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ORIGINAL PAPER

Multi-purpose fossils? The reappraisal of an *Elephas antiquus* molar from El Pirulejo (Magdalenian; Córdoba, Spain)

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Abstract Fossil gathering by humans has been rarely documented in the Iberian Peninsula. In the present paper, a multidisciplinary approach has been taken to analyze a straight-tusked elephant (*Elephas antiquus*) molar retrieved in a Magdalenian deposit at the rock shelter of El Pirulejo in southern Spain. The taphonomical analyses revealed a multifarious use of a tooth that had not only been worked into an anvil-sort-of-tool but also used as a core and partly tainted with a composite pigment. The dating and geochemical analyses further evidenced that the molar derived from an animal

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that had lived in a rather arid landscape with a temperature range between 12.3 and 14.3 °C coincident with a cold episode within marine isotope stage (MIS) 6.6 and probably fed on herbaceous plants. These analyses evidence the potential fossils from archaeological sites bear for addressing a wide range of issues that include both the cultural and paleoenvironmental realms.

Keywords Tooth · Taphonomy · U/Th dating · Isotopes · Iberian Peninsula · Upper Paleolithic · Fossil gathering

Introduction

Whether organic or inorganic, items retrieved in archeological deposits have been traditionally pigeonholed into three major categories: evidence of subsistence, tools, and symbolic items. Notwithstanding the validity of such taxonomy, the fact is that setting apart one domain from the other is not always a necessarily straightforward task. In the case of animal remains, for example, subsistence is probably the easiest activity to document. In the case of tool making sensu lato (i.e., including drafts and discarded items), and except for some very obvious instances where modern analogs exist, the assignment of animal remains to this category is based on inferences of behavior often fraught with multiple problems, of which equifinality is not a minor issue. Finally, to identify a remain within the symbolic realm, also taken sensu lato (i.e., including artwork and ornaments), is speculative to no small degree in that more often than not such assignment implies making inferences about extremely complex questions concerning human evolution as are matters dealing with the development of cognitive processes in people long gone.

These three domains are interconnected to such an extent to render an allocation of a given item to a single domain an unrealistic exercise. Likewise, the precise conjunction of domains that a particular item represents is easier to draw in some instances than others. In this way, it is easy to detect that very often remains of animals that had been consumed were later used as raw materials for the confection of tools. Within this context, one should note that transport (in particular long-distance transport) and recycling of raw materials, both lithic and organic, are a practice documented in humans since at least the Middle Pleistocene aiming mostly at the manufacture of artifacts (e.g., Rosell et al. 2015 with references therein, Wei et al. 2015).

Gathering took on a new dimension when collecting went beyond what one considers to be a practical and/or immediate purpose. Such would be the case of gathering exotic objects such as fossils and ornamental rocks, for which no apparent reason other than sheer beauty or pleasure can be postulated. Although such non-parsimonious and often difficult to prove behavior may at times derive from our sheer lack of analogs that could explain the reasons behind such activity, collecting these kinds of objects has been more or less automatically assumed to dwell in the ritual or symbolic realm. Fossil gathering may qualify within this non-utilitarian domain and has been documented since the Middle Pleistocene at places such as Zoukoudian (China: quartz), Gesher Benot Ya'aqov (Israel: bead-like Jurassic crinoids), and Swanscombe (UK: flakes made from fossil coral bearing chert) (Edwards and Clinnick 1980; Goren-Inbar et al. 1991; Oakley 1975). In the more recent Mousterian and Chatelperronian cultures of the European Upper Pleistocene, the archeological record has provided evidences of Neanderthals collecting items such as pigments (Soressi and d'Errico 2007), feathers, and worked shells at sites such as Combe Grenal (France), Riparo Fumane (Italy), Gorham (Gibraltar), Les Fieux (France), or Los Aviones and Antón (Spain), for no apparent "utilitarian" use (Soressi and d'Errico 2007; D'Errico et al. 2010; Morin and Laroulandie 2012; Peresani et al. 2011; Finlayson et al. 2012; Zilhão et al. 2010). The explosion of the evidence, associated with the increasing cognitive abilities of humans, reached its peak with modern *Homo sapiens* (e.g., see Roberts 2015 and references therein).

The problem on whether animal remains represent consumption, tool making, or symbolic behavior is particularly pressing in the case of proboscideans as these animals have been documented to take roles within all three realms (Rabinovich et al. 2012; Boschian and Sacc 2014; Yravedra et al. 2014; Agam and Barkai 2015). Numerous studies have, in this way, highlighted the nutritional role that elephants played during certain moments of the Lower and Middle Paleolithic while others revealed the use of proboscidean remains in bone tool production in Europe since the Middle Paleolithic and in artwork since the Upper Paleolithic (e.g., Agam and Barkai 2015; Gaudzinski et al. 2005; Boschian and Sacc 2014). To discern whether elephant remains also played symbolic roles has been far more difficult to prove as most of the suspected symbolic cases deal with cranial remains, including mandibles, that often constitute major sources of meat (Agam and Barkai 2015).

Ascertaining whether the various roles played by proboscidean remains operated in isolation or in conjunction at a given place and time, and also what were the specific realms involved in each case, has proved extremely elusive. Such matter, in fact, has seldom been addressed from the standpoint of fossils. For those reasons, and in order to deepen our understanding on the significance of isolated elephant remains and the role that their fossils may bear as proxies for past human cognitive development, in this contribution, we present the results of a multi-disciplinary study that has been performed on a Proboscidean tooth fragment recovered at a cave from southern Iberia.

El Pirulejo

The cave of El Pirulejo is located in the town of Priego de Córdoba (Andalusia, Spain), lying 580 m a.s.l. in the Sub-Betic mountain system, at a distance of ~80 km to the shore of the Alborán Sea (westernmost Mediterranean) (Fig. 1). The site was discovered in 1983 during land removal works. The details of the excavations and history of this site have been reviewed by Cortés-Sánchez et al. (2014).

The chronocultural sequence of El Pirulejo is composed of six levels (Cortés-Sánchez et al. 2008, 2014) (Fig. 2) that, from top to bottom, included the following:

1. *Superficial level*. This was formed by heterogeneous deposits and materials of Modern and Contemporary age.
2. *Level P/1*. Funerary structures from the Bronze Age.
3. *Level P/2*. Mediterranean Late Magdalenian.
4. *Level P/3*. Mediterranean Upper Magdalenian.
5. *Level P/4*. Mediterranean Middle Magdalenian. This is the only level with a C^{14}/accelerator mass spectrometry (AMS) dating of 14,250 ± 90 year BP (Poz-21,164, charcoal) that corresponds to a calibrated date of 17, 458 ± 257 year BP.
6. *Levels P/5 and P/6*. Characterized as representing an indeterminate Upper Paleolithic, P/6, given its position between level P/5 and an underlying travertine rock, possibly derived from the Solutrean dated by U/Th to ~19 ky BP (Díaz del Olmo 1995: 25). It should be noted that the travertine that was dated here was not the rock lying at the very base of the sequence, but a portion of the same formation located on the so-called Adarve sector, lying a mere 500 m away from the cave.

Methods

The taxonomic identification, description, and measurement of the elephant tooth followed the criteria of Osborn (1942) and Aguirre (1968, 1969). All measurements are given in millimeters.

Isotopic and elemental analyses were carried out at the laboratories of the *Instituto Andaluz de Ciencias de la Tierra*. A sample of enamel and another one of dentine were extracted for this purpose. Oxygen was analyzed in the phosphate and carbonate fractions of enamel and carbon in the carbonate fraction of enamel and the collagen fraction of dentine (ivory). Nitrogen was analyzed in the collagen fraction of dentine only.

The two internal standards used for phosphates were EEZ-8 (silver phosphate, $\delta^{18}O = 11.1$ ‰) and EEZ-12 (coumarin, $\delta^{18}O = 14.1$ ‰), calibrated by the international standard IAEA-NO-3 ($\delta^{18}O = 25.6$ ‰). The oxygen from phosphates ($\delta^{18}O_p$) was precipitated as Ag_3PO_4 and transformed into CO at 1450 °C by means of pyrolysis (TC/EA) (Vennemann et al. 2002, and references therein). It was later analyzed in a XL Thermo Finnigan Mass Spectrometer with a coupled TC/EA device. The details of the protocol are provided by García-Alix et al. (2012). Results were expressed in δ notation, using the standard mean ocean water (SMOW) for oxygen. Three measurements were taken on each sample and the standards.

Two internal standards were used for carbonates, EEZ-5 ($\delta^{13}C = 1.80$ ‰ and $\delta^{18}O = -18.43$ ‰) and EEZ-1 ($\delta^{13}C = 2.53$ ‰ and $\delta^{18}O = -4.75$ ‰), calibrated by the international standard NBS-19 ($\delta^{13}C = 1.95$ ‰ and $\delta^{18}O = 2.20$ ‰). The oxygen and carbon from carbonates were analyzed using the classic method of McCrea (1950), with the modifications introduced by Koch et al. (1997) to minimize the effect

Fig. 1 Location and partial view of El Pirulejo cave

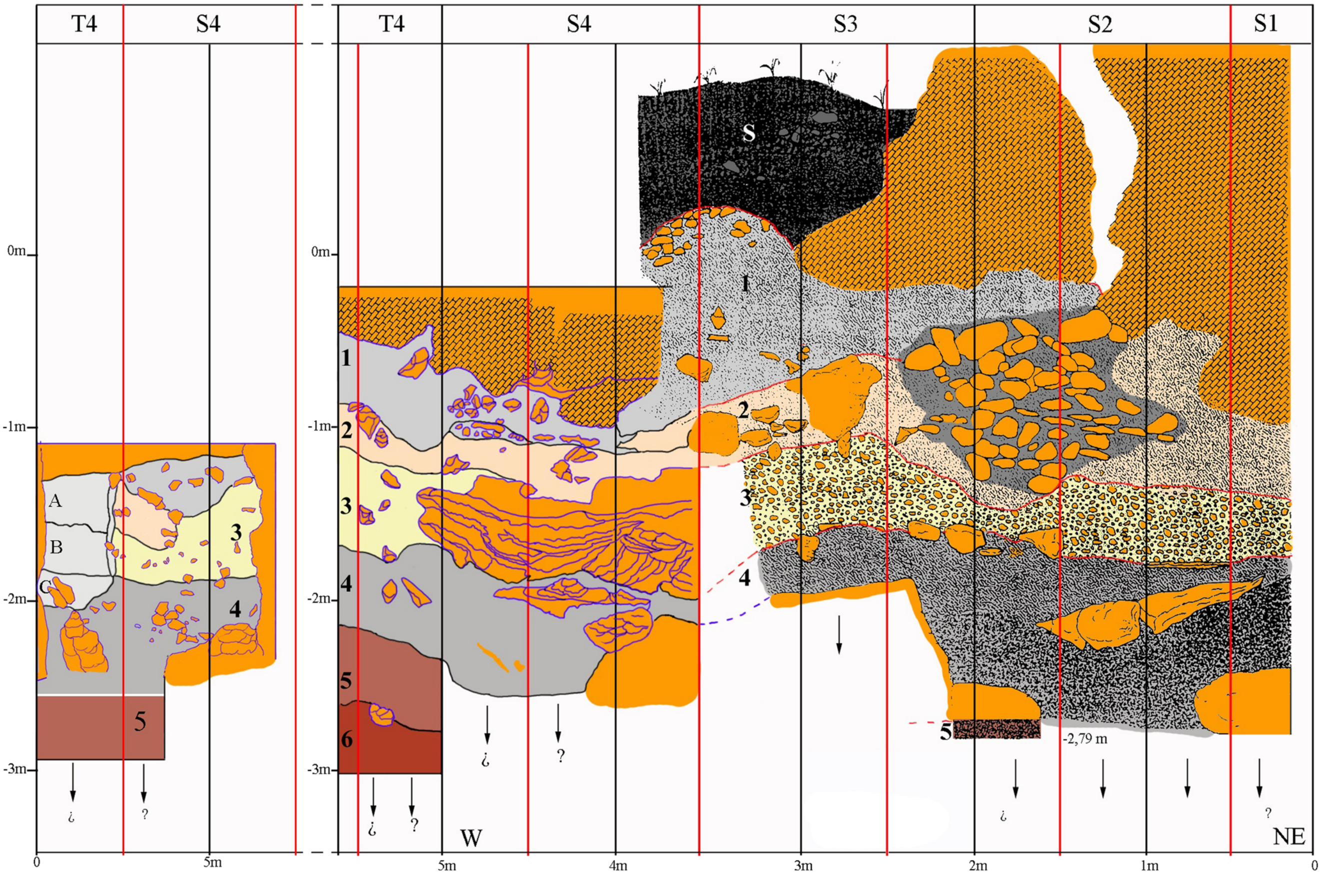


Fig. 2 Stratigraphy of El Pirulejo cave

of the organic matter and the secondary carbonates. Oxygen and carbon were analyzed in a Thermo Finnigan XL mass spectrometer with a coupled Thermo Finnigan Gas Bench II. The results were expressed in δ notation, relative to the pee dee belemnite (PDB) (carbon) and PDB/SMOW (oxygen) standards. Three measurements were taken on each sample.

Three internal standards were used for collagen: UR-05 (urea MERK, $\delta^{13}C = -43.82$ ‰ and $\delta^{15}N = -1.02$ ‰), EEZ-14 (phthalic acid, $\delta^{13}C = -30.63$ ‰), and EEZ-23 (shark cartilage, $\delta^{13}C = -13.27$ ‰ and $\delta^{15}N = 16.01$ ‰), calibrated by the international standards. Collagen extraction followed the protocol provided by Bocherens et al. (1991, 1997). Samples were analyzed in a Thermo Finnigan XL mass spectrometer with a coupled elemental analyzer (EA). Results were expressed in δ notation, using the VPDB (carbon) and N-AIR (nitrogen) standards. Two measurements were taken on each sample and the standards.

In phosphates and carbonates, the estimated precision after correction for mass spectrometer daily drift, and using the standards systematically interspersed in analytical batches, was higher than ±0.1 ‰ in the case of $\delta^{15}N$ and $\delta^{13}C$, and ±0.2 ‰ in the case of $\delta^{18}O$.

The isotopic composition of past meteoric water was estimated from the isotopic composition of the phosphate in the tooth's enamel. This was done following the equation that relates these variables in proboscideans (see Ayliffe et al. 1992).

For U/Th dating, two 0.5-g aliquots were analyzed. Each aliquot was dissolved in diluted nitric acid. After dissolution and filtration, known amounts of ^{232}U and ^{229}Th isotope tracers were added to each aliquot for yield determination. Iron hydroxides, along with dissolved U and Th, were precipitated and separated from the solution. A solvent extraction method, using tributyl-phosphate (TBP) and xilene as the organic phases, was used to separate Th from U, and distilled water later taken to purify the uranium. The Th solution was purified using an anion exchange resin (AG1x8 hydrochloric form) first conditioned in HCl 8 M and afterward in HNO_3 7 M. The purified U and Th solutions were electroplated onto stainless steel disks at 1.2 A during 1 h. Radioactivity of ^{230}Th, ^{232}Th, ^{234}U, and ^{238}U was measured through decay counting in an alpha spectrometer system equipped with PIPS detectors.

In the case of the taphonomic analyses, stigmas on the tooth have been analyzed in order to set apart natural (i.e., non-anthropogenic) traces as well as naturally occurring substances from those evidencing an intentional manipulation of the specimen. In the analysis of traces, both ocular inspection and a WILD MZ5 (X5-X50) stereoscope have been used. In the case of substances, the analysis was performed on a micro-sample of a pigment extracted from the red-colored surface of the elephant tooth. Pigment characterization was carried out by means of a Hitachi S4800 high-resolution (1–3 nm) field emission scanning electron microscope (SEM-FEG), equipped with a 1.33-eV resolution Bruker X Flash 4010 energy-dispersive X-ray (EDX) detector. Fourier transform infrared (FTIR) spectra were obtained using a JASCO FT/IR-6200 IRT-5000 Spectrophotometer. Data were collected by co-adding 32 scans at 4-cm^{-1} resolution. The system was N_2-purged to reduce atmospheric CO_2 and H_2O absorption. FTIR spectra were acquired using the absorbance mode upon pellets of the powdered samples dispersed in KBr. The samples were uniformly ground in an agate mortar with KBr (IR grade), previously degasified at 400 °C. A 13-mm pellet was made using a PerkinElmer holder and a hand press working at 11 t.

The identification of the specimen in terms of the agent responsible for its accumulation followed the taphonomic group criteria described by Gautier (1987).

Results

Description

The proboscidean tooth from El Pirulejo (Fig. 3 and Supplementary material) is a fragment from a molar that weighted 1185 g and was retrieved in level P/2, a Late Magdalenian deposit from the S3 square dated ~14–12.8 ky cal. BP (Cortés-Sánchez et al. 2008). The specimen is now housed at the *Museo Histórico Municipal de Priego de Córdoba* (Spain; inventory code: 2008/44).

The molar preserved five plates corresponding to the central part of the tooth, all of which exhibited marked wearing. The morphology of the enamel loops on the occlusal surface featured clear loxodont sinuses, with the enamel proper being intensively folded. Both traits constitute diagnostic features of the straight-tusked elephant, *Elephas* (*Palaeoloxodon*) *antiquus*. Enamel thickness ranged from 2.3 to 4.5 mm (mean 3.31 mm) (Table 1). The maximum width of the molar

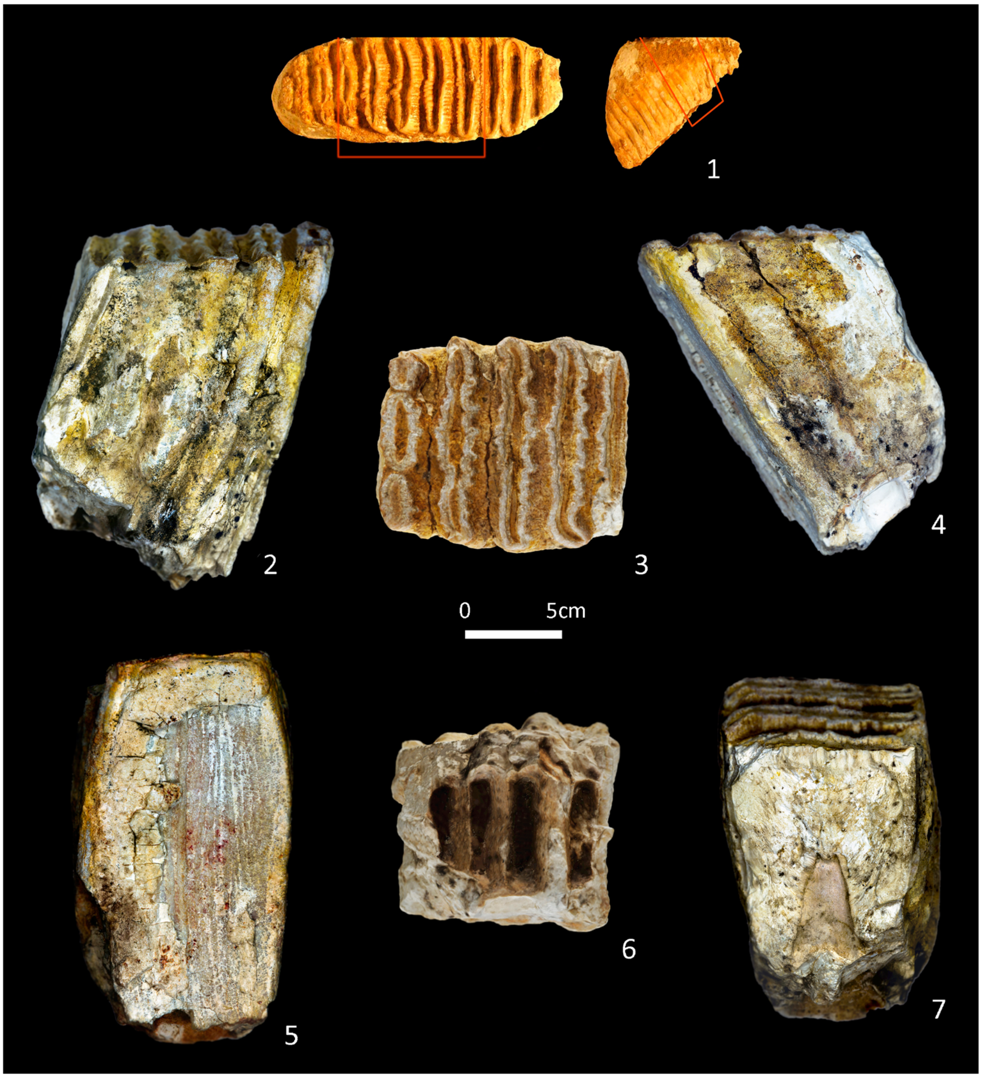


Fig. 3 1 Upper third left molar of straight-tusked elephant *Elephas antiquus*. (*2–7*) M^3 from El Pirulejo cave, (*2*) lingual (buccal) face, (*3*) occlusal face, (*4*) labial (vestibular) face, (*5*) posterior (distal) face, (*6*) apical face, (*7*) anterior (medial) face

Table 1 Enamel thickness measurements of the *Elephas antiquus* molar for the various plates (P)

	1	2	3	4	5	6	7	8	9	10	11	12	13
P1	3.74	4.29	4.28	4.18	4.26	2.84	–	–	–	–	–	–	–
P2	–	–	–	–	–	–	3.42	2.97	–	–	–	–	–
P3	–	–	–	–	–	–	–	–	3.23	3.24	–	–	–
P4	–	–	–	–	–	–	–	–	–	–	3.38	3.64	–
P5	–	–	–	–	–	–	–	–	–	–	–	–	3.27

See Fig. 4 to check where each measurement was taken

(including cementum) was 86.56 mm, whereas its maximum length reached to 91.02 mm (Fig. 4 and Table 1). The plates, obliquely arranged with respect to the occlusal surface, had a maximum height of 152.5 mm. The estimated lamellar frequency was of 4.2. This combination of features revealed the tooth to be an upper third molar (M^3) whose advanced stage of wearing suggested an old individual (i.e., a senile). The asymmetry of the molar in occlusal view indicated that it corresponded to a sinistral (i.e., left) specimen.

Absolute dating

The two U/Th dates provided an average date of 185.15 ± 13 ky BP (1σ, Table 2) for a range of dates set between 198 and 172 ky BP, and evidenced that we were dealing with a specimen from MIS 7.1/6.5 (i.e., Middle Pleistocene, Fig. 5). This date range is well in accordance with the chronological range attributed to the straight-tusked elephant (see the "Paleoenvironmental reconstruction" section). Even though there presently exist no radiometric dates for level P/2, all of the available chrono-cultural data allowed one to safely assign that level to a Late Magdalenian (Cortés-Sánchez et al. 2008). Such assignment was strengthened by the good stratification of the depositional sequence and also by the technological evolution of the three Magdalenian levels at El Pirulejo of which P/2 constituted the latest development. Yet the most compelling evidence of a Magdalenian deposit for P/2 is provided by the 14C/AMS dating of the lowermost Magdalenian level (i.e., P/4, 17.4 ky cal BP; see the "El Pirulejo" section). Given the Magdalenian age of the context in which the tooth was retrieved, the specimen qualified fully as a fossil (i.e., a reworked intrusive, included in group no. 5, sensu Gautier 1987).

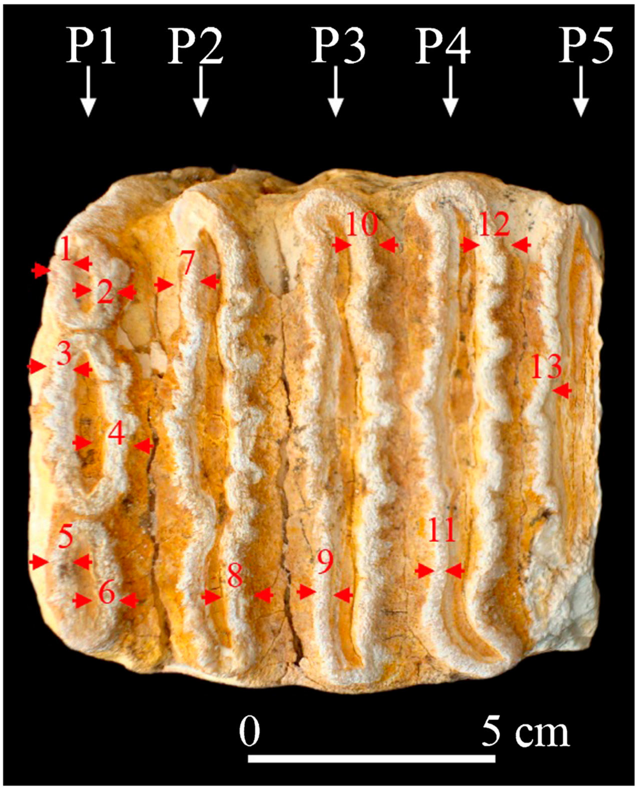


Fig. 4 Occlusal view of the upper third left molar from El Pirulejo cave with indication of the points where enamel thickness measurements have been taken (see Table 1)

Taphonomy and technological analysis

From the taphonomic standpoint, the molar featured a carbonate crust that partly covered its occlusal surface. At the same time, as said, it was fractured on both its anterior (medial) and posterior (distal) ends. Less evident but equally revealing was the fact that the molar lacked most of its roots due to fracturing, leaving the alveoli fully exposed.

The fractures of the anterior and posterior sides were perpendicular to the occlusal surface (Fig. 3, (5) and (7)). Given that the areas in between the plates of elephant molariforms correspond to zones of weakness along which teeth tend to

Table 2 U/Th dating of the molar from El Pirulejo

Sample	U (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	T (ky)(1σ)
Aliquot 1	57.4 ± 1.2	1.722 ± 0.021	0.902 ± 0.029	189.0 ± 13.9
Aliquot 2	54.7 ± 1.0	1.722 ± 0.022	0.885 ± 0.027	181.3 ± 12.1
Average	–	–	–	185.15 ± 13

Uranium concentrations and activity ratios for the two aliquots of the teeth are shown. The errors assigned to the data are 1σ. In the last column, the nominal (EU) ages obtained through the Bateman disequilibrium equation are shown

Fig. 5 Molar of an African elephant *Loxodonta africana cyclotis* evidencing spontaneous crackelling along the weakness planes of the bioapatite crystals due to dehydration, along with a fracturing that may have resulted from that crackelling. One may speculate that it was a natural crackelling of this kind what allowed to wedge open the fossil specimen from El Pirulejo producing the fractures documented in the text (see also Fig. 3; reference specimen from the private collection of one of the authors [AMM])

crack and break off spontaneously (Fig. 6), it was critical to determine whether such had been the case of this specimen or if one could take the fracturing to represent an intentional action (i.e., the result of human manipulation). Two rather compelling pieces of evidence arguing for an intentional fracturing came from the fact that both fracture planes not only were symmetrical (i.e., located at essentially the same distance from the oral and aboral ends of the tooth) but also exhibited an identical coloration which was very different to that of the remaining tooth. This suggested that both fractures had occurred at the same time, a highly improbable event in the case of such a massive element as an elephant molar. The technological analysis further reinforced that interpretation. In this way, it was determined that the breakage of the talons took place by introducing some sort of wedge in the interradicular spaces (cracks?) lying in between the roots (Fig. 3, (5)). By

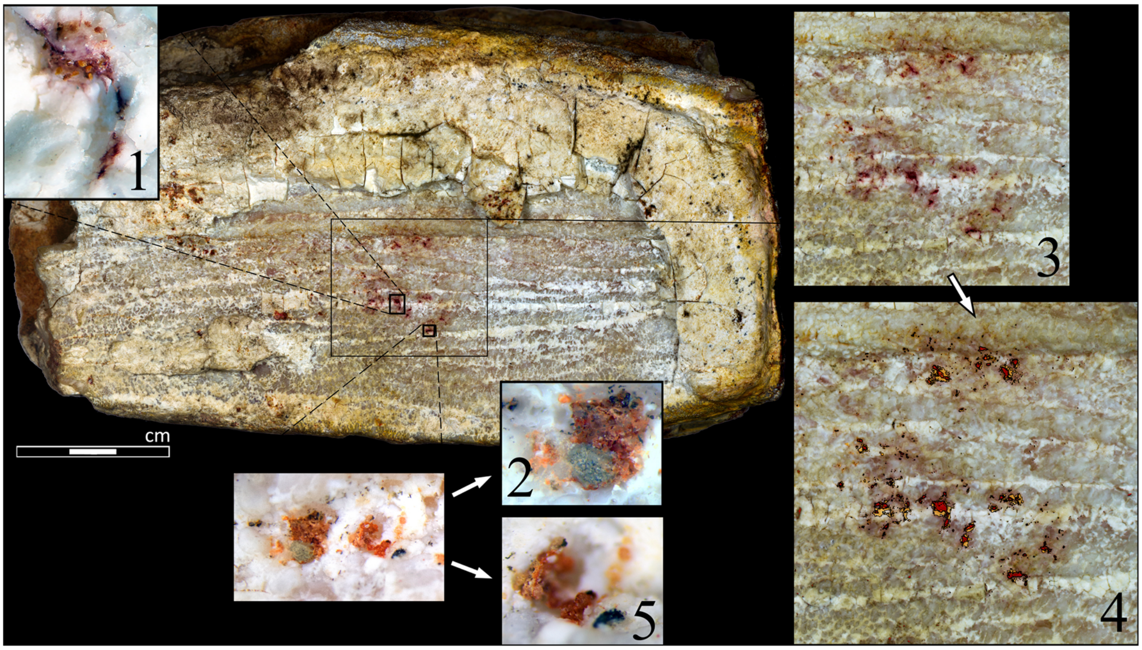


Fig. 6 View of the ochre stain on the posterior (distal) face. (*1–2*) Microphotographs of the ochre; (*3*) close-up view of the ochre speck previous to analysis; (*4*) close-up view of the DIA where the residues of the hematite (*red*) and the clay-like mineral (*yellow*) appear clearly differentiated; (*5*) carbonate crust over the ochre speck

way of indirect percussion and levering movements, the artisan managed to break apart the wall of the tooth leaving exfoliation notches on the impact zones. These (cementum) notches left by the percussions on the extraction surfaces were located just below the occlusal surface and were larger on the posterior face than on the anterior face (compare Figs. 3, (5) and (7)). Lastly, both fracture planes exhibited a series of peculiar striations suggestive of manipulation, and one of the planes also incorporated ochre residues (Fig. 3, (5), and Fig. 7).

EDX elemental analysis using the SEM identified P, Ca, Fe, Si, Al, and O as the main constituents of the residue (Fig. 8). P and Ca were the dominant elements in the sample, a rather unsurprising find given that both are also the main constituents of vertebrate teeth. On the other hand, Si, Al, and Fe reflected the use of some earthy pigment incorporating ferric oxide (i.e., ochre) (Fig. 8).

The infrared spectrum showed prominent bands of hematite at 468 and 560 cm^{-1} and of ferric oxide at 1097 cm^{-1} along with features assigned to calcite and quartz (Bikiaris et al. 2000; Mortimore et al. 2004). EDX analysis revealed the presence of Si and Al that is indicative of clay minerals, along with quartz, as the main silicon-containing ingredients. The infrared spectra (Fig. 9) and the positions of bands listed in Table 3 evidenced that the sample corresponded to a hematite mixed with a clay-like material. This observation would suggest an operation where ochre had been mixed with a binder, with the sample taken being predominantly a clay-like binder with a small amount of hematite. Such hypothesis gains weight through the EDX and FTIR chemical analyses that evidenced the presence of calcium carbonate, quartz, and some kind of clay-like minerals. The only pigment found in these samples was in all cases hematite.

Infrared spectroscopy turned out to be less informative than expected due to the impossibility of spotting features below 450 cm^{-1}, where the most prominent and distinctive bands of hematite occur. Still, the spectrum shown in Fig. 8 revealed strong bands of calcite at 1425 and 870 cm^{-1} as well as a weak band at 711 cm^{-1}. Quartz is responsible for the bands at 1037 and 797 cm^{-1} whereas the broad feature around 1000 cm^{-1} is likely to correspond to silicate minerals (Mortimore et al. 2004).

Calcite was deposited over the pigment as a result of post-depositional processes as can be seen in the microphotographs (Fig. 7, (5)).

It thus seemed likely that hematite was combined here with some clay-like matrix similar to those reported at the Es-Skhul shelter on Mont Carmel (Israel; D'Errico et al. 2010) and Çatalhöyük (Turkey; Mortimore et al. 2004), where iron oxide was mixed homogeneously in a clay matrix. Two additional lines of evidence supported the latter hypothesis: (a) an optical microscopy analysis that clearly evidenced how the stains were indeed from a pigment formed by a combination of red colorant (iron oxide) and a yellowish material (clay-like

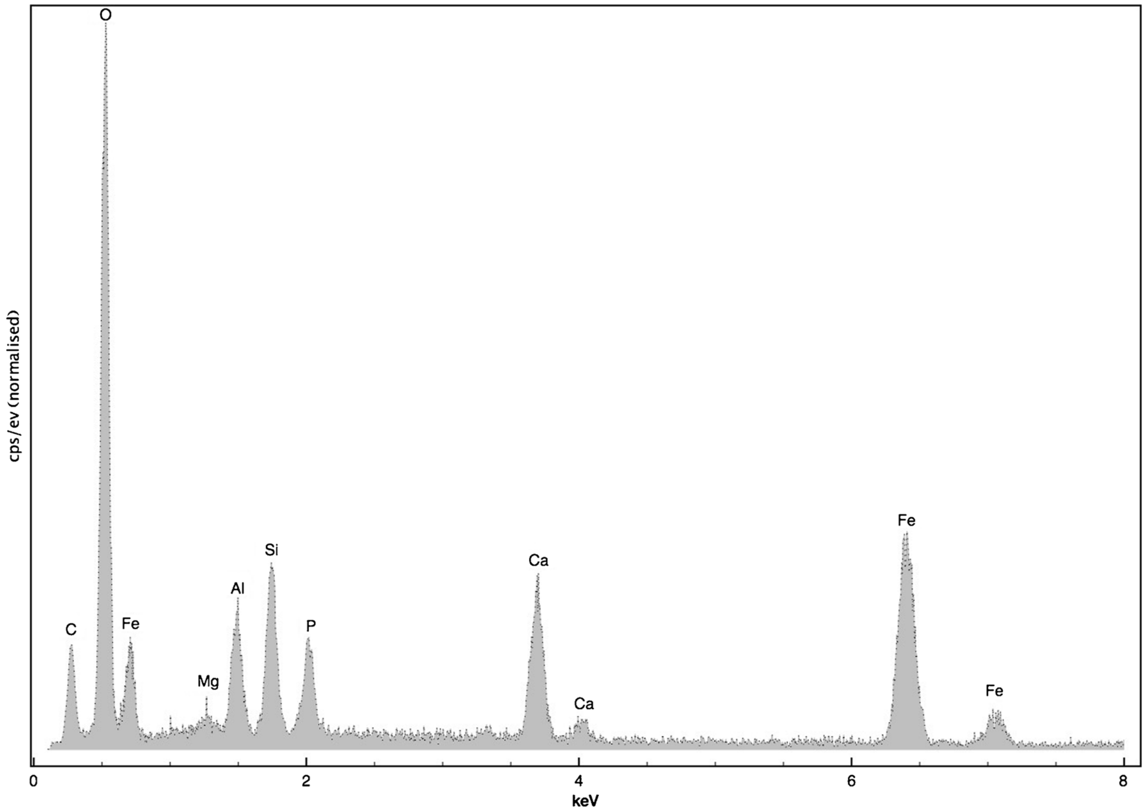
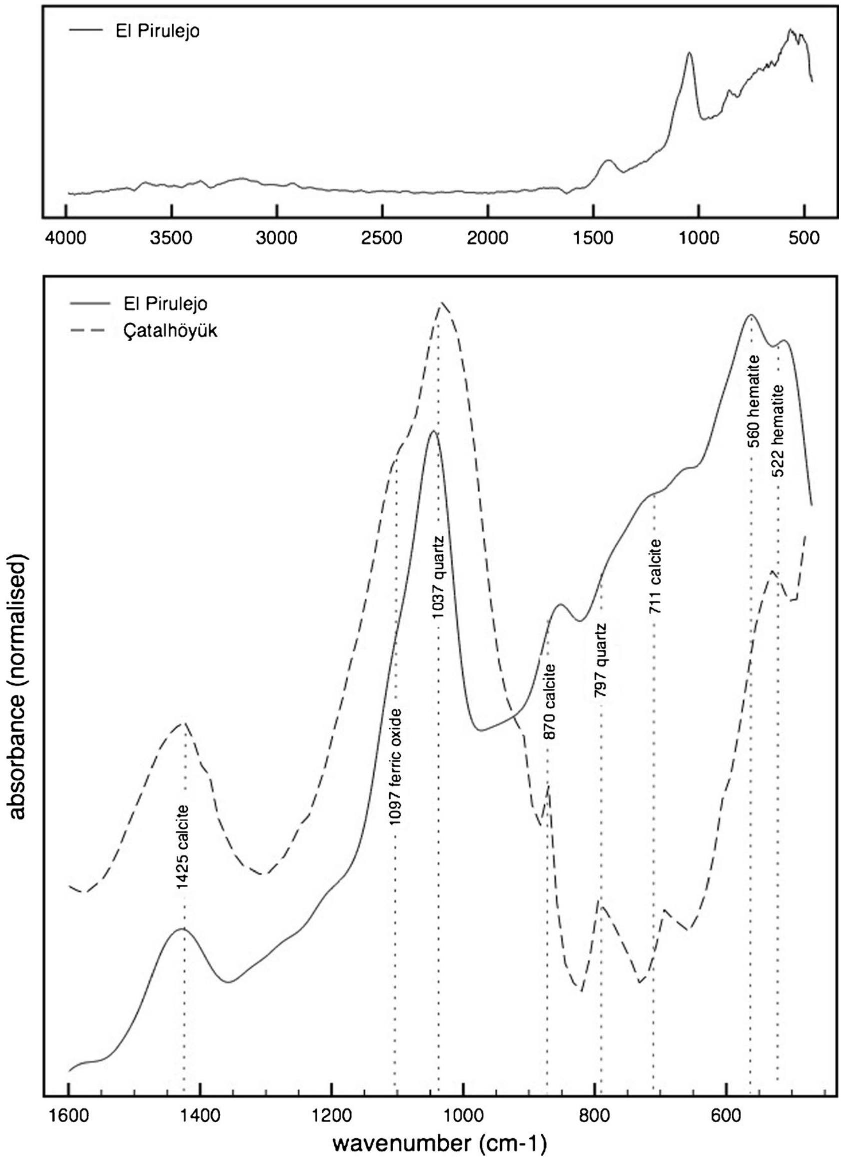


Fig. 7 Spectrogram of the ochre stain. See Fig. 6 for viewing the zone sampled for analysis

Fig. 8 FTIR spectra of the pigment in the ROI 1600–450 cm^{-1} of sampled material compared to Çatalhöyük hematite pigment over calcite plaster (after Mortimore et al. 2004)

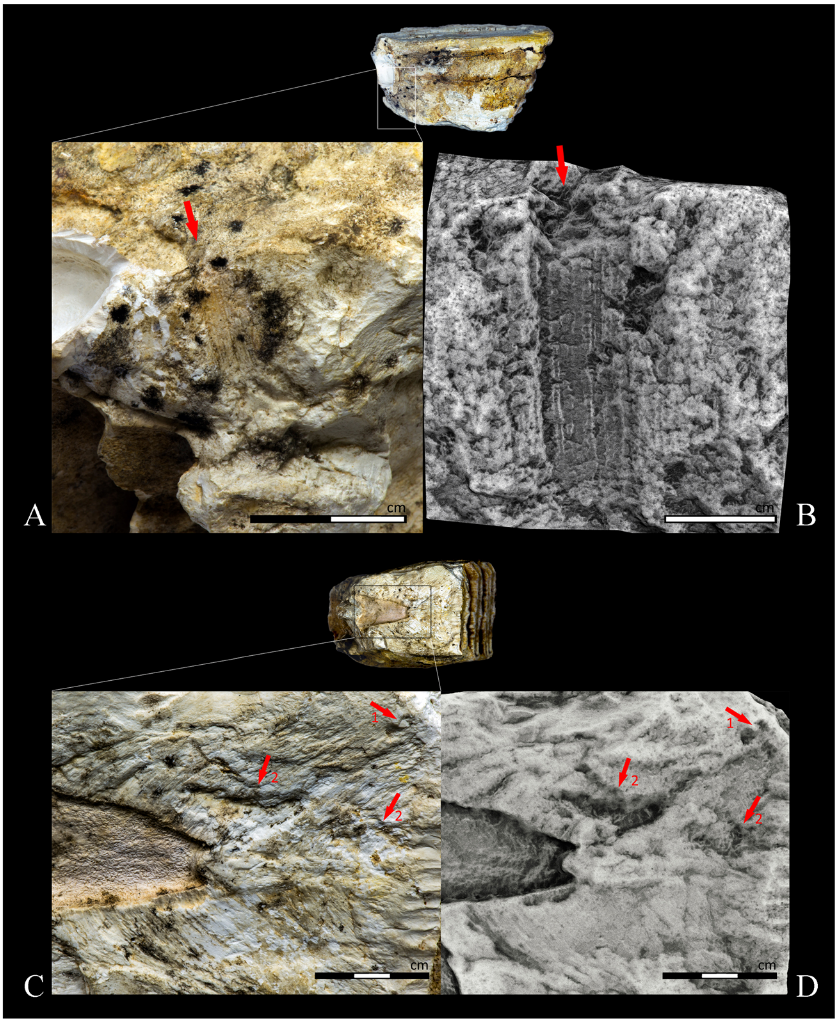


mineral) (Fig. 7, (1)–(4)), and (b) a digital analysis of the surface of the molar where the ochre was located, and the subsequent mapping obtained through SEM. This allowed one to tentatively identify the distribution of the heavily damaged pigment stain as suggestive of a faded imprint, most probably from a fingerprint (Fig. 7).

Various other fractures and splintering suggested an intention to create a cubic shape whose finality was not merely one of acting as an anvil-like tool but also as a core. In this way, on the lingual side of the apical face, the tooth featured a negative withdrawal of a straight longitudinal splinter and along its lower part, several impact fractures that had removed the roots (Fig. 3, (5) and (7)). On the labial side of the apical face, a well-delimited 20 mm × 5 mm area with traces of indirect percussions (see Averbouh and Provenzano 1999), also applied to remove the roots, featured a series of short and grouped longitudinal striations running from the labial edge to the axial plane of the molar (Fig. 3, (7), and Fig. 9a, b). Close to that area, a second negative withdrawal of a straight and longitudinal splinter was present (Fig. 3, (7)). Likewise, one could appreciate a later elimination of the cement surface attached to the plate and the smoothening of its upper margin on one of the fracture planes (Fig. 3, (7)).

The labial (vestibular) face of the tooth (Fig. 3, (4)) featured negative withdrawals from two additional splinters. The larger one measured 83 mm × 70 mm, and the smaller one 50 mm × 31 mm. None of these splinters flaked out cleanly, but only the larger one left a small part of the plaque, near the occlusal face, attached to the core. This narrow longitudinal area, where several short withdrawals from the exterior to the interior of the tooth had been made, measured 55 mm × 7 mm (Fig. 9c, d). Another feature on this same surface was the

Fig. 9 Macro-photographs of technological traces (**a**, **c**) and 3D model rendering of those same images (**b**, **d**) through ambient occlusion analysis (**a**, **d** labial edge of the apical surface (**b**); **c**, **d** anterior (medial) face)



presence of two juxtaposed depressions. The larger, U-shaped one, measured 23 mm × 4 mm and, in contrast with the withdrawal edges of the splinter, featured eroded edges. The smaller depression had an oval shape measuring 12 mm × 8 mm. Both depressions had small impact marks on their interior, similar to those reported for bone anvils (see Évora 2008). Very close to both depressions, small impact marks with V-shaped cross sections were identified (Fig. 9).

Table 3 Infrared bands observed for pigment samples prepared as KBr disks, from El Pirulejo

Wave number	Assigment	Reference
1425	Calcite	Mortimore et al. (2004)
1097	Ferric oxide	Bikiaris et al. (2000)
1037	Quartz	Mortimore et al. (2004)
870	Calcite	Mortimore et al. (2004)
797	Quartz	Mortimore et al. (2004)
711	Calcite	Mortimore et al. (2004)
560	Hematite	Mortimore et al. (2004)
522	Hematite	Bikiaris et al. (2000)

One final and rather relevant piece of evidence was the presence of thermo-alterations, including charring and charcoal remains on the roots and basal portion of the lingual face of the tooth crown (Fig. 3, (2), and Fig. 9).

Taken together, all these lines of evidence testified to an unusually intensive and diversified use and manipulation of the molar.

Geochemistry

The oxygen isotopic composition of the enamel phosphates ($\delta^{18}O_p$) had a value of 17.7 ‰ VSMOW. The isotopic composition of the enamel carbonates was −9.7 ‰ PDB for carbon ($\delta^{13}C_c$), and −3.4 ‰ PDB for oxygen ($\delta^{18}O_c$). The amounts of carbon and nitrogen released from dentine collagen were low (3.4 and 0.6 %, respectively), and the atomic C/N ratio was ≈7.0. The collagen isotopic composition was −33.2 ‰ PDB for carbon ($\delta^{13}C_{col}$), and 6.0 ‰ AIR for nitrogen ($\delta^{15}N_{col}$).

Discussion

Preservation of the sample

A linear relationship has been documented in bioapatite samples from mammals as both $\delta^{18}O_c$ and $\delta^{18}O_p$ precipitate in isotopic equilibrium with internal body water (Longinelli 1984; Luz et al. 1984; Iacumin et al. 1996; Bryant et al. 1996). Also, because the mechanisms of alteration in both oxygen isotopes are different, an isotopically unaltered sample shows an almost constant offset value between $\delta^{18}O_c$ and $\delta^{18}O_p$ (Iacumin et al. 1996; Bryant et al. 1996; Clementz 2012). In our samples, that offset value in SMOW was 9.5 ‰, thus not only in agreement with the range of values for unaltered bioapatite (Iacumin et al. 1996) but also fitting the equation that relates both variables (Iacumin et al. 1996; Bryant et al. 1996). For both reasons, one may safely assume that the inorganic phase of the enamel was well preserved.

Such was not the case of the collagen isotopes. The low content of carbon and nitrogen as well as the high atomic C/N ratio point toward diagenetic alteration of the organic fraction of the tooth, according to DeNiro (1985) and Ambrose (1990), among others. Such alteration might well have been caused by the aforementioned charring and, at any rate, suggests that the specimen had indeed been in contact for a prolonged period either with ashes, a heat source, or both. Although one is unable to decide whether such thermo-alteration was "active" (i.e., achieved by the tooth being intentionally placed in contact with the heat source) or "passive," what seems clear is that a prolonged period of exposure was necessary to attain such a state of alteration.

These differences in preservation between the organic and inorganic fractions are explained because enamel, mainly formed by inorganic material, is far more resistant to degradation than the organic material that appears in greater quantity on the dentine (Binford 1987; Bonnischen and Sorg 1980; Lyman 1994; Stiner et al. 2001).

Paleoenvironmental reconstruction

The U/Th mean value obtained of the upper left M3 (185.15 ± 13 ky BP; 1σ, Table 2) is coincident with a cold episode during an early stage of MIS 6 or the very end of MIS 7. The paleotemperature data provided by the molar correlated, with a 76.9 % confidence interval of the U/Th date, with those from the MIS 6.6 stage, when mean temperatures were similar to those provided by the tooth (Fig. 5). Such date range allowed one to frame the reconstruction of the paleoenvironment at the time the elephant was alive during the final moments of the Middle Pleistocene. The carbon isotopic composition of the carbonates suggested that this particular animal had a C3 plant-based diet. Specifically, the high value of the $\delta^{13}C_c$ (−9.7 ‰), set near the highest values for carbonates from herbivores feeding on C3 plants (Lee-Throp et al. 1989; Cerling et al. 1997), allowed one to postulate that the specimen had inhabited an area with dry conditions. Such scenario conforms to the one postulated for the southern Iberia during MIS 6.6 (Ortiz et al. 2010; González-Mora et al. 2006).

The oxygen isotopic composition of the bioapatite phosphate allowed one to postulate an estimated mean annual isotopic composition of past meteoric waters of −6.0 ‰ SMOW that would be quite similar to the one presently existing in the area where the animal was originally living. Both lines of evidence indicated that the gathering of the fossil took place somewhere on southern Iberia without further specification (Fig. 10). *E. antiquus* is relatively frequent in most of the Quaternary fossil outcrops dotting the basins of the Infra-Betic Arch (Fig. 10). Included here are the Guadix-Baza Basin, the sites of Solana de Zamborino and Loja (Granada Basin) (Ros 2010), and the fluvial terraces along the Guadalquivir River Basin (e.g., La Rinconada, Hornachuelos, and Almodóvar del Río; van Made and Mazo 2001). Likewise, the Salado River, lying just a few meters from the cave entrance, is an affluent of the Guadalquivir River that could have served as the route taken by people to reach the Guadalquivir outcrops. *E. antiquus* has been also reported in the Middle Pleistocene levels at the cave of El Ángel, 35 km away from El Pirulejo, although it appears that these remains represented evidences of scavenging by hyenas (Barroso et al. 2011).

Although *E. antiquus* has been traditionally considered a bio-indicator of forested biotopes, best adapted to mild humid and warm climates (e.g., Stuart and Lister 2007; Pushkina 2007), recent data on its paleoecology and paleodiet suggest wider environmental tolerance. Indeed, the isotopic data obtained on enamel samples from the German sites of Mauer and Steinheim (Table 4) indicated that the species also inhabited relatively open shrubland (Pushkina et al. 2014), and the isotopic signals of the Italian specimens from Polladrara di Cecanibbio and Casal de' Pazzi (Table 4) point to a prevalently browser/intermediate type diet, relatively rich in herbaceous plants, in quite arid environments, during mild (i.e., temperate) climatic phases (Palombo et al. 2005). Lastly, tooth microwear patterns have revealed a wide dietary breadth for *E. antiquus* that ranged from graze-dominated mixed feeders during the Middle Pleistocene to leaf browsers during the Eemian (Rivals et al. 2012). These results evidence the ability of the species to adapt its diet to the vegetation available at a given place and time (Rivals et al. 2012). The results from our stable isotope analyses grant weight and enlarge the geographical scope of these findings in particular for the Iberian Peninsula.

The annual mean temperature for this area could be estimated by taking into account the estimated meteoric water isotopic composition, as well as the difference between present and past seawater oxygen isotopic composition, since the

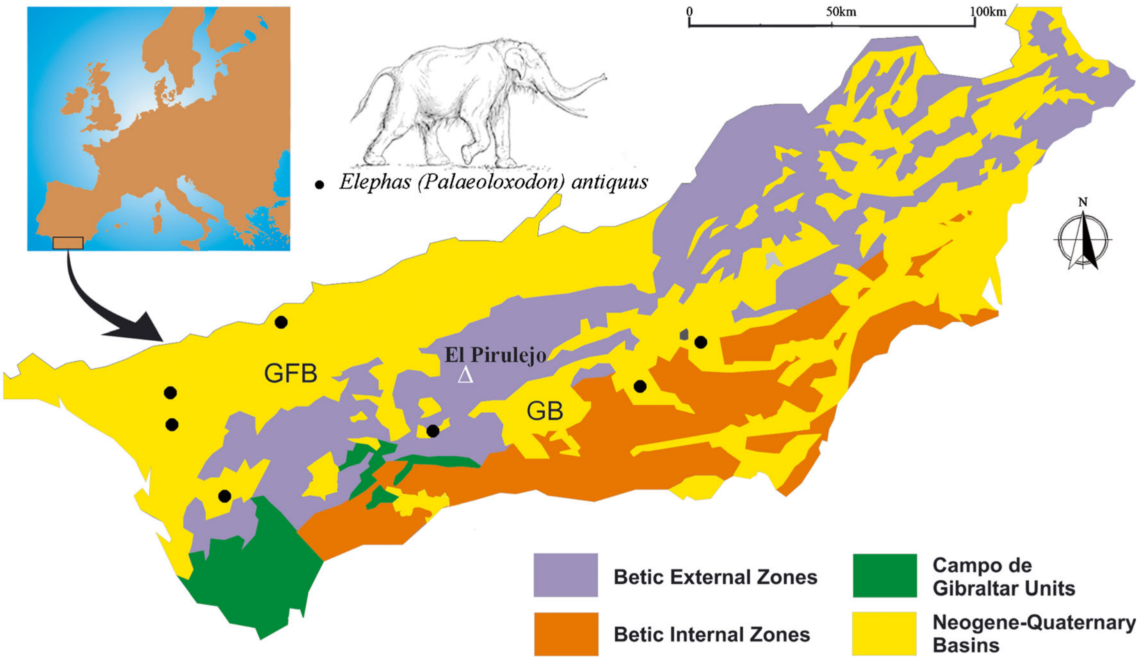


Fig. 10 Location of El Pirulejo cave in the context of the Cenozoic Basins from Southern Iberia and of Quaternary fossil outcrops where remains of *Elephas antiquus* have been documented. *GFB*, Guadalquivir fluvial basin; *GB*, Granada Basin

oxygen isotopic composition of seawater, main source of precipitation at low/middle latitudes, was enriched around −0.6 ‰ SMOW during the period under study (Lear et al. 2000; Zachos et al. 2001). Following the RMA equation relating the isotopic composition of meteoric waters and temperatures in Iberia at large mean annual temperature (MAT) = 2.07 * δO^{18}_{w} + 26.0 (R^2 = 0.75) (Matson and Fox 2010) and southern Iberia in particular MAT = 1.6926 * δO^{18}_{w} + 25.498 (R^2 = 0.88013; $p < 0.001$) (García-Alix 2015), the estimated mean annual temperature (MAT) for the area where the elephant was living would have ranged from 12.3 to 14.3 °C. The mean annual temperatures for the southern Iberian Peninsula presently oscillate, depending on the zone, from the 16 °C of the sierras to the 18 °C for the coast, with intermediate values of ~17 °C in the inner lowlands. For such reason, the estimated temperatures were substantially colder than those of today.

The stable isotopes data confirmed the existence of a cool and dry episode at the time the elephant was alive, and this again would be more consistent with the mean value of the U/Th date signaling an episode within MIS 6.6 (Table 2).

Megafaunal fossil gathering by humans

To determine the fossil status of an animal remain in a given archeological deposit if often far from straightforward. This would be particularly so in the case of long-lived species whose coexistence with humans did not preclude some of their remains qualifying also as fossils (i.e., dating from a time

Table 4 Stable isotope values from selected localities of *Elephas antiquus* tooth enamel

Site		$\delta^{18}O_c$ (‰ PDB)	$\delta^{18}O_p$ (‰ SMOW)
El Pirulejo		−9.7	17.7
Mauer[a]	Mean (*n*)	−12.9 (3)	21.5
	Min–max	−13.85 to −12.38	20.34–22.47
Steinheim[a]	Mean (*n*)	−12.9 (5)	21.3
	Min–max	−13.22 to −12.59	20.49–21.91
Polledrara di Cecanibbio[b]	Mean (*n*)	−10.3 (12)	16.5
	Min–max	−10.9 to −9.0	15.3–17.5
Casal dé Pazzi[b]	Mean (*n*)	−12.1 (11)	15.9
	Min–max	−13.7 to −9.9	14.5–17.0

[a] Taken from Pushkina et al. (2014)

[b] Taken from Palombo et al. (2005)

previous to the formation of a given archeological deposit). By the same token, one could find animals whose temporal range of existence, in particular the time of demise of the last populations, is still largely unknown so that one may erroneously deem as fossil what, in fact, could have been a hunted item.

One major problem in connection with this is that humans have been hunting megafaunas since at least the Middle Pleistocene; thus, remains of large mammals appear regularly on archeological sites representing nothing more than *consumption refuse* (i.e., taphonomic group no. 1 from Gautier 1987). The straight-tusked elephant, particularly frequent during interglacial stages, is well documented in Europe since the Early Middle Pleistocene (~800 ka BP) at sites such as Slivia (Trieste, Italy), Isernia La Pineta (Molise, Italy), and Huéscar I (Granada, Spain) (Mazo 1989; van Made and Mazo 2001; Palombo and Ferretti 2005), when humans were already present in the continent. While its chronology was mainly confined to the Middle Pleistocene, there is good evidence of its persistence into the Late Pleistocene in Italy, the Netherlands, and Iberia, where it was postulated to become extinct ~33–34 ka cal. BP (Stuart and Lister 2007; Mol et al. 2007. In fact, as was also the case with other Pleistocene megafauna and also with Neanderthals, the Iberian Peninsula appears to have been the last stronghold of the straight-tusked elephant (Martín-Penela 1988; Stuart and Lister 2007; Mol et al. 2007). Apparently, in none of these instances was *E. antiquus* reported as representing a fossil.

Although El Pirulejo undoubtedly qualifies as the first case ever where straight-tusked elephant remains are reported as fossils, the practice of collecting fossil megafaunas has been documented at different Upper Paleolithic sites in Europe, in particular from the Magdalenian. Perhaps the most remarkable one in the case of the latter case is that of Gönnersdorf (Germany, 13.3–12.7 ka cal BP) where, in addition to easily recognizable fossils as would be Neogene shark teeth and ichthyosaur bones, a maxilla from an unspecified rhino, and teeth from both the Wooly Rhino and mammoth—the latter from an animal that had died millennia before—were reported as fossils used as building materials, raw materials, or mere "*paleontological curiosities*" (Bosinski 1975, 1981; Poplin 1972; Street and Terberger 2004; Sano 2012; Street et al. 2012). At Kniegrotte (Germany), remains from an unspecified bear (i.e., *Ursus* sp.) of much older age than the Magdalenian deposit in which it was found (i.e., 25 ka BP vs.13 ka BP) were reported by Street and Höck (1998). Likewise, on account of rotting causing ivory plates to exhibit a concave inner surface, a fossil status was granted to several Aurignacian figurines from the Swabian Alb (Southern Germany) and Gravettian figurines from Southern Moravia carved on mammoth ivory (Steguweit 2015). At the Wustermark 23 site in Germany, dated ~12 ka BP, Gramsch et al. (2013) also reported a fish hook dated ~19 ka BP as, "the first evidence in Europe of using subfossil mammoth remains in making tools." (Ibid: 2461). As for ochre, Germonpré and Hämäläinen (2007) have described remains of brown bear (*Ursus arctos*) and cave bear (*Ursus spelaeus*) from the Belgian Upper Paleolithic cave sites of Goyet, Princesse Pauline, and Trou de Chaleux speculating that the ochre films covering them might have been evidence for some sort of ritual.

In contrast with these confirmed fossil finds, the smashed tooth from a Merck's Rhino (i.e., reported as *Dicerorhinus mercki* but presently known as *Stephanorhinus kirchbergensis*) from a Mousterian (MIS 4/3) level at the Grotte de L'Hortus (France) is more problematic (de Lumley 1972). Indeed, although, for all one knows, this species became extinct prior to MIS 4 and could not have been coetaneous with the Neanderthals from that deposit, the possibility exists that the tooth fragments might have belonged to the steppe rhino (*Stephanorhinus hemitoechus*) that only disappeared 40,000 years ago and thus could have coexisted with those humans. In this case, only a correct identification might confirm that fossil status.

In the Iberian Peninsula, there are only two documented cases of a purposeful collection of megafaunal remains and both involve remains of rhinos. The clearest instance comes from the cave of El Castillo in Cantabria (Spain) where a bone of an unspecified *Stephanorhinus* rhino AMS-dated 31, 800 ± 700 (OxA-10,296) was retrieved in an Upper Magdalenian level, reportedly collected as (lit.), "something special or as a trophy" (Bernaldo de Quirós et al. 2006: 457). The second example derives from the Magdalenian IIIA level at Gorham's cave (Gibraltar), where an upper molar fragment from the steppe rhino (reported then as *Dicerorhinus* cf. *hemitoechus* but presently known as *S. hemitoechus*) was described by Riquelme et al. (2011). Because the steppe rhino is found in the Middle-Upper Pleistocene fossiliferous breccias of Gibraltar and the Mousterian deposits from Gorham's and Genista caves (Zeuner and Sutcliffe 1964; Currant 2000; Currant et al. 2012) and, as said, disappeared around 40 ka BP, the find seems consistent with that of a fossil specimen. Still, given the rather narrow margin existing between the Magdalenian period where the remain appeared and the postulated extinction time of the species, only a direct dating of the tooth would help clear the issue, also considering the aforementioned character as a refugium that the Iberian Peninsula represented for large sectors of the Pleistocene megafauna. In connection with the latter issue, one should recall the contentious, presumably Magdalenian (i.e. *ca.* 18–13 ky cal. BP), depictions of Rhinoceros at the Caves of Los Casares (Guadalajara) and Mora (Huelva) that constitute the most southern representations of these animals in Europe (Almagro Basch 1975; de Balbín Behrmann and Alcolea González 1992).

The impression one gathers when all the pertinent literature is considered is that, coinciding with the end of the Upper Paleolithic (i.e., the Magdalenian), hunter and gatherer societies throughout Europe started to routinely collect large-sized animal remains.[1] Given that by that time most of the European megafaunas were extinct, these people must have started to exploit the fossil outcrops where these megafaunas occurred. This is a story that is emerging slowly, but it is a fascinating story. Being able to clearly set apart consumable fauna from remains that have nothing to do with consumption will prove crucial to address the wide range of issues such as, presumably, non-utilitarian gathering behavior implies.

Conclusions

Given the difficulties of assigning fossil status to animal remains, it seems clear that any study aimed at fulfilling this goal would require a battery of protocols to be applied, not the least one of them being a correct taxonomic identification. Indeed, although remains from certain animals are rather easy to certify as fossils, in most cases extinct species are morphologically undistinguishable from their extant descendants, a problem that is compounded in the case of particularly speciose taxa, or when a living species has a fossil record extending in the past for millennia. In these contexts, a direct dating on the specimen might prove crucial not only to determine the chronological discordance that allows one to consider the specimen as a reworked intrusive (sensu Gautier 1987) but also, by virtue of many paleontological species being ascribable to a particular chronozone/age, to confirm the taxonomic identity of the specimen in question as well. Once taxonomic status gets confirmed, the range of places where the specimen could be potentially gathered should narrow down considerably, allowing the analyst to pursue the matter further through geochemical techniques.

A correct identification is, alas, just the first step in a long sequence of operations. As shown in the "Taphonomy and technological analysis" section, a thorough description of the anatomy is critical to correctly report not only the find but also all the subtleties of taphonomic analysis. This often requires the collaboration of different paleontologists and/or archaeozoologists. Taphonomic analysis is also necessary not only to confirm the historical trajectories of different items but also, more importantly, to evidence what sort of processes, manipulative or other, the specimen suffered along its way to the laboratory bench and what do these refer in terms of its functionality. In the case presented, notwithstanding symbolic uses one can often only speculate about, the molar was not just deliberately shaped into a very specific kind of tool (anvil) but also served as a core for the extraction of dentine (ivory) flakes. Certain surface traces also revealed that the anvil had had a prolonged use despite it working on relatively soft material. In addition, SEM-EDX and FTIR data showed that the samples contained a mixture of calcite, quartz, hematite, and clay-like minerals. This suggested a stepwise sequence of events where a hematite pigment had been first applied on the tooth surface by mixing it with a clay-like mineral, and that the calcite on the tooth resulted from later post-depositional processes. The homogeneous nature of the pigment further suggested a deliberate mixing of the iron oxide pigment with a binder. Although the presence of pigment could be taken to reveal a symbolic use, one could equally propose a utilitarian function for the molar, serving as a platform for the grinding of ochre nodules. Still, the presence of a faded imprint ochre mark in one of the lateral surfaces may signal a symbolic value worth exploring further. Thus, although the symbolic functions remain compelling but obviously debatable, what seems beyond doubt is the multi-functional use given to the piece, paleocultural evidence susceptible of emerging only after a thorough taphonomic analysis.

The paleoenvironmental record a fossil harbors is an independent and often unsuspected source of data one can tap when to the previous techniques geochemical analyses are incorporated. From such standpoint, fossils often constitute a gold mine. The first ever carbon isotope analysis carried on bioapatite from an Iberian *Elephas* from a scarcely documented moment of Iberian paleontology (MIS 6.6) evidenced that, contrary to the long-held idea that the straight-tusked elephant fed on C4 plants, this species also subsisted on a C3 plant-based diet, confirming recent evidence from the Italian Peninsula (Filippi et al. 2001). The paleoecological information deduced from the isotopic data additionally revealed a typical Iberian dry and cool episode coinciding with the start for MIS 6.6 and suggested that the fossil was collected in Southern Iberian Pleistocene deposits, possibly not far away from the cave (Fig. 10).

Gathering all this information requires not only experts from a wide range of disciplines but also, equally important, a close cooperation among them. As was previously mentioned, megafauna fossil collecting appears to become a common practice in Europe starting with the Upper Paleolithic, in particular the Magdalenian. As our research showed, Iberia did not remain alien to such development. How this data on the gathering of fossils links with complex phenomena as are the cognitive development of prehistoric humans, establishment of long-range trade routes, etc. is a question that will require a far larger and far richer database than the one presently available in order to be addressed.

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[1] It is in this same context that one should frame the collection of cetacean remains, presumably from stranded animals rather than fossils proper, that include a carved sperm whale tooth retrieved from the Middle Magdalenian site of Las Caldas (Spain; Corchón et al. 2008) and others from the Magdalenian site of Mas d'Azil (France; Poplin 1974).

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