Small toothmarks on *Talpa* cf. *T. europaea* humerus have been identified during the taphonomical study of the micromammal remains found in Sima del Elefante site (Sierra de Atapuerca, Burgos). Toothmarks have been compared to *Mustela nivalis* modern molars and to *Mustela palerminea* and *Beremendia fissidens* fossil remains in order to identify the predator producing the marks. The results indicate that marks were produced by a smaller predator than *Mustela*, and resemble more to those produced by *B. fissidens*. This insectivorous species is smaller than *Talpa* and has a poison injector apparatus that allows it to hunt preys which double its own size. Ethological characteristics of predators and *B. fissidens* physical features seem to point to this insectivore as the agent responsible for the *Talpa* humerus toothmarks at Sima del Elefante TE9 level.

**Keywords**: SIMA DEL ELEFANTE, ATAPUERCA, TOOTHMARKS, TALPA CF. T. EUROPAEA, MUSTELA PALERMINEA, MUSTELA NIVALIS, BEREMENDIA FISSIDENS

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Introduction

Micromammal fossil remains, particularly rodents and insectivores, have been conventionally used by Paleontology as chronological and paleoecological indicators at the strata where they have been preserved. This is due to their great adaptability to environmental changes, rapid reproduction cycle, specialization degree and, especially, their abundance in the deposits (Andrews, 1983, 1990; Fernández-Jalvo & Andrews, 1992; Denys et al., 1995; Fernández-Jalvo, 1996; Denys et al., 1997; Cuenca-Bescós et al., 1999).

Taphonomical analyses are necessary to fully understand the paleoecological and evolutionary significance of these remains at the archaeo-paleontological sites, despite the chronological range studied. In this sense, we have carried out a complete study on the formation of these vertebrate accumulations and their evolution in the stratigraphic sequences at the Sierra de Atapuerca sites (Bennàsar, in prep.).

Micromammals accumulation in archaeo-paleontological sites is mainly originated by allochthonous causes: the ingestion, digestion and deposition from predators (Mellet, 1974; Mayhew, 1977; Korth, 1979; Andrews, 1983, 1990; Denys et al., 1995, 1997; Andrews & Nesbit-Evans, 1983). The main micromammals predators are birds of prey and small carnivores.

Predators and preys occupy similar or nearby habitats. However, there are opportunistic predators that hunt a wide variety of preys in different habitats, showing in their accumulations a high diversity of preys. On the other hand, selective predators hunt a smaller range of preys in delimited habitats, which means low diversity of preys concentration. In this sense, micromammal assemblages may depend on the predator-accumulator agent. Thus, taphonomical analyses are necessary to fully understand the biases produced by the accumulator agent and to correctly interpret the paleoecological significance of micromammals (Denys, 1985; Denys et al., 1997; Andrews, 1990; Fernández-Jalvo & Andrews, 1992).

Andrews (1990) developed a classification method based on the degree of modification produced by predators in their preys. According to this method, the accumulations at Sima del Elefante are mainly produced by the predators category 1 or 2 (Bennàsar, in prep.). Nevertheless, we have identified a toothmark in the micromammal remains that does not correspond to the birds of prey that use to produce those modifications.

The aim of this study is to analyze the mark, by observing the typology, measures and the situation of the toothmarks in the fossil studied, in order to identify the agent-predator causing the alteration.

Geographical and chronological setting

Sierra de Atapuerca is a small hill located about 0°10′E and 42°20′N, near Burgos, northern Spain (Figure 1). The hill is formed by Cretaceous limestone that allows the development of karst complex at the Miocene (Parés & Pérez-González, 1995, 1999). The works on a trench-rail at the west slope of the hill have uncovered various cavities, including the Sima del Elefante, some of them filled up by sediments whose chronology range from 1.5 mya to 200 kya (Falguères et al., 2001).
Sima del Elefante site is a cave of 18 m depth. Sedimentary infilling of the cave can be divided into 3 phases and 16 lithostratigraphic units (Figure 2). Sedimentary phase I (TE7-TE14) has allochthonous origin dipping to the North. Level TE9 is formed by plastic clay matrix supporting debris and pebbles, showing a high slope gradient (Rosas et al., 2001, 2004, 2006; Huguet, 2007). Level TE9 is dated between 1.2-1.1 myr based on biostratigraphy, palaeomagnetism and radiactive decay of cosmogenic $^{26}$Al and $^{10}$Be analysis (Rosas et al., 2001; Cuenca-Bescós & Rofes, 2004; Parés et al., 2006; Carbonell et al., 2008; García et al., 2008).

Level TE9 is rich in bird remains and both small and large mammal remains (Table 1). In addition, human presence at the site has been detected through the stone-tool assemblage formed by 32 artefacts, anthropogenic alterations on large mammal bones (cut marks and percussion marks), and the recent discovery of a hominin mandible, assigned provisionally to *Homo antecessor* (Carbonell et al., 2008).

**Methods and materials**

The recovery process of microfossils begins with the washing of the whole sediment coming from the excavation. Washing is done with three sieves of different wire netting superimposed (10 mm, 5 mm and 0.5 mm). Once the resulting concentrate of washing has been dried is sorted. Finally, each one of the remains is analyzed through a binocular magnifying glass (OPTECH SL Dual 6,5x-60x).
**Toothmarks on micromammals**

**Small mammals**  
(Cuenca-Bescós & García, 2007)  

- Beremendia fissidens  
- Asoriculus gibberodon  
- Crocidura aff. C. kornfeldi  
- Erinaceus cf. E. europaeus  
- Talpa cf. T. europaea  
- Desmaninae indet.  
- Sorex sp.  
- Crocidura cf. C. russula  
- Allaphaiomys lavocati  
- Allaphaiomys nutiensis  
- Allaphaiomys burgondiae  
- Pliomys cf. P. Simplicior  
- Ungaromys sp.  
- Arvicolidae nov.gen.nov.esp.  
- Castillomys rivas  
- Soricidae sp.  
- Elioemyx quercinus  
- Castor fiber  
- Myoictis sp.  
- Rhinolophus sp.  
- Oryctolagus cf. O. lacosti  
- Lepus cf. L. terraerubrae

**Large mammals**  
(Made, J. van der et al., 2003; Rosas et al., 2001, 2004, 2006; Cuenca-Bescós & García, 2007; Huguet, 2007; Carbonell et al., 2008)  

- Homo antecessor  
- Macaca indet  
- Canis sp. (C. arvensis/mosbachensis)  
- Lynx cf. L. issiodorensis  
- Pannonictis nestii  
- Baranogale cf. B. antiqua  
- Lynx sp.  
- Mustela cf. M. palermina  
- Panthera gombaszoogensis  
- Cervidae indet.  
- Dama “nestii” vallonnetensis  
- Equus cf. E. stenonis  
- Eucladoceros giulii  
- Bovidae indet.  
- Bison sp.  
- Suidae indet.

**Birds**  
(Sánchez Marco, 1999, 2004)  

- Haliaeetus albicilla  
- Perdix palaeoperdix  
- Columba livia/oenas  
- Acanthis chloris  
- Corvus antoceras

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**Table 1. List of fauna found in Sima del Elefante level TE9.**

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Reference</th>
<th>Maximal and minimal diameter</th>
<th>dist.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>M. palermina</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>TE11 n10 (n=1)</td>
<td>x x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>TE9a K31 590-600 (n=1)</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td><strong>M. nivalis</strong></td>
<td>Actual (IPHES collection)</td>
<td>n=2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TE9a J30 630-640 (n=3)</td>
<td>x</td>
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<tr>
<td></td>
<td>TE9a K31 590-600 (n=2)</td>
<td>x</td>
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<tr>
<td></td>
<td>TE9a L30 580-590 (n=2)</td>
<td>x</td>
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<td></td>
<td>TE9b L30 650-660 (n=1)</td>
<td>x</td>
<td></td>
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<td></td>
<td>TE9b K29 620-630 (n=1)</td>
<td>x</td>
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<tr>
<td></td>
<td>TE9e K31 1340-1350 (n=4)</td>
<td>x</td>
<td>x</td>
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<td></td>
<td>TE9e K/L31 1330-1340 (n=3)</td>
<td>x</td>
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<tr>
<td></td>
<td>TE9e L29 1290-1300 (n=3)</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TE9e L29-31 1280-1290 (n=1)</td>
<td>x</td>
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</tbody>
</table>

**Table 2. Fossil remains and present-day specimens measured for this study. Symbols: a, b, c, d, e and dist. = Cusps measured (see Fig. 4); n = Number of specimens measured; x = Measured.**
Some remains can be washed thoroughly in an ultrasonic cleaner with 10 ml demineralized water and 0.2 ml phosphate-free neutral liquid soap (DERQUIM LM 02).

For a detailed observation of the bones, we used Environmental Scanning Electron Microscope (ESEM), model FEI Quanta 600, in low vacuum conditions. Using the ESEM allows to avoid the metallization of the sample. All high-resolution images were taken by applying high voltage (15 or 20 kV) to secondary electron large field detector.

Taphonomical analysis of micromammal assemblages has been based on Andrews’s method (Andrews, 1990). This method focuses mainly on skeletal element representation, fossil breakage and digestion degree. The combination of these three variants provides differential patterns series that make possible to identify the predator responsible of the accumulation.

Currently 6,992 microvertebrate remains have been analyzed at TE9. Out of them, 4.5% of remains of TE9 correspond to *Talpa* cf. *T. europaea*. Among these remains we have found one left humerus showing a physical alteration on the bone surface. The location of alteration and its morphology indicate that it is a toothmark (Figure 3). This toothmark has been studied using the methodological approach proposed by Andrews and Fernández-Jalvo (1997), in which the toothmark types, the location in the bone and the type of bone tissue are considered.

The small size of bone and the depressions, the short distance between them and their position point to a small-sized predator and, therefore, with scarce capacity to produce fractures. The possible small predators present at TE9 with these features are *Mustela palerminea* and *Beremendia fissidens* (Cuenca-Bescós & Rofes, 2004; Rofes & Cuenca-Bescós, 2009). In order to assign the agent of this toothmark, we have measured fossil remains of *M. palerminea* and *B. fissidens* from Sima del Elefante. Due to the bias of the mustelid fossil record, we have measured current specimens of *M. nivalis* (Figure 4 and Table 2). *M. palerminea* is a close relative to *M. nivalis*, but larger than its current representative (García & Arsuaga, 1999). Measure of *M. palerminea* M1 is small. We believe that this specimen is not representative of *M. palerminea* sample, so this measure is not included.

**Results**

The toothmark is formed by five depressions in the cranial side and one depression in the caudal side. These depressions, with defined edges, have a circular or oval morphology. Some of them show cortical tissue collapsed inside the depression (Figure 5). There are neither traces of digestion nor other alterations on the fossil. This alteration is included in the type G, described as molar puncture prints made by multicuspid teeth (Andrews & Fernández-Jalvo, 1997; Diez et al., 1999). Toothmark diameters and distances
Toothmarks on micromammals

Figure 4. Diagram with the most probable cusps involved in toothmarks. I. *M. palerminea* and *M. nivalis*: a. Canine maximal and minimal diameter; b. M₁ paraconid maximal and minimal diameter; c. M₁ protoconid maximal and minimal diameter; d. P³ paracone maximal and minimal diameter; e. P⁴ paracone maximal and minimal diameter; dist. Distances inter-canine and inter-cusps. II. *B. fissidens*: a. Incisor maximal and minimal diameter; dist. Distances between the incisives and the anteromolar cusps of the same side.

<table>
<thead>
<tr>
<th></th>
<th>Maximal</th>
<th>Minimal</th>
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<th>1-3</th>
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<th>1-5</th>
<th>2-3</th>
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<td>2</td>
<td>1.21</td>
<td>1.02</td>
<td>3.43</td>
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<td>3</td>
<td>1.13</td>
<td>1.05</td>
<td>3.32</td>
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<td>4</td>
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<td>5</td>
<td>0.42</td>
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<td>1.9</td>
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<tr>
<td>6</td>
<td>1.03</td>
<td>0.35</td>
<td>2.37</td>
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Table 3. Maximal and minimal diameter, as well as distances between depressions of *Talpa cf T. europaea humerus* (see Fig. 5). All measures are in millimetres.
Figure 5. Photographs in the ESEM. a. Detail of depressions in the cranial side. b. Detail of the depression. 3: Cortical tissue collapsed inside the depression. c. Detail of the depression 4. d. Detail of the depression 5. e. Detail of the depression 6 in the caudal side (See fig. 3 for the location).
Toothmarks on micromammals

are very small (Table 3). We have compared these data with dimensions and distances of fossil remains and current specimens showing similarity and differences (Figure 6).

The size of the canine of *M. nivalis* is bigger than 1.4 mm, in maximal and minimal diameter, whereas the depressions of *Talpa* do not exceed 1.2 mm. In contrast, the diameters of P₄ paracone and M₁ protoconid cusps are included in the range of the humerus depressions. Dimensions obtained for *B. fissidens* incisors range from 0.3 to 1.35 mm. This range includes the greatest depressions measures in the *Talpa* humerus studied (Figure 6a).

In figure 6b it can be observed that the intercanine distance of *M. nivalis* surpasses 5 mm and P₄ and P₂ paracones distance is about 3.50 mm. However, the distance between M₁ protoconid and paraconid varies from 2.35 mm to 3.94 mm, corresponding with the distance observed between the depressions 1-5 and 2-4 of *Talpa*. Nevertheless, the distance between the depressions 1 and 2 of the studied humerus is 1.89 mm. This measure is lower than those obtained in the three measured distances of *M. nivalis* molars and premolars.

The range obtained for *B. fissidens* incisors and anteromolars is the more suitable with distances between depressions 1-5 and 2-4 of humerus. This likely suggest that *B. fissidens* is the agent that produced the damage on humerus *Talpa*. However, presently this hypothesis has not been possible to confirm yet, due to the absence in the fossil assemblages of *B. fissidens* fused symphysis, and the impossibility to measure the intercusp distances of incisor.

**Discussion**

The toothmark studied is located in the transverse axis, affecting a unique and small humerus portion. No dissolution or other alteration related to the action of salivary enzymes or digestion have been detected.
The data indicate that this mark is the result of a specific and determined action on an exceptional fossil.

Dimensions obtained for the *Talpa* humerus are not conclusive regarding a particular predator, even if we consider that the most likely responsible of the traces is *B. fissidens*. The ethological features of these predators, the disposition and organization of the studied depressions, as well as the absence of other alterations would allow us to exclude the Mustelids.

Current *M. nivalis* is a small mustelid that consume insects, rodents, frogs, etc. It can measure between 165 and 255 mm and, although they present a great sexual dimorphism, male usually do not exceed 120 g (females range between 30 and 55 g). Males are able to hunt larger preys such as hares or rabbits. The mustelid found at Sima del Elefante site, *Mustela cf. M. palerminea*, is the smallest carnivore found at the site, it is still larger than its modern counterpart *M. nivalis* (García & Arsuaga, 1999). Therefore, in TE9 bigger toothmarks would be expected if *M. palerminea* were acting. In addition, Mustelid intervention may result in an intensive damage of the remains, if hunting becomes consumption. Then we could expect more depressions or destruction of edges in the remains.

In contrast, *B. fissidens* is a soricine that weights between 40 and 45 g. This shrew has a poisonous-saliva injector apparatus, comparable to those on modern solenodons and some other shrews, which are their current closest relatives (Cuenca-Bescós & Rofes, 2007; Rofes & Cuenca-Bescós, 2009). Development of a poisonous-saliva injector apparatus in insectivores may be related to the percentage of vertebrates included in their diet, and also the need of facing larger preys than themselves (Dufton, 1992). Poison injection by *B. fissidens*, in addition with the rapidity in the attack, would reduce the energy cost and increase the hunting success.

Diet of large size insectivores mostly consists of invertebrates, but is supplemented by small vertebrates such as rodents, amphibians, reptiles, fish and birds.

Solenodons, with the groove in the second incisor similar to those in *B. fissidens*, approach with quick movements and lengthen the jaw to lift the prey, which is immobilized by toxic saliva (Macdonald, 2006). Short-tailed shrew (*Blarina brevicauda*) is highly voracious and poisonous. It is estimated that these shrew may consume three times their body weight per day, coming up to hunt preys that double its own size. Its saliva, one of the most toxic types, leaves its prey in comatose state, causing the death in small vertebrates like mice and toads (Kita *et al.*, 2004).

Fossil remains show that *B. fissidens* is larger than current soricines. Their jaws through the pointed vertex (Cuenca-Bescós & Rofes, 2007; Rofes & Cuenca-Bescós, 2009).
are robust and have stronger symphysis, which would increase significantly the bite pressure exerted on the preys. Besides, it has a poisonous-saliva injector apparatus highly specialized (Cuenca-Bescós & Rofes, 2007). These characteristics might respond to a hunting adaption to larger preys (Rofes & Cuenca-Bescós, 2007). An insectivore intervention could result in a more precise action to inject the poison in the prey at the capture moment. For this reason, it is possible that the insectivore does not produce any trace of alteration during the consumption.

Conclusions

Dimensions and distances of *B. fissidens* teeth are compatible with mole humerus depressions. The typology and situation of the toothmark on the studied fossil, and the absence of breakage or other toothmarks discard *M. nivalis* and, consequently, *M. palerminea* as the agent producing the alteration. On the other hand, ethological features of *B. fissidens* relatives, their large size comparing with the modern insectivores, their jaws strength, and their poison injector apparatus support the hypothesis that *B. fissidens* would have acted as a predator of “large-preys” like *Talpa*.

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