood micropolish, archaeological piece; d) bone micropolish, experimental piece.

At the beginning, we said that in our hypothesis, in order to differentiate natural traces of the tooth from the traces of use, in terms of contact matter and kinematics, it was necessary to understand how the teeth are used in life by the animal, and what its feeding and chewing habits are. The cutting and chewing movements described by Stefena *et al.* (2011) explain the location and morphology of the wear on the bevelled section of the incisors of both species. Both the upper and lower incisors have a wear plane at the distal end, on the lingual face, inclined with respect to the tooth axis. Due to the teeth's continuous growth, these wear planes are permanently renewed. Natural traces that we could identify, on the macroscopic level, are wear planes on the lingual faces of the incisors of both species studied. At microscopic scale of analysis, traces take the form of abrasion, striation, and micropolish. One of the main characteristics is that these traces are produced as a consequence of a chewing movement that has a fixed directionality, since it depends on the biological function of the tooth. As a result, the kinematics deduced from the distribution of traces is conventional, as opposed to the anthropic use of the teeth, which has different directions. In addition to the macroscopic wear planes, there are microscopic features that have to do with the environment and the habits of each species, and the difference between their use on soft plant material or on wood. Both beavers and capybaras have semi-aquatic habits and live in environments with soft herbs that they use as food. However, there are differences between different families of

Rodentia. Some of them have cavimorphic habits, that is, they excavate underground burrows, and in these cases, the incisors, beyond the use described above, are also used to excavate the sediment. The structure of these incisors is different, since they must withstand a higher tension and then the enamel pattern is double-layered (Álvarez *et al.* 2015). In the case of the capybara, its feeding habits on herbs are the main reason for the characteristics of natural microtraces observed on the surfaces. In the case of the beaver an extremely important difference in terms of their living habits is the use of incisors on wood to cut branches and logs.

The traces of use generated by the natural wear of teeth leave evidence at a microscopic level, but in the observations we made as part of our experimentation, these natural micropolishings are not very intense. We understand that this is due to the activity of each animal and the type of movement they perform with their jaws throughout their lives.

In the case of experiments using teeth as instruments, natural traces are not a problem, since they are traits that are quickly obliterated when work begins. The microsplintering that occurs rapidly in actions on bone and wood, as well as the detachment of enamel in actions on skin, remove and obliterate the natural traces.

As for functional experimentation, there are similarities in terms of the effectiveness of teeth when used to work different materials, as well as in the stabilization of the edges. Chipping occurs in the first few minutes of work, mainly in the enamel, and stabilizes after approximately 10 minutes of work. Regarding the development of micropolish with the different materials, between the first 5 to 10 minutes, characteristic striations and micropolishes are already observed. We were able to observe differences in some cases depending on the kinematics used or the level of chipping caused at the beginning of the work, until edge stabilization.

Regarding the type of traces, we observed the development of bright micropolishes in wood and bone work, the latter being the most intense, while the micropolishing produced by hide work had a more irregular and opaque general appearance. The striations produced by wood and hide work are wide and deep, in contrast to those from bone work, which are generally long and thin.

It is important to emphasize that enamel and dentin react differently when working with these materials. The enamel is generally detached by microsplintering, while the dentin tends to round, probably due to the detachment of grains, and on that surface, the micropolishing is formed more easily during work. As for the stabilization of the edges, it depends mainly on the enamel. This difference in behaviour in terms of the formation of traces between dentin and enamel, depends essentially on their different composition, which is discussed later.

Another important aspect is that of the mechanisms of use-wear trace formation. The results obtained in these experiments show that the traces produced on the dental surfaces, when they are used to work on different materials, are very similar to traces produced on lithic surfaces. Another important aspect is that of the mechanisms of the formation of wear marks due to use. The results obtained in these experiments show that the traces produced on tooth surfaces, when used to work different materials, show polishing developments similar to those produced on lithic surfaces. We believe that this similarity is directly related to the chemical composition of teeth. As we explained at the beginning, the crown of the tooth is superficially covered by enamel, composed of hydroxyapatite. In it, the crystals are organized into nuclei called prisms, which give it its characteristic hardness. In the case of mammals, the teeth have different mechanical demands; they show combinations of different types of enamel to meet various biomechanical requirements during chewing (Álvarez *et al.* 2015).

Hydroxyapatite is a biological mineral, known as bioapatite, consisting of calcium, phosphorous, and hydrogen (Ca5 (PO4) 3 (OH)). It is the main component of the teeth. The enamel is 90% bioapatite and the other 10% is divided between organic matter and water, while dentin is made up of approximately 70% bioapatite. The other 30% is made up of water and collagen fibers. These components make enamel and dentin behave differently mechanically. Bioapatite is analogous to apatite of geological origin (Ca10 (PO4) 6 (OH) 2). Here we agree with Pasteris *et al*. (2008), who sustain that there are some differences in the structure, its relationship with the other components, and in the time scale in which the structural changes take place (in the case of teeth, in years, in relation to the life of the individuals, vs the geological times for the mineral), and specifically refer to the difference in the arrangement of the crystals in the form of plates in the bioapatites, and in prisms in the apatite of geological origin.

Beyond these differences, both components are minerals (one of biological origin and the other of geological origin) and have a similar structure. For this reason, we believe that the microwear analysis to identify possible uses in teeth does not vary in its methodology, nor in the approach to the pieces *strictu sensu*, to that of the lithic pieces. Therefore, it is possible to study teeth as working tools since traces of use will be recorded on their surfaces, much as occurs with lithic tools.

6. Conclusions

The work we have presented here explores the existing archaeological and ethnographic evidence for the use of rodent teeth directly without modification, as might be interpreted from the experimental work we have developed here. The experiment showed that the teeth can be used directly without modification.

The results obtained from the experimental work carried out using beaver and capybara teeth as instruments to process other materials, confirm that it is possible to identify such instruments in archaeological sites.

The investigations carried out have confirmed that teeth used as tools are efficient for working with different materials and with different kinematics. They were performing for the various tasks throughout the experiments, and their edges attained their stability profile relatively quickly, making them efficient for the duration of the experiment and thereafter. This observation confirms the efficiency of teeth as informed by ethnographic records.

Regarding functional analysis, we were able to characterize and explain the traces of the natural use of the tooth in order to differentiate them from the anthropic traces of use. Natural traces are characterized by being standardized both in terms of contact material and movement, as a result of the biological role of the tooth in cutting and chewing. In addition, they are not developed too intensely, since we understand that they are constantly renewed because of the teeth's permanent growth.

Finally, we were able to characterize the traces of use, at macroscopic (binocular loupe) and microscopic (metallographic microscope) scales, which have different characteristics according to the material worked and the kinematics. We also observed that the reaction of the two parts of the tooth, dentin and enamel, is different, since both have slightly different chemical compositions. However, because of their mineral nature, dentine and enamel develop traces that are very similar to those produced on certain types of lithic raw materials.

Consequently, we believe that functional analysis can be developed on teeth of other animal species, including human teeth. These analyses will contribute to our knowledge of the ways of life of past societies.

Data accessibility statement

All data generated or analysed during this study are included in this published article.

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Los dientes como materia prima lítica: Experimentación y análisis microscópico

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Resumen:

Este trabajo explora la evidencia arqueológica y etnográfica sobre el uso de dientes de roedores, sin modificación directa (sin manufactura) como instrumentos, en reemplazo de materias primas líticas. Existen publicaciones que muestran su uso, extraídos de la mandíbula, en prehensión manual directa o enmangados, pero también usados dentro de la mandíbula que funcional como mango. Sin embargo hasta ahora, la mayoría de los dientes que aparecen en contextos arqueológicos han sido estudiados en el marco del análisis zooarqueológico. La posibilidad de que hayan sido utilizados como instrumentos es rara vez tenida en cuenta, en parte debido a que se pensaba que no era posible identificarlos entre los restos faunísticos.

En investigaciones previas desarrollamos un trabajo experimental preliminar utilizando dientes de dos grupos de roedores, castor (*Castor canadensis*) y capybara (*Hydrochoerus hydrochaeris*), para procesar otros materiales. Observamos que era posible identificar rastros de uso, que permitirían reconocer tales instrumentos en sitios arqueológicos. Para hacerlo, utilizamos el mismo equipamiento y metodología que se emplea habitualmente para el análisis de rastros de uso en material lítico.

A lo largo de los años hemos desarrollado numerosas líneas experimentales sobre diferentes tipos de materias primas líticas. En este trabajo, efectuamos un estudio comparativo de ambas especies y discutimos sus similitudes y diferencias con el material lítico. De manera comparativa mostramos las huellas de uso desarrolladas en riolita, una materia prima lítica común de Tierra del Fuego. Los resultados muestran que los dientes utilizados como instrumentos son eficientes para trabajar diferentes materiales y con diferentes modos de uso. Mediante análisis macro y microscópico (lupa binocular y microscopio metalográfico), pudimos caracterizar y explicar los rastros de uso naturales de los dientes y diferenciarlos de los rastros de uso antrópicos producidos cuando se los utiliza como instrumentos. También observamos que el comportamiento de las dos partes del diente, la dentina y el esmalte, es diferente, ya que su composición es ligeramente diferente. Finalmente, pudimos caracterizar estos rastros de uso a escala macro y microscópica; tienen características diferentes según el material trabajado y cinemática, y al mismo tiempo muestran similitudes con los rastros que se producen sobre ciertos materiales líticos.

Las huellas producidas en los dientes al ser utilizados sobre diferentes materiales son muy similares a las producidas sobre materias primas líticas. La razón de ello es la composición química de los dientes. Las piezas dentales de todos los animales, incluido el ser humano, están formadas por bioapatita, un mineral producido por fenómenos biológicos, mientras que el esmalte dental está formado principalmente por fluoroapatita (Ca5(PO4)3F). La presencia de este mineral provoca la formación de microtrazas de desgaste similares a las de los minerales en cualquier materia prima lítica. Al mismo tiempo, pudimos comprobar que los dientes utilizados como herramientas son eficientes para trabajar diferentes materiales y con diversas cinemáticas. Esta observación confirma la eficacia de los dientes tal y como se informa en los registros etnográficos.

En consecuencia, creemos que es posible desarrollar análisis funcional sobre dientes de diferentes especies animales, y que estos análisis contribuirán a nuestro conocimiento sobre las formas de vida de las sociedades pasadas.

Palabras clave: instrumentos; diente; castor; capibara; rastros de uso