Small mammals (Didelphimorphia and Rodentia) of the archaeological site Calera (Pampean region, Buenos Aires Province, Argentina): Taphonomic history and Late Holocene environments

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ABSTRACT

Small mammal (Rodentia and Didelphimorphia) remains were recovered from the archaeological site Calera, Pampean region, Buenos Aires Province, Argentina. This site is located in the upper course of the Arroyo Tapalqué, at the western portion of the Tandilia range system. Calera is formed of a series of transgressive features (pits) that were infilled with faunal, lithic, and ceramic materials. The samples studied here are from Pit 2, with radiocarbon dates of 3008 ± 44 BP (bottom), 3005 ± 66 BP (middle) and 2075 ± 44 BP (top). Sigmodontine rodents are diverse, including at least nine species; also recorded were four caviomorph rodents and one didelphid marsupial. Taphonomical analyses suggest that the remains were mainly accumulated by owls and later transported and reworked by water action. The small mammal assemblage of Calera suggests that the environmental conditions at the beginning of the Late Holocene were similar to the present ones, temperate-humid, or perhaps slightly warmer and/or humid. In overall terms, recorded taxa at Calera are indicative of a mosaic of grasslands, flooded terrains and lentic to lotic water bodies. Noteworthy records are those of the sigmodontine rodents *Bibimys* cf. *Bibimys torresi* and *Pseudoryzomys simplex*, both hundreds of kilometers south of their current ranges. The regional extinction of these two mammals over a large area of central-eastern Argentina is perhaps a very recent event, mostly triggered by human impact.

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1. Introduction

Small mammals have a unique potential for yielding information about environmental and climatic change, particularly during Quaternary times (e.g., Avery, 1982; Andrews, 1990; Lister, 1992). However, accurate interpretation is not always an easy job. Theoretical and methodological advances produced during the last four decades have contributed to establish an adequate framework to analyze the small mammals fossil record from a taphonomical perspective (e.g., Dodson, 1973; Korth, 1979; Andrews, 1990; Fernández-Jalvo and Andrews, 1992, 2003; Schmitt and Juell, 1994; Denys et al., 1995; Stahl, 1996; Pardiñas, 1999a,b; Gómez, 2007; Landt, 2007; Lloveras et al., 2008). Owls, small mammal carnivores, humans and water transport are the main agents usually involved in small mammal accumulations in archaeological and paleontological sites (e.g., Andrews, 1990; Semken and Falk, 1991; Fernández-Jalvo and Andrews, 1992; Badgley et al., 1998; Belmaker, 2002;

Weissbrod et al., 2005). Understanding the taphonomic history, unique to each assemblage, can help to improve paleoenvironmental reconstructions (Andrews, 1990; Semken and Falk, 1991; Fernández-Jalvo and Andrews, 1992; Badgley et al., 1998; Pardiñas, 1999a; Belmaker, 2002). Different predators and processes are characterized by distinct signatures (e.g., bone representation and breakage patterns, digestion intensity) and produce different types of small mammal accumulations (Andrews, 1990). For example, generalist species, such as several owls, can produce rich and diverse micromammal assemblages, that reflect accurately the environments from which the fossils originally came (e.g., Avery, 1982; Andrews, 1990). In turn, human-made assemblages are constituted by large, diurnal, usually social or colonial rodents (e.g., Simonetti and Cornejo, 1991; Pardiñas, 1999a,b). At the same time, bone assemblages can be dispersed, destroyed and re-accumulated by post-depositional processes, such as scavenging, hydraulic or aeolian transport and by the action of various soil fauna (e.g., earthworms, ants), thereby contributing to further interpretative ambiguity (Andrews, 1990, 1995; Armour-Chelu and Andrews, 1994; Stahl, 1996; Badgley et al., 1998; Belmaker, 2002; Weissbrod et al., 2005).

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The small mammal fossil record of the Pampean region, in particular for the sigmodontine rodents, is unevenly distributed, both spatially and chronologically (Pardiñas, 1999b). The best represented period correspond to the Late Holocene (last 3500 BP), although with significant differences between regions. For example, northeastern Buenos Aires Province, an area of wetlands, grasslands and forests, is characterized by sites with small sample sizes, low to moderate specific diversity, and chronologies restricted between 1500 and 500 BP (Pardiñas, 1999b,c; Teta et al., 2004). Several samples and sequences are known for the southeastern portion of the Pampas, including rich sigmodontine and didelphid marsupial assemblages for the last 1500 BP (Pardiñas et al., 2010a,b). In overall terms, most of the studied sites are located in or near coastal areas, whereas the vast interior plains are characterized by scarce and widely dispersed micromammalian remains (e.g., Pardiñas, 1991, 1999b). Taphonomical analysis of some of these assemblages reflects that several processes and agents were involved in its genesis, including etho-ecological causes (Pardiñas, 1999b; Teta et al., 2004; Gómez and Messineo, 2007; Gutiérrez and Gómez, 2007; Escosteguy, 2010), predation by owls and small carnivore mammals (Gómez et al., 1999; Pardiñas, 1999b; Gutiérrez and Gómez, 2007; Silveira et al., 2010) and human consumption (Pardiñas, 1999b; Quintana et al., 2002; Acosta and Pafundi, 2005; Quintana, 2005; Escosteguy, 2010; Silveira et al., 2010; Quintana and Mazzanti, 2011). The need for accurate taxonomic identifications is fundamental in the exercise of paleoenvironmental reconstruction (Andrews, 1995). However, species recognition of small and fragmented remains, especially mandibles or isolated teeth, is not an easy task, and in some cases

has been overcome through the recognition of different group sizes as analytical units (e.g., Gutiérrez and Gómez, 2007).

This work presents the study of the bone and dental remains of rodents and marsupials recovered from the archaeological site of Calera (Pampean region, Buenos Aires Province, Argentina), expanding a preliminary analysis conducted by one of the authors (Scheifler, 2010). The primary goal was to determine the origin of this assemblage, identifying the main agents and processes involved in its formation. Secondarily, some paleoenvironmental and biogeographical considerations concerning the taxonomic structure of the studied samples are presented, adding information about the community structure of Late Holocene micromammal assemblages. It is hoped that this information will enable a better understanding of formation processes on a site with unusual characteristics for the Pampean region and the environments in which hunter-gatherers lived during the Late Holocene.

2. Calera site and regional setting

2.1. Calera site

Calera is an open-air archeological site of approximately 15 m², located at the western portion of the Tandilia range system, in the upper course of the Arroyo Tapalqué, ca. 7 km E of the city of Olavarría (36°53′37″S, 60°19′23″W; Fig. 1). The local landscape is a small valley surrounded by low hills (<260 masl) drained by the San Jacinto stream (Fig. 1). This water course is now ca. 500 m of the site and it is the only permanent water source in the area. This site was accidentally found by workers of the company Cementos
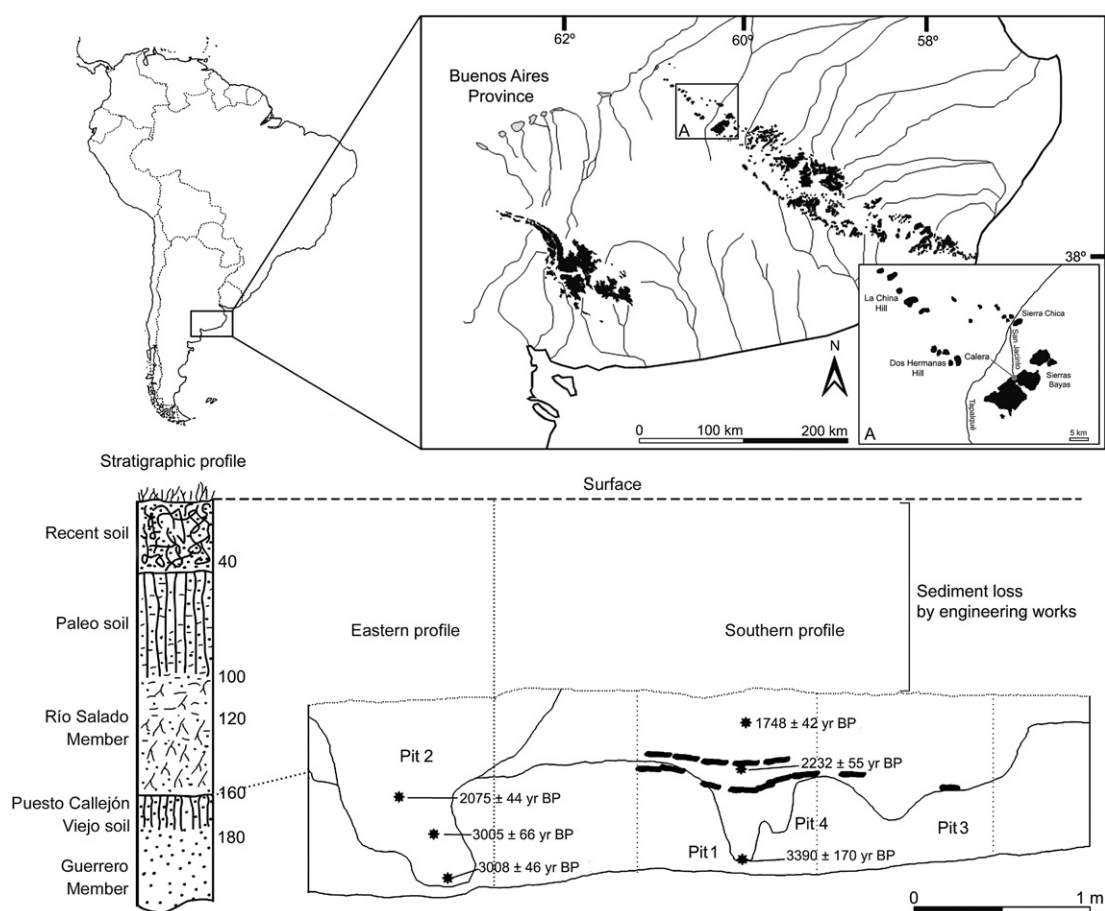

Fig. 1. Geographic location of the archaeological site Calera (Late Holocene, Pampean region, Argentina; above) and schematic stratigraphic profile of the site (below).

Avellaneda S.A. during the construction of a road (Politis et al., 2005).

Four intentionally excavated pits were found in Calera, infilled with a variety of cultural remains. Geoarchaeological data indicate that pits were excavated by humans in sediments referable to the Río Salado (Holocene) and Guerrero (latest Pleistocene) members of the Lujan Formation (Steffan et al., 2005; Fig. 1). Six radiocarbon dates obtained from bone and dental tissues of *Lama guanicoe* (Artiodactyla, Camelidae) indicated Late Holocene chronologies, bracketing the site between 3400 and 1750 BP (Politis et al., 2005). The recovered remains include approximately 6000 lithic artifacts, 310 pottery sherds, a shell bead, 1760 mineral pigment remains, four marine molluscs, several instruments made of guanaco bone and deer antler, an engraved rocky plate, and a phallic cylindrical statuette. In addition, thousands of bone remains were found, corresponding to different species of birds (e.g., *Rhea americana*, *Anas platalea*, *Dendrocygna viduata*, *Rhynchotus rufescens*, *Fulica armillata* and *Theristicus* sp.), fishes (*Synbranchus marmoratus*, *Corydoras* cf. *Corydoras paleatus* and *Pimelodella* sp.) and mammals (*L. guanicoe*, *Ozotocerus bezoarticus*, *Zaedyus pichiy*, *Dasypus hybridus*, *Chaetophractus villosus*, *Lagostomus maximus*, *Myocastor coypus*, *Dusicyon avus*, *Lycalopex gymnocercus*, *Puma concolor*, *Leopardus colocolo* and *Conepatus* sp.; Kaufmann and Álvarez, 2007; Álvarez, 2009). The analysis performed to date indicates a cultural origin of these pits and most of the archaeological remains, suggesting that site was the product of ritual offerings and/or ceremonial trash generated during periods of hunter-gatherer band groupings in the Late Holocene (Politis et al., 2005; Barros and Messineo, 2007; Di Prado et al., 2007; Kaufmann and Álvarez, 2007; Messineo and Politis, 2007; Álvarez, 2009).

2.2. Regional setting

The Pampean region is a huge, open and grassy plain that occupies the central-eastern portion of Argentina, between 30° and 39° S, including the Province of Buenos Aires and parts of the provinces of Córdoba, Entre Ríos, Santa Fe, and La Pampa (Soriano et al., 1992). Its present climate is mesothermal subhumid (Thornthwaite, 1948), characterized by an east-west moisture gradient and increasing continentality toward the northwest (Burgos, 1968). Average temperatures vary between 24 °C (January, NE) and 10 °C (July, NE) to 20 °C (January, SW) and 7 °C (July, SW). Rainfall increases from west to east; the highest precipitation is in the NE (∼1000 mm/y) and the lowest in the SW (<500 mm/y) (Murphy, 2008). Rainfall is equally distributed along the year, although with some tendency to occur in spring, summer, and autumn; interannual variations are large, both in quantity as in monthly distribution, leading to situations of water excess or deficit in the same locality from one year to the other (Vervoorst, 1967). In the upper course of the Arroyo Tapalqué, mean annual temperature is 14.2 °C, varying from 21 °C (January) to 6.9 °C (July); rainfall reaches a mean of 951 mm/y and potential evapotranspiration is around 733 mm/y (Arena et al., 1967; Sallies, 2002, 2006; Barrionuevo and Ceverio, 2004).

Phytogeographically, the upper course of the Arroyo Tapalqué is included within the boundary between the Southern and Flooding Pampa subdivisions of the Pampean region (Soriano et al., 1992). In overall terms, the landscape corresponds to a mosaic of steppes or pseudo steppes of Gramineae, halophilous and psamophilous steppes, and prairies (Cabrera, 1968). Pristine vegetation in this area is usually dominated by the grasses *Stipa neesiana*, *Stipa clarazii*, *Piptochaetium napostaense*, *Piptochaetium lejopodium* and *Poa ligularis* (Soriano et al., 1992). Wetlands, streams and lagoons are usually surrounded by tall and dense hidrophilous vegetation, including "juncales" (= reed) of *Scirpus californicus*, "totorales"

(= reed) of *Typha domingensis* and *Typha latifolia* and sub-shrub communities of *Ludwigia peploides* and *Solanun malacoxylon* (Cabrera, 1968). Dominant species in rocky sites and hills correspond to grasses of the genera *Cortaderia*, *Eryngium* and *Paspalum*; this general Gramineae matrix is intermixed with small patches of low shrubs (2–2.5 m high), such as *Colletia paradoxa*, *Baccharis tandilensis* or *Dodonea viscose* (Cabrera, 1968).

Zoogeographically, Ringuelet (1961) included the Pampean region within the Dominio Pampásico. This author typified the area as a transitional zone between the biotic units Guayano Brasileña and Andino-Patagónica (but see the discussion in Pardiñas et al., 2010b).

3. Materials and methods

3.1. Materials

The small mammal materials analyzed here come from Pit 2, a feature 1 × 0.5 m and 0.9 m deep, with radiocarbon ages of 3008 ± 44 BP (AA-67732) at the base (level 9), 3005 ± 66 BP (AA-71671) at the middle (level 6) and 2075 ± 44 BP (AA-67733) at the top (level 2) (Fig. 1) (Politis et al., 2005). Radiocarbon dates allow identification of two main depositional events within this pit, which were called "Inferior Unit" (IU, thereafter; including the materials from levels 9 to 6) and "Superior Unit" (SU, thereafter; levels 5 to 1). These units are used here in order to discuss the small mammal evidence. The sediments extracted from Pit 2 were washed in the laboratory and bone and dental remains were retained using a mesh of one-millimeter and then separated by manual picking. The studied small mammal materials are deposited in the archeological and paleoantological collection of the INCUAPA (*Investigaciones Arqueológicas y Paleontológicas del Cuaternario Pampeano*), *Facultad de Ciencias Sociales* (FACSO), Olavarría, *Universidad Nacional del Centro de la Provincia de Buenos Aires* (UNCPBA), Argentina, under the acronym FCS.C (*Facultad de Ciencias Sociales. Calera*).

3.2. Methods

The taphonomic approach used here follows the general methodology presented by Andrews (1990) and Fernández-Jalvo and Andrews (1992). The remains were examined microscopically, according to the procedure described by Andrews (1990). Photographs were taken using an USB digital microscope (Dino-Lite Pro Digital Microscope, AM-413T) with variable magnification. Anatomical and taxonomical identifications of cranial and dental remains were made using reference materials housed at the *Colección de Mamíferos del Centro Nacional Patagónico* (Puerto Madryn, Chubut, Argentina), *División Zoología de Vertebrados*, *Sección Mastozoología* of the *Facultad de Ciencias Naturales y Museo* (La Plata, Buenos Aires Province, Argentina), *Laboratorio de Arqueología* of the *Facultad de Ciencias Sociales de Olavarría* (UNCPBA), as well as from references.

Taxonomic structure in the taphonomical context was addressed through the indexes developed by Pardiñas (1999a,b) based on the sizes and habits of the recorded small mammal species. These are the Size index = (MNI small [mammals with head and body <120 mm] + MNI medium [120–170 mm])/(MNI large [170–250 mm] + MNI very large [>250 mm]); the Activity index = (MNI nocturnal species + crepuscular)/(MNI diurnal), and the Predictability index = (MNI colonial + MNI gregarious + MNI grouped)/(MNI cryptic + MNI solitary).

Relative abundances of skeletal parts were quantified through the representation of each element in the sample (MNEi), based upon the expected number of each skeletal element in the

individual (Ei), and the minimum number of individuals (MNI), using the formula: MNEi/(Ei × MNI) × 100 (Andrews, 1990). To evaluate the relationship between cranial and post-cranial elements, two indices proposed by Andrews (1990) were calculated: [(femur + tibia + humerus + radius + ulna) × 16/(mandible + maxilla + molars) × 10] × 100, and [(humerus + femur)/(mandible + maxilla)] × 100. Relative abundances were compared with patterns available for raptors and mammalian carnivores of the Pampean region (Andrews, 1990; Gómez, 2005, 2007; Gómez and Kaufmann, 2007; Montalvo et al., 2007, 2008; Carrera and Fernández, 2010) and against the potential groups of fluvial transport proposed by Korth (1979). The relationship between distal and proximal elements of the limbs was calculated with the index: [(tibia + ulna)/(femur + humerus)] × 100 (Andrews, 1990). Finally, the proportions of individual teeth were evaluated using the formula: [(incisors)/(premaxillary alveoli + mandibular alveoli)] × 100, and [(molars)/(maxillary alveoli + mandibular alveoli)] × 100 (Andrews, 1990).

Two different criteria were followed for analyzing the fragmentation: breakage of cranial and post-cranial elements and teeth, and fracture types in cranial and post-cranial elements. Breakage of cranial and post-cranial bones was analyzed following the categories proposed by Andrews (1990) and Fernández-Jalvo and Andrews (1992). Each category identified was measured by the frequency. Breakage of teeth includes both transverse and longitudinal breaks and assumes only one break per tooth, and was calculated separately for isolated and *in situ* molars and incisors (Fernández-Jalvo and Andrews, 1992). Teeth loss was also considered, both on upper and lower jaws (see Andrews, 1990). Fracture types were classified according to the criteria of Johnson (1985).

Different types of bone surface modifications were recorded, including digestion (Andrews, 1990; Fernández-Jalvo and Andrews, 1992), thermal alteration (David, 1990), weathering (Andrews, 1990), abrasion (Korth, 1979; Fernández-Jalvo and Andrews, 2003), manganese staining (López-González et al., 2006) and root marks (Lyman, 1994). Intensity of digestion was measured by frequency of molars (loose and *in situ*), incisors (loose and *in situ*) and post-cranial bones (humerus and femur) with evidences of digestive corrosion. Categories of digestion (i.e., absent, light, moderate, heavy and extreme) follow the classificatory scheme of Andrews (1990) and Fernández-Jalvo and Andrews (1992). Both intensity and frequencies of each category were compared with available patterns for raptors and mammalian carnivores of the Pampean region (Andrews, 1990; Gómez, 2005, 2007; Gómez and Kaufmann, 2007; Montalvo et al., 2007, 2008; Carrera and Fernández, 2010). Abrasion, manganese staining and root marks were noted as presence vs. absence. Paleoenvironmental reconstruction was based on comparisons between archaeological and recent micromammal assemblages produced by owl predation and trapping data (see Pardiñas, 1999b; Leveau et al., 2004; Teta et al., 2010).

4. Results

4.1. Taxonomic structure

The Calera sequence (i.e., both units IU and SU) is characterized by high frequencies (>10% of MNI) of the caviomorph *Ctenomys* sp. and the sigmodontine rodents *Akodon azarae*, *Holochilus brasiliensis*, *Necromys* spp., and *Reithrodon auritus* and moderate values (2–9%) of the cavies *Cavia aperea* and *Galea* sp. and the mice *Bibimys* cf. *Bibimys torresi*, *Oligoryzomys flavecens*, and *Oxymycterus rufus* (Fig. 2; Table 1). Other taxa were recorded in much lower proportion (<2%), such as the vizcacha *L. maximus*, the didelphid marsupial *Monodelphis dimidiata* and the sigmodontine

Pseudoryzomys simplex and *Calomys* sp. (Fig. 2; Table 1). Relative frequencies for each taxon between IU and US were remarkably similar (Table 1), although *Calomys* sp. was registered only in IU. Size index was 1.8 for IU and 1.6 for SU, reflecting an elevated proportion of small to medium-sized mammals. Activity index was low both in IU (0.3) and SU (0.5), indicating that most of the identified taxa have nocturnal or crepuscular habits. Finally, Predictability index was also low (IU = 0.5; SU = 0.4), suggesting that the assemblages were dominated by cryptic and/or solitary species.

4.2. Bone representation

Relative abundances of skeletal element of both assemblages are detailed in Table 2. Isolated incisors were the most frequent elements both in IU and SU, reaching values of 90.3% and 87.3% in IU and SU, respectively. The second place was taken by isolated molars (IU = 43.2%; SU = 37.7%) and femora (IU = 37.7%; SU = 33.1%). Other elements reached values below 30%. These patterns are different from those produced by owls, diurnal raptors and/or mammalian carnivores of the Pampean region (Fig. 3). However, there are some similarities with those produced by *P. concolor*. In terms of fluvial action, those bones that are resistant to water transport (Group II, II/III and III; Korth, 1979) were better represented (Fig. 4) than those that are immediately transported by flotation (Group I and I/II; Korth, 1979).

The values obtained for the indices calculated (post-cranial/cranial, distal/proximal elements and % isolated teeth) are presented in Table 3; those indexes that evaluate the relationship between post-cranial and cranial elements show different results. The index that estimates the relationship between appendicular and cranial elements indicates a better preservation of skull parts. On the other hand, the index that compares the relationship between proximal appendicular elements and mandibles and maxillaries suggests a better representation of the first. The difference between these two indexes reflects the dominance of isolated molars in the studied samples and the low percentage of delicate elements such as maxillae and mandibles. The index that estimates the relationship between distal and proximal elements of the limbs indicates a loss of distal bones. Finally, the index that measures the relative proportion of isolated teeth shows that most of the molars and incisors have been separated from the maxillaries and mandibles. These values are in accordance with the large representation reached by isolated molars and incisors in the site. Teeth are assigned to Korth settling group II/III (Korth, 1979).

4.3. Fragmentation

Table 4 summarizes the presence of cranial, dental and post-cranial breakage. Both samples (IU and SU), including cranial and post-cranial elements, were highly fragmented. No complete skulls were found, and most of the maxillaries have broken or directly lacks zygomatic arches. However, maxillaries with zygomatic arches were best represented in SU. Few complete mandibles were recovered, although with some differences between samples. Breakage of post-cranial elements was also high, a picture better reflected by the low percentage of complete specimens (3–15%). Femur and ulna show a high proportion of proximal epiphysis, while humerus was best represented by distal epiphysis and tibiae by equal proportions of shafts and proximal and distal parts. Teeth loss was high in both assemblages while teeth breakage was low. Cranial and post-cranial bones were affected mostly by modern fractures (IU = 52.2%; SU = 58.3%); while the types irregular (IU = 41.1%; SU = 38.2%) and transversal (IU = 6.7%; SU = 3.5%) were much less frequent.
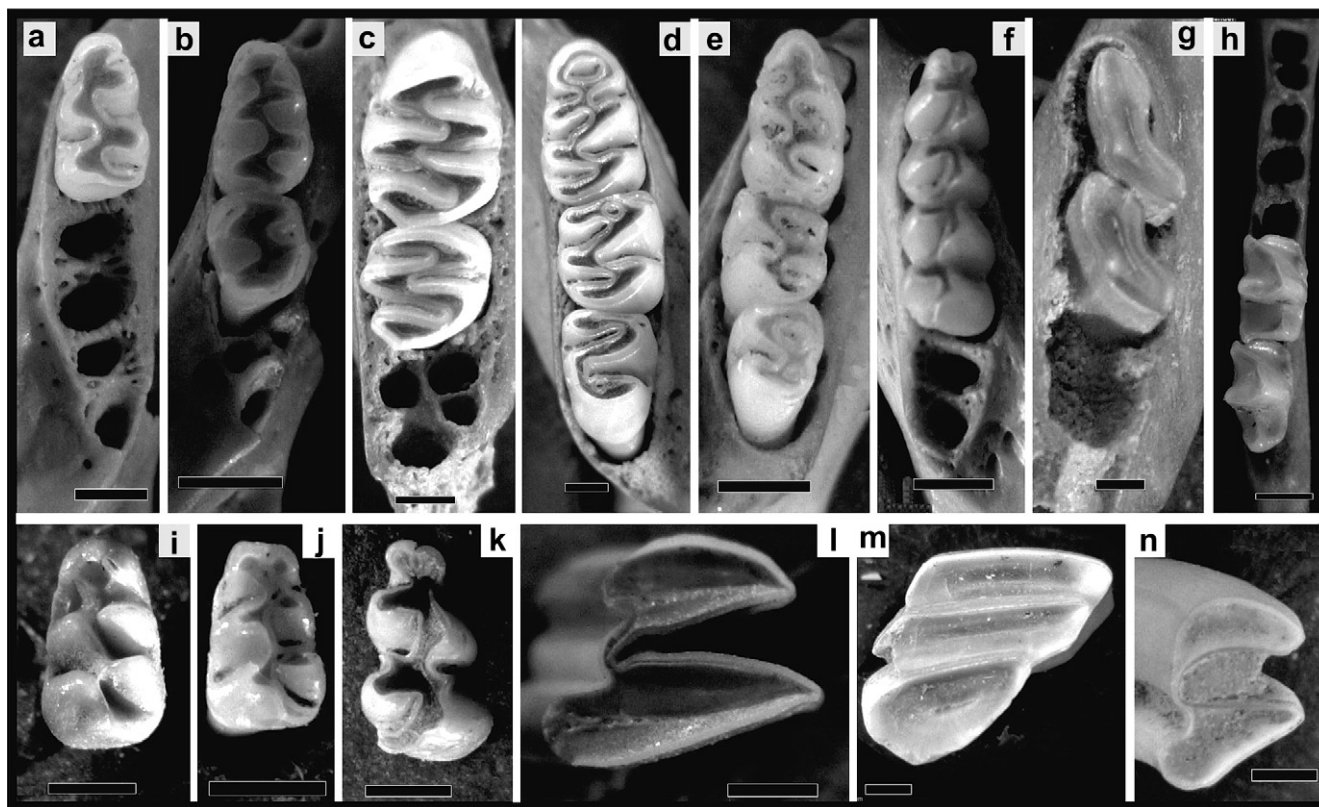
Fig. 2. Upper (M) and lower (m) molar series and isolated molars in occlusal views of micromammals from the Calera archeological site (Late Holocene, Pampean region, Argentina): (a) *Necromys* sp., left mandible with m1 (FCS.C.15006); (b) *Calomys* sp., left mandible with m1-2 (FCS.C.15007); (c) *Reithrodon auritus*, right maxillary with M1-2 (FCS.C.15012); (d) *Holochilus brasiliensis*, right mandible with m1—3 (FCS.C.15170). (e) *Bibimys* cf. *B. torresi*, left mandible with m1—3 (FCS.C.15175); (f) *Akodon azarae*, right mandible with m1-2 (FCS.C.15404); (g) *Ctenomys* sp., left mandible with p4-m1 (FCS.C.15383); (h) *Monodelphis dimidiata*, right mandible with m3-4 (FCS.C.15403). (i) *Pseudoryzomys simplex*, left m1 (FCS.C.16035); (j) *Oligoryzomys flavecens*, left m1 (FCS.C.15760); (k) *Oxymycterus rufus*, right m1 (FCS.C.15337); (l) *Galea* sp., right P1 (FCS.C.15114); (m) *Lagostomus maximus*, left M3 (FCS.C.15231); (n) *Cavia aperea*, right P1 (FCS.C.16682). Scale = 1 mm.

4.4. Bone surface modifications

Corrosive effects of digestion were present both in IU and SU (Fig. 5, Fig. 6 and Table 5). In both assemblages, bone remains with digestion evidence were relatively low; 10—30% in the case of incisors and molars and 20—30% in post-cranial elements. Most of

Table 1

Small mammal assemblages of Calera archeological site (Late Holocene, Pampean region, Argentina). MNI = Minimum Number of Individuals; MNI% = Minimum Number of Individuals expressed as percentage.

	Inferior unit		Superior unit	
	MNI	MNI%	MNI	MNI%
Didelphimorphia				
Didelphidae				
Didelphidae gen et sp. indet.	1	0.9	1	1.5
Monodelphis dimidiata	1	0.9	1	1.5
Rodentia				
Caviidae				
Cavia aperea	4	3.5	5	7.7
Galea sp.	6	5.3	2	3.2
Chinchillidae				
Lagostomus maximus	2	1.8	1	1.5
Ctenomyidae				
Ctenomys sp.	23	20.1	8	12.3
Cricetidae				
Cricetidae gen et sp. indet.	4	3.5	6	9.2
Akodon azarae	12	10.5	6	9.2
Bibimys cf. *B. torresi*	6	5.3	2	3.2
Calomys sp.	1	0.9	0	0
Holochilus brasiliensis	14	12.3	6	9.2
Necromys spp.	20	17.5	13	20
Oligoryzomys flavecens	3	2.6	2	3.2
Oxymycterus rufus	4	3.5	3	4.6
Pseudoryzomys simplex	1	0.9	1	1.5
Reithrodon auritus	12	10.5	8	12.3
Total	114		65	

Table 2

Minimum Number of Element (MNE) and relative abundances of skeletal parts of the small mammals from the Calera archeological site (Late Holocene, Pampean region, Argentina).

|	Inferior unit		Superior unit	
	MNE	Relative abundance	MNE	Relative abundance
Maxilla	31	13.6	24	18.5
Mandible	75	32.9	30	23.1
Isolated Molars	588	43.2	294	37.7
Isolated Incisors	412	90.3	227	87.3
Vertebra	39	1	30	1.3
Scapula	10	4.4	14	10.8
Humerus	58	25.4	32	24.6
Ulna	45	19.7	32	24.6
Radius	8	3.5	14	10.8
Pelvis	52	22.8	28	21.5
Femur	86	37.7	43	33.1
Tibia	29	12.7	14	10.8
Metapodial	53	2.3	43	3.3
Calcaneus	36	15.8	13	10
Astragalus	40	17.5	14	10.8
Ribs	38	1.4	16	1
Total	1587		839	
MNI	114		65	
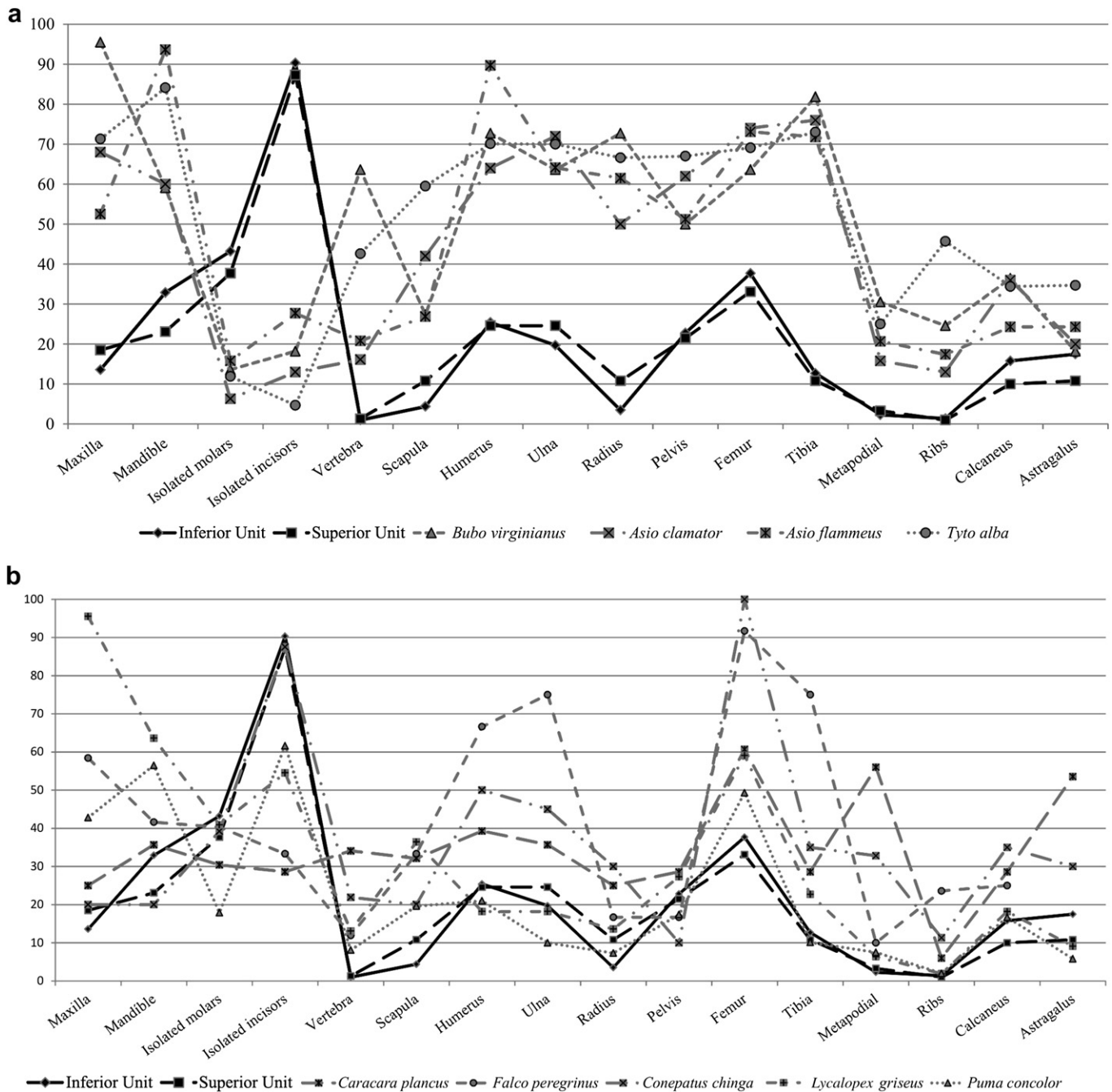
Fig. 3. Skeletal element proportions expressed as proportions of the expected numbers for each element based on the Minimum Number of Individuals, comparing Calera archeological site (Late Holocene, Pampean region, Argentina) and samples produced by owls (a), diurnal raptors and carnivore mammals (b). Data taken from Gómez (2005, 2007; *B. virginianus*, *A. cunicularia*), Carrera and Fernández (2010; *A. clamator*), Andrews (1990; *A. flammeus*, *F. peregrinus*, *T. alba*), Montalvo and Tallade (2009; *C. plancus*), Montalvo et al. (2008; *C. chinga*), Gómez and Kaufmann (2007; *L. griseus*) and Montalvo et al. (2007; *P. concolor*).

these specimens were classified within the absent or light categories of Andrews' (1990) classificatory scheme. In molars, most of the studied elements have their enamel surface slightly corroded, with a wavy appearance; occlusal cusps relatively rounded and, with minor extent, completely disappeared enamel parts (Fig. 6). Heavy and extreme digestion, with only enamel islands remaining, was detected in very few specimens. Most of the analyzed incisors maintain almost intact enamel surfaces, showing slight to moderate pitting. In most cases, the digestion was concentrated at the tip, where the enamel was totally or partially removed (Fig. 6). This situation suggests that the incisors were retained in the jaw during its digestion (Fernández-Jalvo and Andrews, 1992). Isolated molars and incisors were more affected by digestion than those *in situ*, which is related to the major vulnerability to corrosion of isolated teeth compared to those retained in jaws (Andrews, 1990). In most post-cranial bones with digestion evidence, the articular surface shows holes and depressions with rounded edges (Fig. 6). Only in a few cases did digestion affect the shaft. In overall terms, the degree of digestion, with dominance of the categories absent and light, and the percentage of digested specimens (Fig. 5) were broadly coincident with those patterns produced by owls. Assemblages originating from owl pellet deposition are characterized by
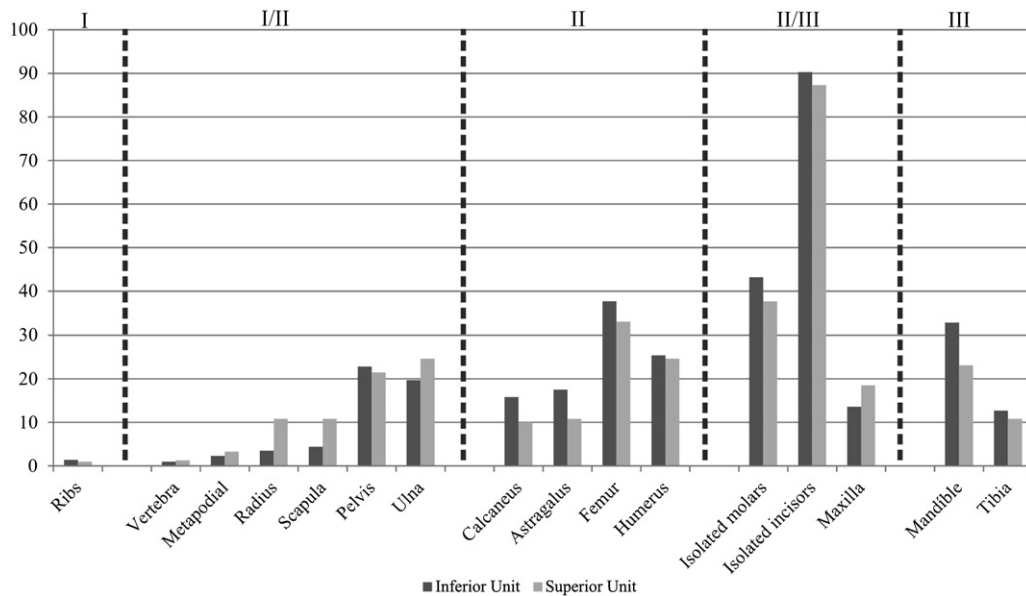
Fig. 4. Skeletal element proportions expressed as proportions of the expected numbers for each element based on Minimum Number of Individuals from Calera archeological site (Late Holocene, Pampean region, Argentina), arranged according to potential groups of hydric displacement established by Korth (1979).

the accumulation of bones with predominance of absent to light degrees of digestion and low levels of the categories moderate, heavy and extreme (e.g., Andrews, 1990; Gómez, 2005; Carrera and Fernández, 2010).

One distal humerus epiphysis and one tibia shaft had several shallow holes of rounded contour. These marks may be referable to the tooth marks of a small mammalian carnivore and/or those produced by beaks and/or talons of raptors (Lloveras et al., 2008; Montalvo and Tallade, 2010).

Weathering was low in both units (category 1; sensu Andrews, 1990), with minimum values of traces such as splitting, cracking, or exfoliation (IU = 1.8%; SU = 7.8%). This situation suggests a rapid incorporation of the materials into the pit. In this context, the slightly higher percentage of weathered bones in SU could be related to longer exposure to atmospheric conditions. Only two specimens present a whitish coloration and a corroded surface, perhaps indicating some kind of chemical alteration by plants or fungi (see Lyman, 1994).

Hydric abrasion was also detected in both units (Table 6). An elevated percentage of specimens (>60%) show polished surfaces and rounded osseous processes. As has been observed in some experimental works, this polish is almost homogeneous in the bone surface (cf. Fernández-Jalvo and Andrews, 2003). Polishing and rounding was also high (>70%) within fossil fracture surfaces, both

Table 3
Values of the indices calculated (post-cranial/cranial, distal/proximal elements, % isolated teeth) for the Calera archeological site (Late Holocene, Pampean region, Argentina).

	Inferior unit	Superior unit
Post-cranial/cranial		
[(femur + tibia + humerus + radius + ulna) × 16/(mandíble + maxilla + molars) × 10] × 100	38.7	47.3
[(humerus + femur)/(mandíble + maxilla)] × 100	135.8	138.9
Distal/proximal elements		
[(tibia + ulna)/(femur + humerus)] × 100	51.4	61.3
% Isolated teeth		
% isolated molars	326.7	367.5
% isolated incisors	597.1	667.6

Table 4
Breakage in cranial, dental, and post-cranial elements of small mammals from Calera archeological site (Late Holocene, Pampean region, Argentina).

|	Inferior unit		Superior unit	
	N	%	N	%
Breakage of skull				
Complete skull	0	0	0	0
Maxillary with zygomatic	7	17.1	11	42.3
Other (without zygomatic arch)	34	82.9	15	57.7
Molars missing from maxillary (%)		52.7		44.4
Incisors missing from maxillary (%)		41.9		37.5
Breakage of mandible				
Complete mandible	25	31.3	3	7.9
Inferior border broken	19	23.7	9	23.7
Other	36	45	26	68.4
Molars missing from mandible (%)		58.2		50
Incisors missing from mandible (%)		74.7		83.3
Breakage of teeth				
Broken molars *in situ*	2	1.9	2	3.7
Broken isolated molars	67	11.4	57	19.4
Broken incisors *in situ*	3	17.6	0	0
Broken isolated incisors	387	72.2	233	77.2
Breakage of post-cranial elements				
Humerus				
Complete	14	14.4	1	2.3
Proximal	13	13.4	6	14
Shaft	12	12.4	4	9.3
Distal	58	59.8	32	74.4
Ulna				
Complete	3	6	1	3
Proximal	45	90	32	97
Shaft	2	4	0	0
Distal	0	0	0	0
Femur				
Complete	16	12.9	3	5.7
Proximal	86	69.4	43	81.1
Shaft	8	6.4	3	5.7
Distal	14	11.3	4	7.5
Tibia				
Complete	8	10	4	12.9
Proximal	17	21.3	7	22.6
Shaft	26	32.5	14	45.2
Distal	29	36.2	6	19.3
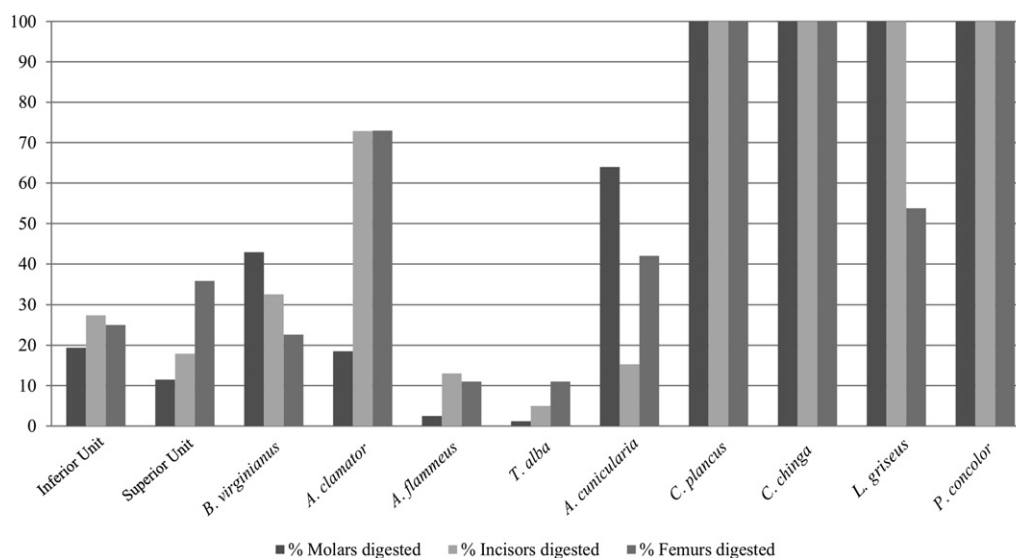
Fig. 5. Digestion levels in small mammal teeth (molars [*in situ* + isolated], incisors [*in situ* + isolated]) and femurs (heads) expressed as percentages in Calera archeological site (Late Holocene, Pampean region, Argentina) and samples produced by owls (*Bubo virginianus*, *Asio clamator*, *Asio flammeus*, *Athene cunicularia*), diurnal raptors (*Caracara plancus*) and carnivore mammals (*Conepatus chinga*, *Lycalopex griseus*, *Puma concolor*). Data taken from Gómez (2005, 2007), Carrera and Fernández (2010), Andrews (1990), Montalvo and Tallade (2009), Montalvo et al. (2008), Gómez and Kaufmann (2007) and Montalvo et al. (2007).

in the irregular and transversal types. This kind of modification can also be caused by gastric action (e.g., Andrews and Evans, 1983; Andrews, 1990; Schmitt and Juell, 1994; Montalvo et al., 2007, 2008). However, a digestive effect is distinguishable because it partially affected the specimens (Fernández-Jalvo and Andrews, 2003). Finally, several mandibles show typical wearing, bone thinning and formation of holes (Fig. 7) that characterized hydric abrasion in experimental samples (Korth, 1979; Fernández-Jalvo and Andrews, 2003).

Manganese staining was present in a few specimens (post-cranial, $n = 2$ [IU]; $n = 1$ [SU], isolated molars, $n = 8$ [IU]; $n = 1$ [SU], and one incisor [SU]). Thermal alteration was low in both assemblages, including post-cranial ($n = 5$ [IU]; $n = 1$ [SU]), isolated molars ($n = 4$ [IU]; $n = 1$ [SU]) and isolated incisors ($n = 1$ [IU]; $n = 3$ [SU]). These specimens have homogeneous grayish to blackish coloration and crackled surfaces, referable to the calcined and carbonized stages, respectively. Species affected by thermal effect correspond to the taxa *H. brasiliensis*, *R. auritus* and *Necromys* spp. in IU and *Ctenomys* sp. in SU. The low proportion of burned remains does not allow discussion of human exploitation in rodents and marsupials recovered from Pit 2 of Calera, as they could have been altered by random and/or natural causes (Stahl, 1996; Pardiñas, 1999a,b). No cut, skinning, or trampling marks were detected.

5. Discussion

5.1. Taphonomic history

Corrosive effects of gastric digestion are present in specimens of all species recovered, suggesting that predator activity was the main cause of death of small mammals of the Calera assemblages. Both in IU and SU, the classes of digestion (absent and light) and the percentage of digested specimens mostly correspond to categories 1 and 2 of Andrews (1990) classification. These categories are represented mostly by owls, which are characterized by the production of bone assemblages with low levels of damage and the predominance of absent to light degrees of digestion (Andrews, 1990; Gómez, 2005, 2007; Carrera and Fernández, 2010; Fig. 5). In addition, the small mammal samples from Calera are dominated

by small to medium, mostly nocturnal, cryptic and solitary taxa. In overall terms, the diet of owls from the Pampean region is mostly focused on nocturnal, solitary, small to medium-sized micro-mammal species, usually <400 g (Pardiñas, 1999a; Bellocq, 2000; Leveau et al., 2004; Pardiñas et al., 2005; Pautasso, 2006; Teta et al., 2006; Isacch et al., 2000; Bó et al., 2007; Gonzales Fischer et al., 2011). At least four species of owls, with generalist and opportunistic trophic habits, are present in the Pampean region, including the barn owl (*Tyto alba*), the stripped owl (*Asio clamator*), the short-eared owl (*Asio flammeus*) and the great horned owl (*Bubo virginianus*). Most of the small mammal species represented at Calera are between 10 and 150 g, a picture broadly coincident with the pattern of predation described for *T. alba*, one of the most common owl species of the Pampean region. However, the percentage of digested specimens is quite high for *T. alba* (Fig. 5). One possibility is that the bones come from a nest of *T. alba*, where juvenile birds produce higher levels of digestion (and broken bones) than do adults (Andrews, 1990). Alternatively, it is possible that the small mammal bone assemblages from Calera come from different species of generalist and opportunistic owls, including *T. alba*, *A. clamator*, *A. flammeus* and/or *B. virginianus*, which exhibit some differences between them in digestion levels (see Fig. 5).

Contrary to the pattern expected from an accumulation produced by owls, Calera assemblages are characterized by low percentages of post-cranial and cranial elements and by a high representation of isolated molars and incisors and broken specimens (Fig. 3, Table 2 and Table 4). Owl accumulations are recognizable by a high proportion of post-cranial and cranial elements, low representations of isolated teeth and high levels of unbroken specimens (Andrews, 1990; Gómez, 2005, 2007; Carrera and Fernández, 2010). However, several post-depositional processes are responsible for this pattern. First, most of the documented fractures are recent, perhaps as the result of the excavation methodologies employed in the field and/or laboratory activities, such as washing and sieving of the sediments. Second, the edges of fossil fractures are mostly polished and rounded, suggesting that part of the bone destruction could be linked to water transport and abrasion. In any case, there is no other modern raptor or mammalian carnivore that produces bone assemblages with low percentages of
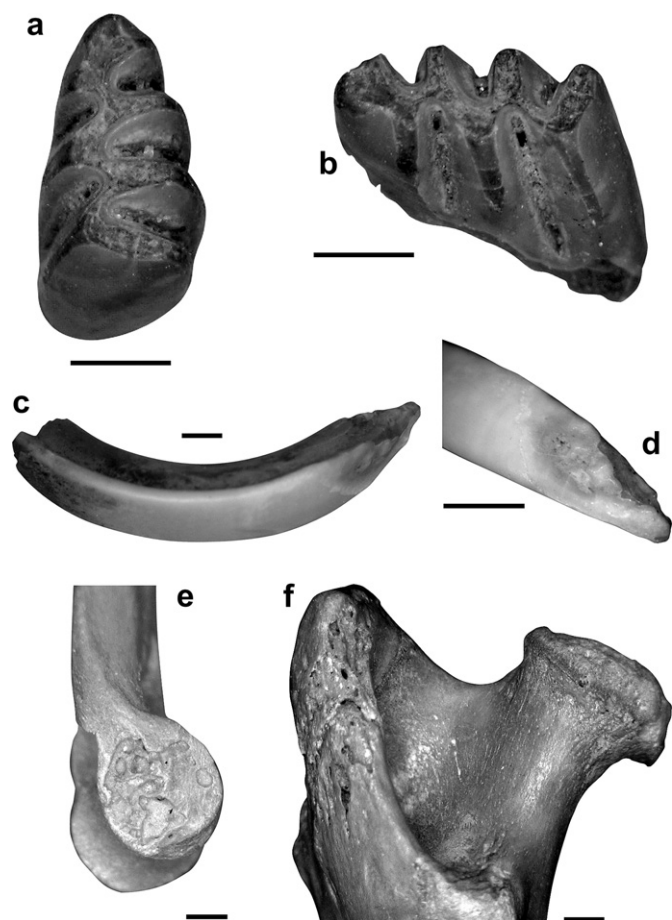
Fig. 6. Bones and teeth from Calera archeological site (Late Holocene, Pampean region, Argentina) showing evidences of digestive corrosion: (a) *Reithrodon auritus*, left m1 (FCS.C.16689) in occlusal view showing removed enamel and exposed dentine along salient angles (moderate digestion); (b) lateral view of the same specimen; (c) upper incisor (FCS.C.17590) in lateral view showing the digestion of the tip; (d) detail of the same specimen in frontal view; (e) distal humerus (FCS.C.15669) showing evidence of light digestion on the lateral epicondyle; (f) proximal femur (FCS.C.16210) showing evidence of light digestion on the greater trochanter. Scales = 1 mm.

post-cranial and cranial elements, a high representation of isolated molars and incisors and broken specimens, coupled with a low intensity of digestion of the absent and light classes, such as those described for Calera. Even when the frequencies of skeletal representation were mostly similar to those produced by *P. concolor*,

Table 5
Representation for digestive corrosion classes in small mammal bones from Calera archeological site (Late Holocene, Pampean region, Argentina).

	Absent		Light		Moderate		Heavy		Extreme	
	N	%	N	%	N	%	N	%	N	%
Inferior Unit										
Molars *in situ*	100	93.5	6	5.6	1	0.9	0	0	0	0
Isolated molars	460	78.2	76	12.9	28	4.8	19	3.2	5	0.9
Incisors *in situ*	15	83.3	3	16.7	0	0	0	0	0	0
Isolated incisors	387	72.2	126	23.5	15	2.9	5	0.9	3	0.5
Proximal femur	39	75	13	25	0	0	0	0	0	0
Distal humerus	39	84.8	6	13	1	2.2	0	0	0	0
Superior Unit										
Molars *in situ*	51	94.4	3	5.6	0	0	0	0	0	0
Isolated molars	257	87.4	27	9.2	5	1.7	1	0.3	4	1.4
Incisors *in situ*	5	100	0	0	0	0	0	0	0	0
Isolated incisors	248	82.1	42	14	8	2.6	4	1.3	0	0
Proximal femur	9	64.3	4	28.7	1	7.1	0	0	0	0
Distal humerus	12	60	8	40	0	0	0	0	0	0

Table 6
Representation of polishment and rounding in small mammal bones (mandibles, maxillaries and post-cranial specimens) from Calera archeological site (Late Holocene, Pampean region, Argentina).

	Polished and/ or rounded		Not polished and rounded	
	N	%	N	%
Inferior Unit				
Bone surface and process	325	68.9	147	31.1
Edges of fractured bones	133	74.7	45	25.3
Superior Unit				
Bone surface and process	162	72.3	62	27.7
Edges of fractured bones	64	77.1	19	22.9

bone assemblages generated by this felid are characterized by much higher levels of digestion (100%), with similar participations of the light, moderate, heavy and extreme classes (Montalvo et al., 2007; Fig. 5).

The comparison with the experimental results published by Korth (1979) indicates that both in IU and SU the best represented specimens were those more resistant to water transport (e.g., isolated molars and incisors), while more movable elements were underrepresented. In this context, it is possible to propose that the incorporation and burial of Calera micromammal assemblages was mainly produced by fluvial deposition and differential transport of bone accumulations primarily produced by owl predation. Thus, while water moved those more easily transportable elements away from the site, those with more resistance to fluvial action were deposited in Pit 2 of the Calera site. This would suggest that water energy was low, unable to carry those bones more resistant to water transport (Korth, 1979; Fernández-Jalvo and Andrews, 2003).

A high proportion of abraded small mammal bones could have two possible explanations, including the sediment type in which the bones were transported and/or long transportation distances (Korth, 1979; Fernández-Jalvo and Andrews, 2003). In this context, Fernández-Jalvo and Andrews (2003) indicate that sandy (as those of Pit 2 of Calera) and gravelly sediments are more abrasive on small mammal bones. On the other hand, fluvial transport for an extended period of time will tend to disperse an assemblage rather than to accumulate it (Hanson, 1980). This would suggest that the distance between the place of primary accumulation and the Calera site was short. Similar scenarios were suggested by Badgley et al. (1998) for the Siwalik deposits (Pakistan) and by Belmaker (2002) for Ubeidiya site (Israel).

Low values of weathering suggest that small mammal bones were not exposed for a long time on the surface before burial. Remains protected within pellet structures are subjected to less weathering prior to the deposition and burial than bones of disintegrated pellet or accumulated from decomposed carcasses (Andrews, 1990; Pardiñas, 1999a,b). Pellets exposed to constant
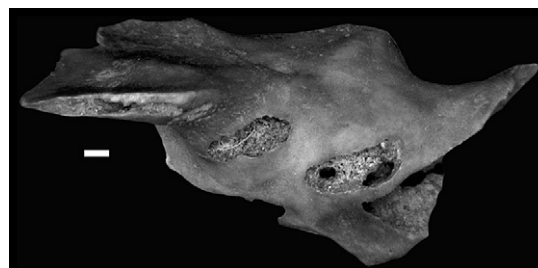

Fig. 7. Right dentary of *Ctenomys* sp. in labial view from Calera archeological site (Late Holocene, Pampean region, Argentina) showing holes at the base of teeth, similar to those produced by hydric abrasion (Korth, 1979; Fernández-Jalvo and Andrews, 2003).

wetting or resting on damp substrate disintegrate rapidly, and their bones are easily dispersed and accumulated in new localities by post-depositional processes such as fluvial transport (Korth, 1979; Stahl, 1996; Fernández-Jalvo and Andrews, 2003). The presence of specimens with manganese staining is suggestive of alternating cycles of oxidation–reduction (Courty et al., 1989), a common process in sites with unstable water bodies (Gómez et al., 1999; Gómez, 2000; López-González et al., 2006; Fernández et al., 2011).

Sedimentological, malacological and taphonomical data reinforces the taphonomic history discussed above (e.g., Álvarez, 2009; Steffan, 2009). For example, gastropods, diatoms, ostracods, and the sandy-loam sediments present in Pit 2 of Calera suggest the development of low energy, fresh water microenvironments that drained to the San Jacinto stream (Steffan, 2009). Desiccation periods are also documented, evident by calcium carbonate deposition in some specimens (Steffan, 2009). At present, the hydrological and geomorphological characteristics of the hilly valleys around Calera, which have gentle slopes and scarcely vegetated runoff surfaces, allow the formation of vast swamp areas, transient lagoons and the temporary accumulation of water in low and shallow places (Steffan, 2009).

Taphonomic analysis suggests that both the IU and SU are similar in taphonomic history, both in genesis (i.e., owls) as well as in post-depositional trajectories (i.e., fluvial transport). The limited differences observed between them (e.g., frequencies of complete mandibles, weathering) are not significant in the overall understanding of the agent and processes that contributed to form the small mammal bone assemblages of this site. Hence, it is assumed that the biases exerted on the two units were almost similar, and that the micromammal taxonomic structure of both IU and SU can be used to infer environmental conditions and to test different paleoenvironmental hypothesis proposed for the Late Holocene of the Pampean region in previous works.

5.2. Paleoenvironments

The small mammal assemblage recorded in Calera is almost composed by species that are still frequent elements of the Pampean mammalian fauna, such as the sigmodontine *A. azarae*, *Calomys* sp., *H. brasiliensis*, *Oligoryzomys flavescens*, *O. rufus* and *R. auritus*, the cavy *C. aperea*, and the didelphid *M. dimidiata*. However, some of these taxa are scarcely represented in the archaeological sample, contrasting with their dominance in recent communities. *Calomys* sp. was represented by only one individual at Calera, while its current participation in micromammalian assemblages of the Pampean region reaches percentages up to 60% or more (Pardiñas, 1999b,c, 2000; Pardiñas et al., 2010a,b; Teta et al., 2010). *Calomys* sp., together with *A. azarae* and *O. flavescens* form the bulk of small mammal species in Pampean agroecosystems (Pardiñas et al., 2010b; Teta et al., 2010). In turn, other marsupial and rodent taxa, such as *M. dimidiata*, *Necromys* spp. or *R. auritus*, have moderate to strongly fragmented distributions, usually restricted to natural grassland patches in cultivate field borders (Pardiñas et al., 2010a,b).

Two sigmodontine species present at Calera, *Bibimys* cf. *B. torresi* and *P. simplex* have their nearest recent records ca. 300 and 720 km north, respectively (Fig. 8). Both species were also found at several coastal paleontological sites of Buenos Aires Province, between 36° and 38° S, and in hilly environments of Tandilia (Pardiñas, 1995, 1999b,c). Originally, Pardiñas (1995, 1999b, 2000) interpreted the extralimital occurrence of these species as indicative of warmer and possibly more seasonally marked climate during the Late Holocene (see also Pardiñas and Tonni, 2000). However, both species inhabit more humid, temperate to subtropical, grasslands in central-eastern (*Bibimys* (Massoia, 1979), Fig. 7) and northeastern
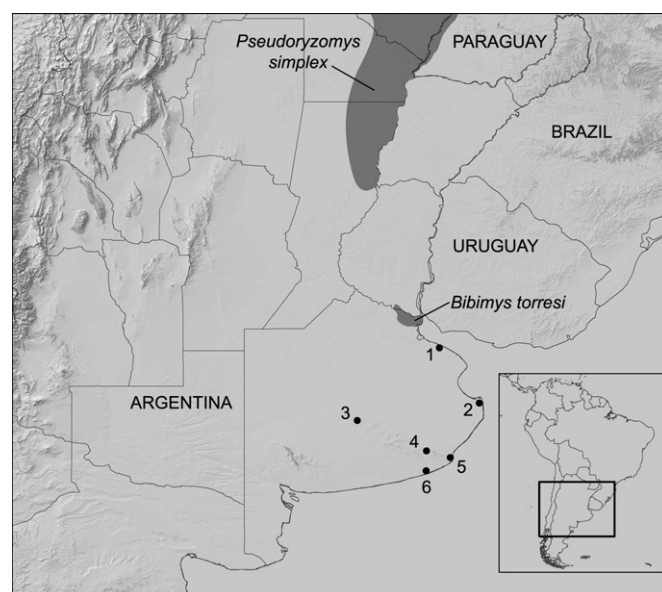

Fig. 8. Recent distribution (shadow areas) and Late Holocene records (black dots) for *Bibimys torresi* and *Pseudoryzomys simplex*. References: 1.- La Higuera (Pardiñas, 1999b [1000–500 BP]), 2.- Divisadero monte 6 (Silveira et al., 2010 [500 BP]), 3.- Calera (this work [3000–2000 BP]), 4.- Cueva Tixi (Pardiñas, 1995 [700-200 BP]), 5.- Balneario Menta (Pardiñas, 1999b [1100 BP]), 6.- Centinela del Mar (Pardiñas, 1999b [500 BP]). Fossil specimens of *Bibimys torresi* were found at the sites 1–6; *Pseudoryzomys simplex* was registered at 2–6.

(*Pseudoryzomys* (Pardiñas et al., 2004), Fig. 8) Argentina. The evidence at hand, including a larger set of Holocene and recent records, suggests that perhaps both species were once typical Pampean elements, at least during the Late Holocene, now regionally extirpated. The record at Calera extended *Bibimys* and *Pseudoryzomys* to 3000 BP.

From an environmental perspective, and taking into account the current habitat requirements of the recorded taxa, the small mammal fauna of Calera suggests a mosaic of open grasslands, flooded terrains and lentic to lotic water bodies. Climatic conditions were similar to the recent ones or perhaps slightly warmer and/or humid. The paleoecological significance of *Reithrodon*, usually considered an indicator of arid to semiarid conditions (e.g., Tonni et al., 1988; Kaufmann and Álvarez, 2007; Bonomo et al., 2009), needs to be reconsidered, as this form is well represented in recent small mammal communities of the southern Pampa (Teta et al., 2010). High abundances of the amphibious rodent *H. brasiliensis* are in agreement with the existence of large areas of flooding grasslands (Pardiñas and Teta, 2011).

The inferred environmental conditions based on small mammals for Calera are basically in accordance with the findings of Steffan (2009). This author studied the molluscan assemblages recovered in this site suggesting lacustrine conditions, perhaps under a more humid climate, for the period between 3000 and 2000 BP. In contrast, Prieto (1996) infer a subhumid-dry climate for most of the last 3000 BP from a pollen profile recovered ca. 15 km SW of Calera (but see Tonello and Prieto (2010), who infer subhumid-humid conditions, similar to the present ones, for this same site). In partial agreement with the data, Bonomo et al. (2009), studying siliceous microfossils (i.e., phytoliths, diatoms, chrysophytes, sponges), microcharcoal remains and the mammalian fauna of a coastal site (38° LS), indicate a warm temperate climate with evidences of dryness and marked seasonality between 3100 and 2700 BP. Some of the mammal evidence highlighted by these authors is debatable: some species traditionally considered as

part of the "Central or Patagonian Domains," such as *R. auritus*, are typical Pampean elements (cf. Teta et al., 2010).

In overall terms, the Calera assemblage is much more rich and diverse than most of the modern local communities at the Pampean region, a picture also shared by other Late Holocene micro-mammalian fossil records (see Pardiñas, 1999b,c, 2000; Pardiñas et al., 2010a,b). The analysis of >100 modern barn owl pellet samples, covering almost all the Pampean region, suggests that the current taxonomic composition of the region, mainly dominated by *Calomys* spp., was achieved during the last centuries as a result of the interplay between human activities and the present climatic conditions (cf. Pardiñas, 1999b,c; Pardiñas et al., 2010a,b). Anthropic disturbances include the extensive use of fire, the conversion of natural grasslands into agroecosystems, cattle grazing, urbanization, and introduction of exotic weeds (Soriano et al., 1992). These changes may have aided both the dispersal as well as the increased present-day abundance of some opportunistic taxa, such as *Calomys* spp. (Pardiñas et al., 2010a,b and references therein). Mostly based on the evidence found at coastal fossil sites, Pardiñas et al. (2010b) suggested that Late Holocene communities of Pampean micromammals, prior to the European impact, were dominated by *A. azarae*, *Necromys* spp., and *R. auritus*, with *Calomys* sp. marginal to the assemblages. The micromammalian record of Calera is broadly coincident with this scenario, suggesting that, with some regional differences, environmental conditions in the interior Pampean plains were similar to those on coastal areas.

6. Conclusions

This paper has discussed the origin and paleoenvironmental significance of the micromammal assemblage recovered at the archaeological site Calera. The recorded marsupial and rodents were firstly predated by owls and later incorporated into the site by differential water transport in one or more events at the beginning of the Late Holocene. Analysis of specific richness and diversity, coupled with the study of >100 modern owl pellet samples, reinforces the hypothesis that recent micromammal communities are mostly the result of the human impact during the last centuries. "Weedy" species, such as *Calomys* spp., capitalized on these changes, with dramatically increasing populations. The climatic signal provided by extralimital forms, especially *Bibimys* and *Pseudoryzomys*, is still difficult to explain: it is believed that their local extirpation from the Pampean region was mostly triggered by anthropogenic disturbances. Finally, this study provides new evidence to understand the development of Late Holocene environments at the Pampean region, and through this, to understand the climate in middle latitudes of southern South America during the last 3000 BP.

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