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An indentation in a 33,000-year-old right calcaneus of the ground sloth *Lestodon* (Xenarthra, Folivora) from Uruguay and its possible human agency

Richard A. Fariña[1,2,7*], Elspeth Hayes[3,4,7], Luis A. Lemoine[5,7], Richard Fullagar[6,7,8], P. Sebastián Tambusso[1,2,7] and Luciano Varela[1,2,7]

Abstract

Several sites in the Americas are proposed to have evidence of human occupation before the Last Glacial Maximum (LGM). The timing of human colonisation of the Americas is a matter of debate due to its intrinsic interest, but also because of the implications of that arrival for the extinction of the megafauna. Here, we study a notable indentation in the right calcaneus of a giant extinct ground sloth *Lestodon armatus* from the Arroyo del Vizcaíno site, Uruguay, dated to ~ 33 cal kyBP. We use a combination of 3D CT-scan modelling, high-resolution silicone casting, and microscopic wear and residue analysis to describe the morphology of the lesion, its associated residues, and the possible mechanisms behind its formation. Considering the indentation's features, including its shape, depth, and the presence of organic residues, we argue that it could have been created by a penetrating object with a rounded tip, possibly a bone, ivory or hardened wood tip attached to a shaft. This evidence contributes to discussions on the dates of human arrival in South America and the potential interactions with the megafauna.

Keywords Pleistocene, Human arrival, America's first settlers, Microscopic wear, Residues, Megafauna, Xenarthra, CT-scan, Composite tools, Giant sloth

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*Correspondence:
Richard A. Fariña
dogor@netgate.com.uy
[1] Departamento de Paleontología, Facultad de Ciencias, Universidad de La República, Iguá 4225, 11400 Montevideo, Uruguay
[2] Servicio Académico Universitario y Centro de Estudios Paleontológicos (SAUCE-P), Universidad de la República, Santa Isabel S/N, 91500 Sauce, Canelones, Uruguay
[3] MicroTrace Archaeology, Wollongong, NSW 2500, Australia
[4] School of Geography, Earth and Atmospheric Sciences, Faculty of Science, The University of Melbourne, Melbourne, VIC 3010, Australia
[5] Fundación Arqueológica del Caribe - ARCA, Hoyo de la Puerta, Caracas, Venezuela
[6] Department of Archaeology and History, La Trobe University, Melbourne, Australia
[7] School of Archaeology, College of Humanities, Arts and Social Sciences, Flinders University, Adelaide, Australia
[8] Archaeology Discipline, School of Social Sciences, The University of Western Australia, Perth, Australia

Fig. 1 Location of the Arroyo del Vizcaíno site

Introduction

Determining when people first arrived in America is important for understanding modern human dispersals and megafaunal extinctions (Fariña et al., 2013), which have been attributed, as in other continents, to climatic change (Stewart et al., 2021) and the impact of humans (Prates & Pérez, 2021). The earliest most widely accepted timing for human arrival in the Americas is White Sands National Park (New Mexico, United States), dated at ~ 23 cal kyBP) (Bennett et al., 2021). Other proposals of human presence before the Last Glacial Maximum (LGM, 26.5–19 kyBP, Clark et al., 2009) are contentious (Potter et al., 2018; Sutter, 2020; Prates et al., 2020; see Pérez Balarezo et al., 2023 for thorough discussion), despite reports of several very early sites in both North America (Ardelean et al., 2020; Holen et al., 2017) and South America (Boëda et al., 2021; Pansani et al., 2023) that indicate the possibility of human presence prior to the LGM.

One of these early sites proposed to show human-megafauna interaction in the Americas is Arroyo del Vizcaíno, located near the town of Sauce in southern Uruguay (34° 37′ S, 56° 2′ W; Fariña et al., 2014) (Fig. 1). With a chronology established by 12 radiocarbon ages clustering at around 30 kyBP (over 33 cal kyBP), obtained from purified and non-purified collagen as well as from wood analysed in different laboratories and at different times (Fariña et al., 2022). The site has yielded over 2000 skeletal elements of megamammals that include 15 species, but most of the recovered specimens belong to the giant sloth *Lestodon armatus* (Varela et al., 2023). Among other findings, the mortality profile of the numerous individuals recovered from the site and the anatomical representation of skeletal remains (Fariña et al., 2014) substantiate the inference of human presence.

However, the most important aspect of that research is the presence of cut-marks on some of those bones (Domínguez-Rodrigo et al., 2021; Fariña, 2015; Fariña et al., 2014). Previous interpretations of human agency are based on state-of-the-art methodologies, such as the probabilistic approach in Fariña (2015) and the application of deep learning techniques (Domínguez-Rodrigo et al., 2021), which has further diminished the grounds for reasonable doubt (see a sceptical critique by Holcomb et al., 2022 and our responses, Domínguez-Rodrigo & Baquedano, 2022; Fariña et al., 2022).

Many authors have pointed out the lack of hunting lesions and projectile traumas recognised in the archaeological record (Gaudzinski-Windheuser et al., 2018; Letourneux & Pétillon, 2008; Smith et al., 2007). A great number of the identifications are based on embedded projectile points in human and animal bone and other artefacts (e.g., Mothé et al., 2020), with fewer based on direct associations between bones and projectile points (Smith et al., 2007). Identifications based on wound morphology are the least common, since embedded projectile points result from very specific circumstances with forces strong enough to produce perforations but not enough to completely break the bone. This phenomenon, coupled with methodological bias, could explain the rarity of identifications of projectile lesions made with low-velocity wooden weaponry (Gaudzinski-Windheuser et al., 2018).

Previous studies investigating wound morphologies on skeletal remains have indicated that weapon-like objects create distinctive lesions that can be distinguished from those produced by carnivores, taphonomic processes and other agencies (Domínguez-Rodrigo & Yravedra, 2009; Fernández-Jalvo & Andrews, 2016). Penetrating injuries resulting from pointed artefacts like close-range thrusting spears and clubs have been identified based on their form, position and other microscopic features (Carlini et al., 2022; Gaudzinski-Windheuser et al., 2018; Letourneux & Pétillon, 2008; Smith et al., 2007).

Among the specimens recovered from Arroyo del Vizcaíno is the calcaneus of a giant sloth *Lestodon armatus* with a deep indentation (Fig. 2), which had been preliminarily assigned to human agency (Fariña et al., 2014). In this study, we analyse the indentation using advanced imaging techniques, wear pattern analysis, and residue examination to characterize its formation. While evidence aligns with possible human agency, alternative natural or taphonomical explanations are also discussed.

Material and methods

Stratigraphic provenance

The indentation reported in this study is located on the external half of the dorsal face of a right calcaneus tuberosity of *Lestodon armatus* numbered CAV 45 (Fig. 2), recovered in 1997 from the Arroyo del Vizcaíno (AdV) site in Uruguay. The specimen is housed in the Servicio Académico Universitario y Centro de Estudios Paleontológicos, Universidad de la República, in Sauce, Uruguay.

The AdV site is located at the bottom of a stream, where a natural pond has formed due to the erosion of Cretaceous silicified sandstones (Mercedes Formation). The fossil-rich layer consists of a bed that transitions from a muddy sandy gravel facies to a muddy sand facies containing polymictic clasts. All the collected fossil bones, including the calcaneus described here, come from this stratigraphic level. Previous studies have indicated that the site formed over a short period (Fariña et al., 2014; Domínguez-Rodrigo et al., 2021) with several AMS dates providing overlapping time ranges (Fariña et al., 2022).

Computed Tomography scan (CT-Scan)

A CT-scan of the entire clean bone provided 3D detail of surficial marks, including those in and around the indentation and features of the inner volume (see Supplementary Information for details). The viewer tool allows a 10 × digital magnifier, which was also used to identify relevant details described in the analysis. Additional 3D reconstructions and measurements were performed with the software 3D Slicer (Fedorov et al., 2012).

Silicone cast

A silicone rubber cast of the internal wound cavity was made to assess microscopic details that the CT-scan might not reveal. Prior to sampling, the cavity was cleared of sediment and protected with polyethylene

Fig. 2 Bone showing indentation: **a** bone with impact zone shown in white box; **b** detail of impact zone

glycol to prevent the detachment of spongy tissue when the cast was removed.

Microscopic wear and residue analysis

Although cleaning of the calcaneus and casting the indentation were undertaken years before the opportunity to examine microscopic functional traces, usewear and residue analysis was still considered worthwhile because of the bone's excellent preservation and because neither cleaning nor cast production appeared to have modified microtopography of the bone surfaces. In fact, preparation and consolidation were carried out considering standard recommendations in order to minimize impact (López-Polin, 2012). Indeed, although the cleaning process may have removed residues (see below), it enabled a more reliable study of the bone surface modifications in and around the indentation. Wear and residue traces associated with the indentation were documented microscopically under low magnification (×6.7 to ×45) using an Olympus SZ61 stereozoom microscope with an external fibre optic, 150-Watt halogen light source (Olympus LG-PS2). Observations were made directly on the calcaneus and the silicone cast. Multi-focal microscope images were captured using an Olympus Infinity 1 camera and stacked using Helicon Focus software (Version 7.6.3).

Residues were extracted from four locations surrounding the indentation (Fig. 2) using clean metal tweezers (n = 1 extraction) and distilled water dispensed with a variable pipette fitted with a disposable nylon pipette tip (n = 3 extractions) (see Supplementary Information for sampling procedures). We noted no trace of a surface film, as might have been left by the application of polyethylene glycol, which, in any case, would be soluble in the water used to extract residues. Consequently, any residues that survived cleaning and were firmly attached or trapped in micro-cavities at the time when the bone indentation formed were and are still potentially recoverable.

Following sampling, extracted residues were prepared on glass slides (see Supplementary Information for procedures) and examined under high magnification transmitted light using an Olympus metallographic microscope (model BX53M) with vertical incident light (brightfield and darkfield), polarising filters, and objective lenses of ×10, ×20, and ×50. Following an initial inspection, all four residue slides were stained using a protein-specific stain "Orange G" ($C_{16}H_{10}N_2Na_2O_7S_2$) to identify collagen fibres (see Hayes & Rots, 2019; Hayes et al., 2022) (see Supplementary Information for stain application procedure) and re-examined under the transmitted light microscope to confirm the presence of collagen, indicated by positive colour change (collagen tissue will stain orange).

Results

Indentation morphology

At the bone surface, the indentation opening has a maximum diameter of 21.5 mm and a minimum of 18.4 mm with an eccentricity of 0.52 (relatively circular). The indentation cavity is 40.9 mm deep, has 2.4–4.5 mm of cortical bone thickness, and is located on the external right half of the dorsal face of the tuberosity of the right calcaneus. There are no other perforations or marks of any type on the same bone related to the one presented here.

The impact mark is roughly circular in plan view at the entrance of the indentation, relatively symmetrical, with no abrasion marks or traces of bone illness around it (Fig. 3). Overall, the indentation cavity is roughly cone-shaped with increasing irregularities and flattened elliptical cross sections towards its maximum depth, where the deepest zone is narrower and rounded (Figs. 4, 5a). The orientation of the cavity suggests a straight segment of entry at the upper edge of the calcaneus with a high angle of penetration (Fig. 4). The shape and diameters of the cavity at successive depths suggest that when the penetrating object was maximally inserted, there was a collar or zone of slightly higher diameter, extending about 10 mm from the cavity entrance.

The area around the cavity opening displays multiple ring fractures on the surface (Fig. 3). There is a group of conchoidal fractures with cortex or cortical bone fragments pressed into the conical wound channel at an obtuse angle and with sharp edges (Fig. 3b). Adjacent to that, there is a semicircular fracture with cortical bone detachment at right angles and with an acute edge (Fig. 3d). The outer rim of the cavity opening has a sharp edge (Fig. 3d).

There are no apparent signs of infection or bone reconstruction around the injury. The arrow in the figure indicates the likely angle of penetration of approximately 60 degrees with respect to the ground (or 30 degrees from the leg) (Fig. 4c).

Microscopic usewear and residue analysis

Usewear documented on the silicone cast taken from within the indentation includes sets of fine parallel striations oriented parallel to and within ~ 30 degrees of the direction of penetration. These striations extend along the length of the cast and curve around the endpoint (Fig. 5b). These traces indicate that the penetrating object rotated and moved laterally during episodes of penetration and withdrawal. The striations were probably created during impact, resulting from the crushing of external

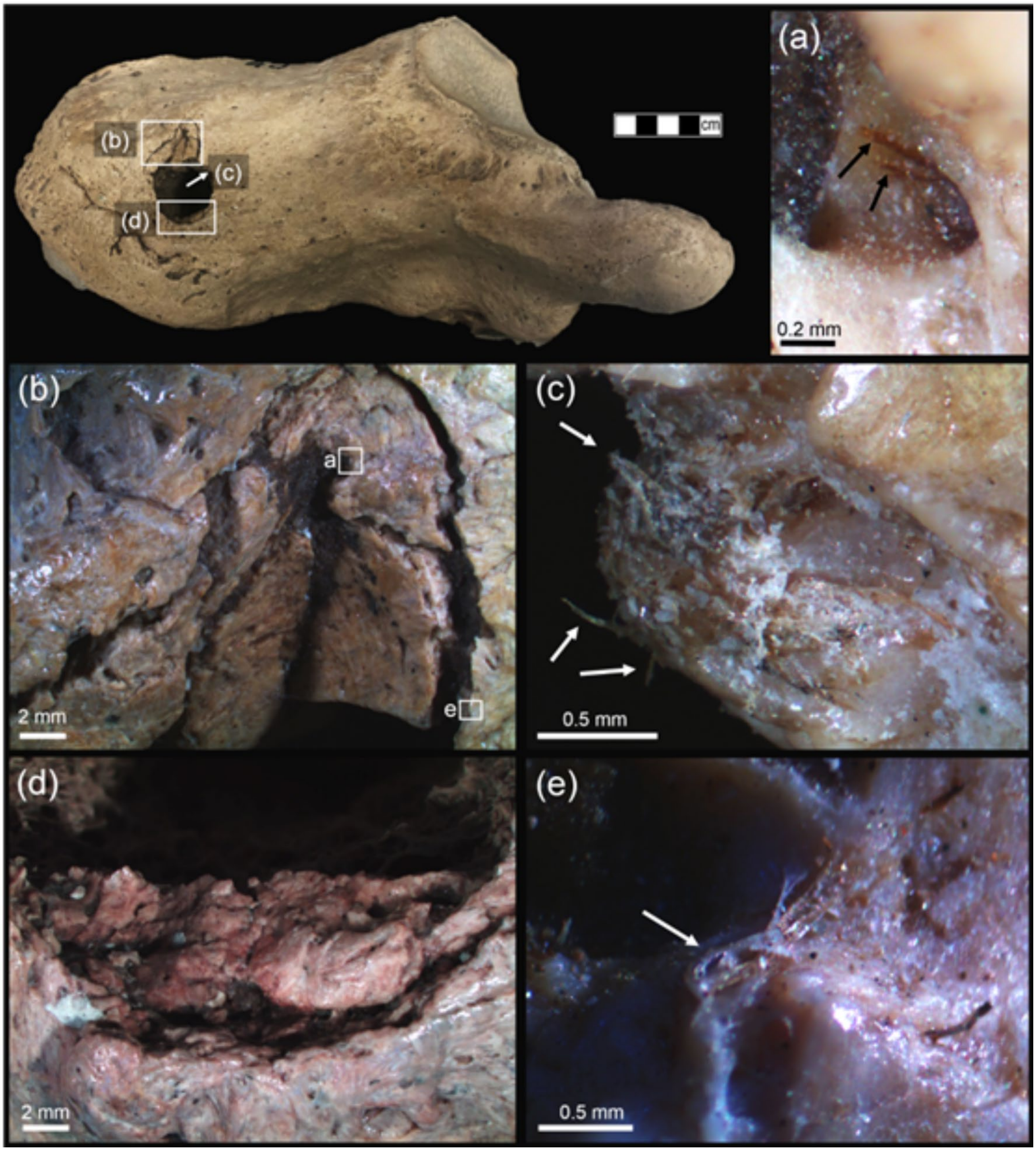

Fig. 3 Microscopic impact wear and residues documented on and around the indentation: **a** organic fibre (indicated by black arrows), cf. collagen (detail of b); **b** conchoidal fractures with cortical bone fragments pressed into the conical wound channel; **c** bundle of organic fibres pressed into the wound channel (fibres indicated by white arrows); **d** circumferential cracks on the opposite side of the conical wound channel; **e** organic fibre (indicated by white arrow) (detail of b)

bone particles that were subsequently smeared along the wall of the indentation cavity to create a thin layer on tissue. Broken bone particles and other debris from the impact tool then acted as additional abrasive agents to create the striations.

Organic tissues (mostly fibres) were documented in and around the circular indentation in all four residue extractions (Table 1). Plant-derived residues were documented in all extractions and included cellulose fibres, sieve cells and lignified (woody) tissue (Fig. 6h–l/r-s). Due to their high frequency, we consider the latter two residue types to be use-related. Starch grains were also documented in low abundance in Extraction 3 (Fig. 6p) but may derive from post-depositional contamination (see

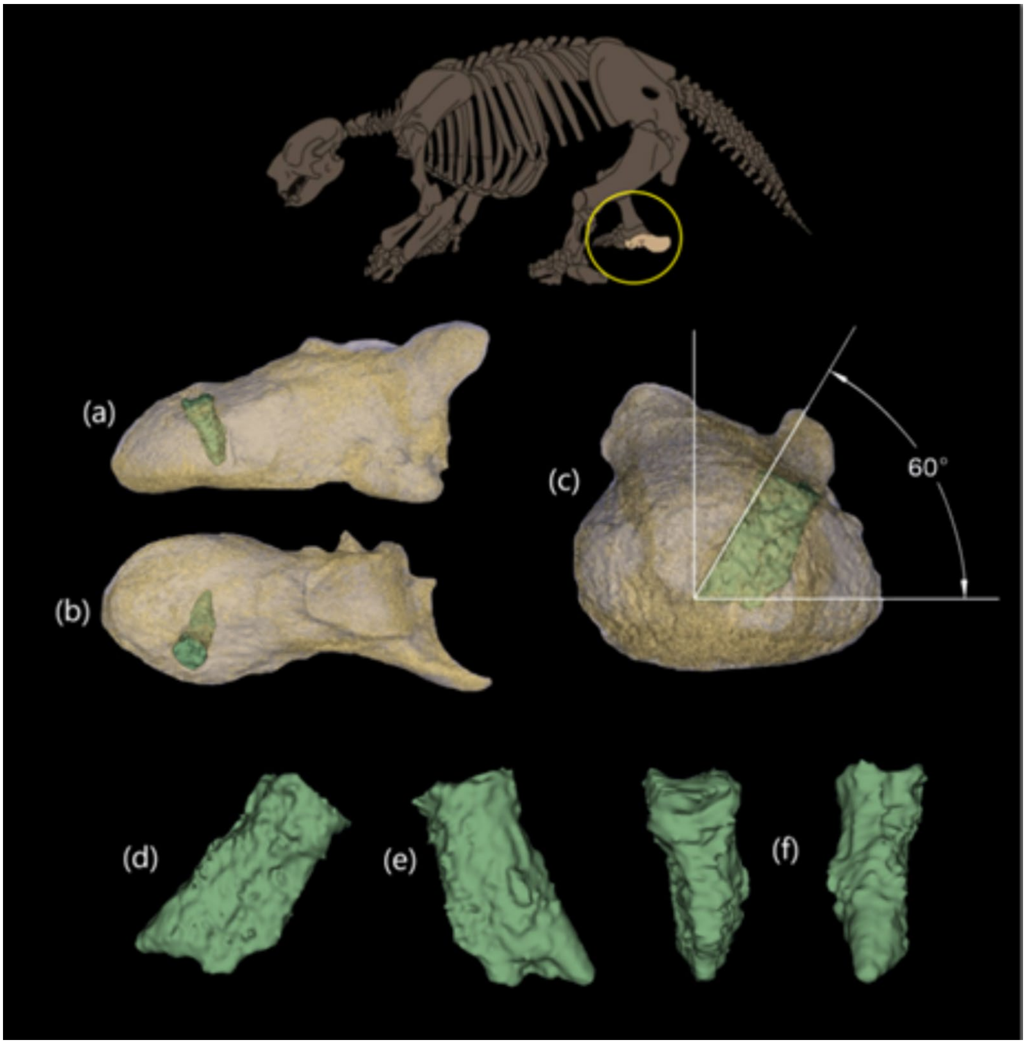

Fig. 4 Anatomical position of the indentation in the calcaneus as seen in the skeleton of the ground sloth *Lestodon*; **a** lateral view with the indentation filled with a virtual cast as reconstructed from the CT scans; **b** idem in dorsal view; **c** posterior view showing the angles with regard to the ground (60°) and with the vertical (30°); virtual cast in **d** lateral view, **e** medial view, and **f** anterior and posterior view. Skeleton of *Lestodon* taken from www.megafauna3d.org

Crowther et al., 2014). Animal-derived residues included collagen fibres (detected using the protein-specific stain, Orange G) (Fig. 6f, g, t) but were less common than plant-derived residues, documented in two of the three solvent extractions and as a band of residues around the rim of the bone that was sampled with the tweezers (Table 1). The origin of the collagen fibres is probably the *Lestodon* calcaneus itself but a relationship with the penetrating implement cannot be completely discarded.

Discussion

The sharp fracture edges, the obtuse-angled folding of the outer cortical bone within the lesion, and the absence of bone regeneration (e.g., woven bone) indicate that a perimortem-stage puncture-penetrating element may have caused the cut. There is no apparent evidence of infection from the puncture-penetrating mark or injury, thus indicating that the animal died shortly after the injury was caused, or that the animal had recently died. All these elements also allow us to confidently discard other types of pathologies, such as neoplastic lesions (Marques, 2019).

Another possible source of the cavity to be ruled out is a canine of a large carnivore, such as the sabre-tooth cat (*Smilodon populator*): the indentation is rather straight with circular section, i.e., without the typical curvature and elliptical section of the felid's tooth. In fact, wounds attributable to *Smilodon* have been previously reported

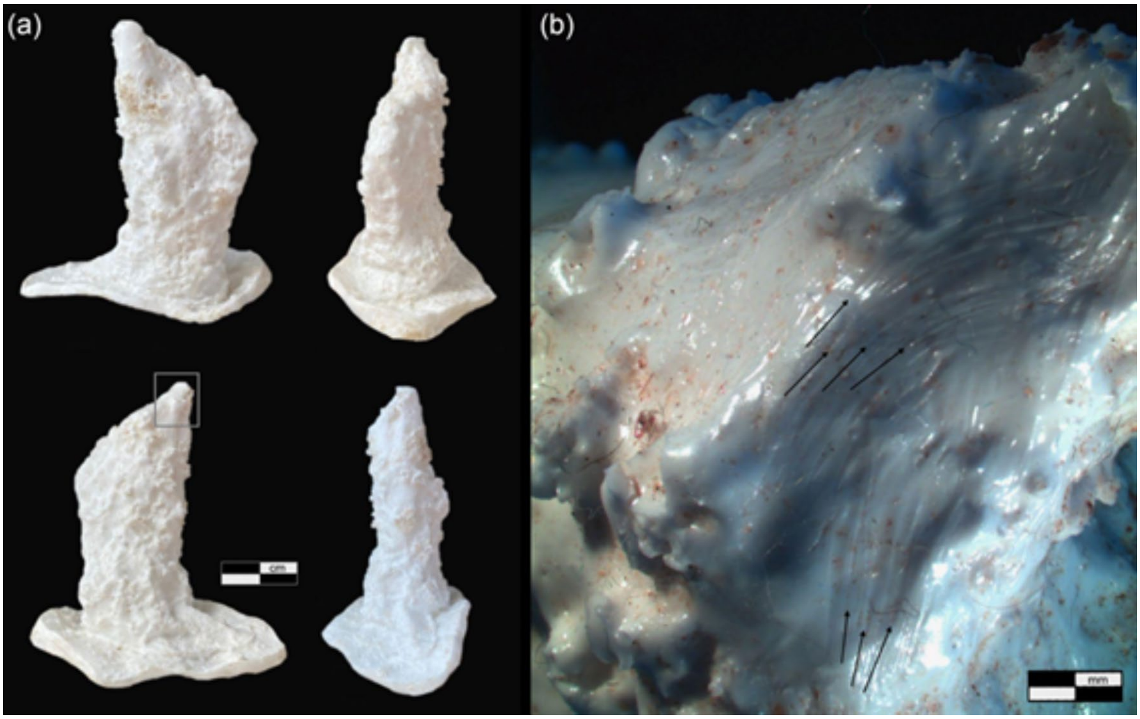

Fig. 5 Silicon cast of the bone indentation: **a** four perspectives of the cast that indicate a roughly cone-shaped cavity with increasing irregularities and flattened elliptical cross-section towards its maximum depth, where the deepest zone is narrower and rounded; **b** detail of the tip of the cast viewed under the stereomicroscope. Sets of fine parallel striations (black arrows) that extend along the length of the cast and curve around the endpoint. Note that the striations are oriented parallel to, and within ~ 30 degrees of the penetration direction

Table 1 Residues documented within extractions sampled on and around the bone indentation

Extraction number	Extraction technique	Micro-residues
1	Pipette + distilled water	Collagen fibres*, plant fibres, plant sieve cell, sediment
2	Pipette + distilled water	Plant fibres, phytoliths, sediment
3	Pipette + distilled water	Collagen fibres*, lignified (woody) tissue, starch, sediment
4	Metal tweezers	Lignin (woody) tissue, plant fibres, collagen tissue*, collagen fibres*, sediment

Extraction numbers represent sampling points shown in Fig. 5

* Identified with application of staining agent Orange G

in cases of intraspecific agonistic interactions (Chimento et al., 2019), but the morphology of the resulting cavity in those cases clearly resembles the canine. Furthermore, it would be unlikely that a *Smilodon* would risk a fracture of the rather fragile tooth that would be laterally bent if it were to bite a robust bone as this ground sloth's calcaneus. Finally, there is no evidence of a mark from the other canine, nor the lower jaw teeth. The same geometric grounds, coupled with the lack of other teeth traces and teeth dimensions less than the indentation depth (40.9 mm) and more elliptical cross section shape, are also valid for ruling out the action of the teeth of other carnivores such as canids or ursids, especially *Arctotherium platensis*. On the other hand, *Lestodon armatus* has a large caniniform tooth (a front tooth analogous to a canine that is often present in sloths) and some research has pointed to the potential existence of intraspecific antagonistic behaviours probably related to a marked sexual dimorphism (Varela et al., 2022). Such behaviour, including male fighting, could potentially relate to the indentation reported here; however, this hypothesis has two main drawbacks. One, the structure of *L. armatus* teeth, as in other xenarthrans, lacks enamel, the strongest tissue in mammal teeth, and is covered by an outer layer of cementum, making it considerably fragile and an improbable candidate to perforate

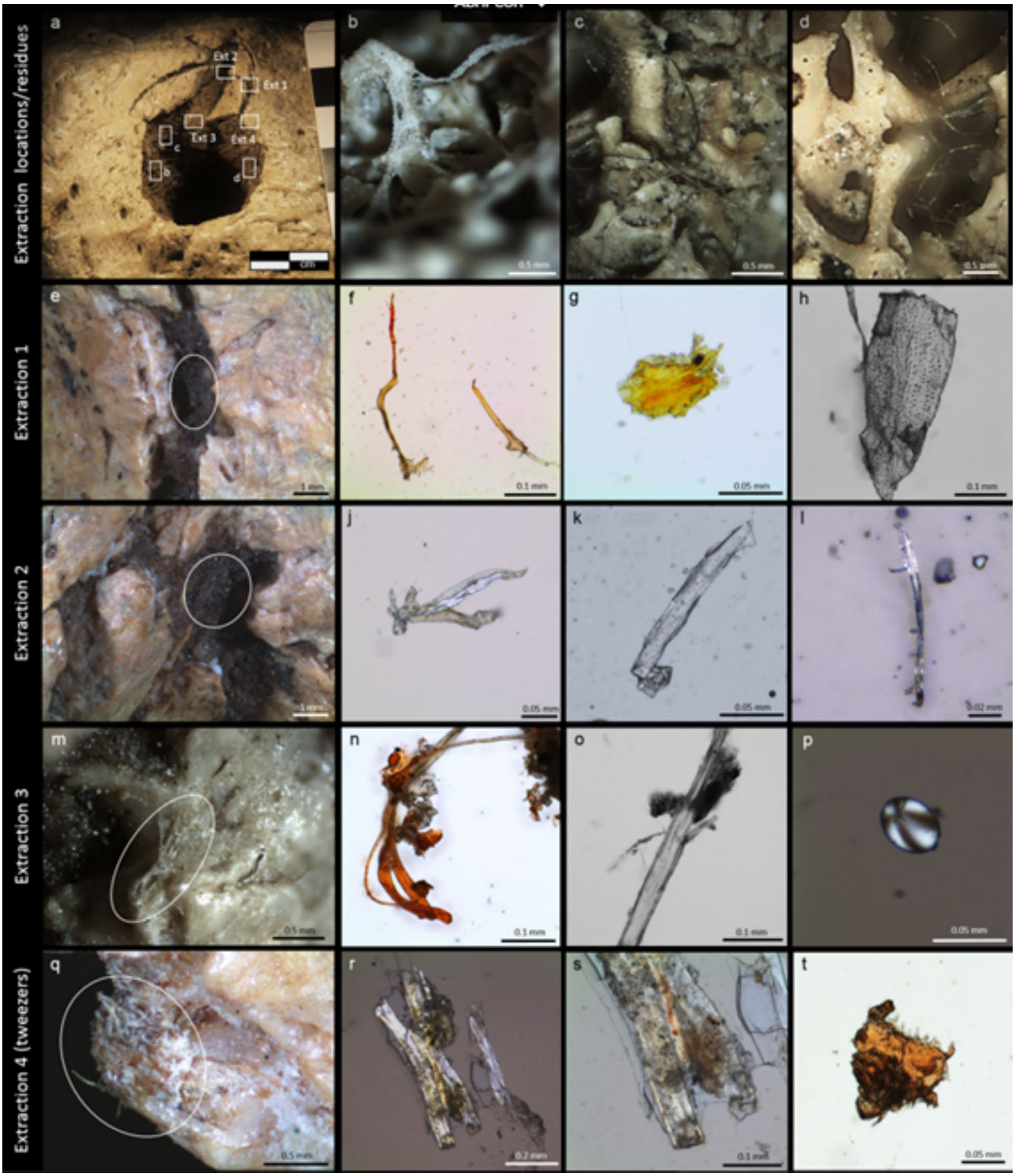

Fig. 6 Residue extraction locations, contaminant fibres and extracted material documented under the transmitted light microscope: **a** conical wound channel, square outlines indicate the location of the contaminant fibres and extractions; **b** rootlet from within the wound channel (post-depositional contamination); **c**, **d** fungal hyphae (black and transparent fibres) from within the wound channel (modern contamination); **e** location of pipette Extraction 1 (ellipse indicates the location of water removal); **f**, **g** collagen fibres/tissue stained with Orange G from Extraction 1; **h** sieve cell (plant residue) also from Extraction 1; **i** location of pipette Extraction 2; **j**, **k**, **l** plant fibres from Extraction 2, note that these fibres did not stain with the application of Orange G and are therefore not of animal origin; **m** location of pipette Extraction 3; **n** collagen fibres/tissue stained with Orange G from Extraction 3; **o** woody tissue from Extraction 3; **p** starch grain (plant) from Extraction 3, note that this grain was found in isolation and thus may be contamination; **q** bundle of fibres sampled with clean metal tweezers; **r**, **s** wood tissue within extracted fibre bundle; **t** collagen tissue stained with Orange G within extracted fibre bundle

bone. Secondly, the triangular cross section of *L. armatus* caniniforms would produce a radial fracture pattern with a less symmetrical perforation shape. A similar argument can be considered to discard the large claws (made of a bone covered by a sheath of keratin) of sloths as responsible for the indentation (see further discussion on this point in Patiño & Fariña, 2017 and Patiño et al., 2021).

The microscopic usewear surrounding the indentation is consistent with previous experimental work investigating bone fracturing that has resulted from penetration with sharp implements (e.g., Gaudzininski-Windhauser et al., 2018). Around the outer rim of the perforation, bone fragments have been pushed into the wound on two opposing edges, with multiple circumferential cracks (Fig. 3). We suggest that these likely formed on impact when the penetrating object pierced into the bone.

Regarding the cavity's shape, we argue that rather than indicating the precise shape of the penetrating object, it more probably indicates a roughly conical object that rotated and moved laterally after penetration, creating a cavity with internal dimensions wider than the entrance–what we call a 'double cavity' (Figs. 4, 5a). Furthermore, the microscopic usewear documented on the silicone cast is consistent with this interpretation that the indentation was formed by a fast, penetrating movement with a sharp implement that was blunted on impact and was subsequently rotated. The interior space of the lesion of a symmetrical conical type with a round, non-acute end, with internal cavity similar to the external dimensions (close to cavity entrance), suggests that the lesion was caused by an object strong enough to be rotated and moved laterally. The circular shape and bone marks of the indentation are aligned with experimental results caused by osseous projectile points (Letourneux & Pétillon, 2008). This analysis further indicates that the lesion is probably perimortem, which suggests that a human could have carried it out at the time of the death of the animal.

The analysis of the energy involved in creating the indentation also sheds some light on its possible agency. Even though there have been refinements to the model in hierarchical structures like bone (see Sabet et al., 2016), it is currently valid to consider that the work required to break an object has two parts (Alexander, 1983; Alexander et al., 1999): (1) the strain energy capacity or the energy to be stored when ultimate stress is reached, which, for similar specimens of the same material, is proportional to the volume; and (2) the work of fracture or the energy needed to create new surfaces (calculated as the area of these surfaces multiplied by the typical work of fracture of the material). The work of fracture is the relevant component for stiff specimens such as bones. Since the area of the indentation is about 60×10^{-2} m^2 and the work of fracture for bone is 20 kJ m^{-2} (Jaslow, 1990), the energy needed to create the new surface in the indentation must have been about 120 J. The volume of the cavity is 24×10^{-6} m^3. Assuming conservatively that the whole of the object penetrated the bone and it was made of stone (density ~ 3000 kg m^{-3}) and that none of the energy was lost in other effects, the relative speed needed to have inserted it into the calcaneus must have been nearly 60 m s^{-1}. A spear thrown from a distance should be ruled out as the possible cause because it is virtually impossible for a human to deliver an object with that kinetic energy. For example, some tests on Clovis projectiles yielded an estimate of 100 J (Whittaker et al., 2017) and, for reference, the current record of javelin throw involves a delivery of energy of about 400 J (World Athletics webpage). Moreover, a stabbing action with an unhafted object would also imply only a fraction of the energy needed. The same way of reasoning could be used to state the unlikelihood of other possibilities, such as a rock transported by a nearly impossible fast current or by another big animal stepping on a conveniently placed and shaped rock fragment (later to be lost from the deep indentation it must have caused). Moreover, even in the improbable case that they could have provided the necessary amount of energy, those agents should have also had the perfect direction to make clean progress through the hard tissues of the specimen. As a matter of fact, in an incidental observation, one of us (RAF) failed to penetrate the diaphysis of a cow's femur with a sharpened, 30-cm long piece of hardwood (*Tabebula* sp.) but succeeded in the same region of the bone with a geological hammer.

The analysis of the mark and rounded surfaces within the indentation suggests that the perforating object had a rounded cross-section without a sharpened tip. We propose it was more likely to be made of bone, ivory or (less likely) hardened wood, inserted into a shaft or sleeve that was long enough to allow sufficient energy to penetrate the thick bone and allow rotational and lateral movement to generate the double cavity visible in the CT scan (Fig. 4). In addition, the attack angle and location (Fig. 4) suggests a very close range attack of about 1 or 2 m away, which requires a club like and a hafted point heavy enough to produce the force required to break the relatively thick flat face of the calcaneus at this short distance. Specifically, it has been proposed that short distance attacks from 10 to 13 m away (Letourneux & Pétillon, 2008) should produce attack angles less than 45 degrees in regard to the ground in order to maximise the force and facilitate the desired point of target. This idea might shed light on a potential hunting strategy, perhaps with the purpose of reducing the giant animal's mobility.

Stone artefacts found within the deposit of Arroyo del Vizcaíno are uncommon but include a few lithic remains, one of which displays usewear consistent with use as a scraper (Fariña et al., 2014). However, arrowheads and barrel-type points that could be related to the indentation presented here are absent. On the other hand, at least 40 bones from the deposit had cut-marks (Fariña, 2015), and several specimens showed a variety of potentially human-related surface modifications, including a mandible with a perforation similar to the calcaneus indentation described here (Fariña et al., 2014), which will be further discussed somewhere else.

Existing collections of lithic points with a relatively rounded but biconvex cross section (i.e., Jaimes et al., 2024a, 2024b) with sharp edges, make indentations with an oval cross section and radial fracture patterns. These lithic points are uncommon in Uruguay, but where present in sites of much younger age, they resemble biconvex points in the 14.8 kyBP Monte Verde II site, according to Suárez (2014). It should be pointed out that it has been stated that El Jobo points have been found in some similarly dated Venezuelan sites, e.g., Taima-Taima and Muaco (Jaimes et al., 2024a; Vargas et al., 2024). Most of the lithic points found in regional collections belong to the fishtail projectile point type with a relatively thin biconvex section, which does not match the indentation pattern and comes from a timeframe of 13 kyBP or less (Suárez, 2015; Suárez & Santos, 2010).

Artefacts recognised across the rest of the continent before and during the LGM mostly include different types of unifacially shaped tools (although in pre-LGM sites in Siberia and other regions spear thrower levers such as the atlatl did not use unifacial points) (Gómez Coutouly, 2016; Kozlikin et al., 2020; Rybin, 2014). More recent discoveries of bifacially amygdaloid shaped tools have been recovered from the early layers of different sites in both North and South America, including Toca da Tira Peia and Vale da Pedra Furada in Brazil, and more recently, Chiquihuite Cave in Mexico (Ardelean et al., 2020; Boëda et al., 2021; Lahaye et al., 2013).

The Serra da Capivara region, which is 4000 km northeast from Arroyo del Vizcaíno, presents a series of sites among the earliest dated sites of South America (see above), in some cases with dates over 20 kyBP (Boëda et al., 2013). Artefacts recovered from the earliest layers of these sites include pieces with convergent edges, rostrums and becs made mainly on quartz and quartzite pebbles. Although no bone, ivory or wooden points have been recovered from these archaeological contexts, organic materials are not expected to survive as the soils are highly acidic. This is a recurrent problem in many early archaeological contexts. Spears, darts, and arrows made of bone, ivory, ground stone or wood have been proven especially useful in many forested areas and are common in recent contexts (Bryan & Gruhn, 2003). In the case of ivory, only a small number of artefacts have been reported, namely tusk fragments that may show signs of human modification (Fiedel, 1999) belonging to gomphotherids from Monte Verde II, Chile (~ 14.6 cal kyBP; Dillehay et al., 2008); a possible foreshaft of a dart made from a neonate tusk at Taguatagua 2, Chile (~ 11.7–11.2 cal kyBP; Jackson et al., 2011); a likely projectile made from the tip of a tusk from the Toro site, Colombia (around 10 cal kyBP; Rodríguez, 2007); and two probable tools from a Late Pleistocene–Early Holocene site close to Taima-Taima, Venezuela (Carrillo-Briceño et al., 2025).

Osseous projectile technologies are representative of the Early Upper Palaeolithic to Late Upper Palaeolithic industries in central and eastern Siberia and are key to understanding initial human dispersal in the Americas. Relevant for the context of human dispersal from Siberia to Beringia, a broad spectrum that ranges from large points made from mammoth or horse to smaller points made on cervid antler or bone, osseous points, together with other bone, antler or ivory implements, are found in most of Middle Upper Palaeolithic sites that preserve faunal remains in those regions (Graf & Buvit, 2017).

Previous studies have provided indirect evidence for the hunting of sloths by humans in the late Quaternary (e.g., Bustos et al., 2018; Jaimes et al., 2024b; Politis et al., 2019; Redmond et al., 2012; Stinnesbeck et al., 2020). Most of these studies present evidence for bone modifications interpreted as cut-marks, which were likely produced through human butchering activities. In addition to those found in bones of *Lestodon armatus* at Arroyo del Vizcaíno, other authors have reported similar modifications in other sloth taxa. For example, Politis et al., (2019) report several cut-marks and anthropogenically modified bones of a *Megatherium americanum* specimen found in Campo Laborde in Argentina. In Mexico, the presence of cut-marks in the ground sloth *Xibalbaonyx oviceps* was reported (Stinnesbeck et al., 2020). Also, Redmond et al. (2012) described several cut-marks in a femur belonging to the ground sloth *Megalonyx jeffersoni*. Recently, several cut-marks were described in the glyptodont *Neosclerocalyptus* sp. from the Pampean region of Argentina, dated at 21 kyBP and attributed to human agency (Del Papa et al., 2024). In Brazil, Pansani et al. (2023) reported the finding of human-modified osteoderms of the ground sloth *Glossotherium phoenesis* in a Late Pleistocene layer dated about 27 kyBP that includes human-made lithics and interpreted them as personal artefacts. Also, the Venezuelan site of El Vano shows the only hunting, killing and butchering site of an *Eremotherium laurillardi*, with associated El Jobo points fragments (see Jaimes et al., 2024b and references therein).

On the other hand, ethnographic records that describe traditional hunting practices resulting in penetrating foot injuries in large mammals are scarce or lacking. Potential examples could be related to traps or pitfalls associated with Indigenous peoples in Africa (e.g., Turnbull, 1965). However, these types of strategies and the likely injuries are incompatible with the direction of penetration, the double cavity and other internal features of the indentation registered in the *L. armatus*' calcaneus. Furthermore, due to the difficulty in diagnosing foot-specific trauma in fragmented assemblages, direct archaeological evidence of penetrating foot injuries is rare, which undoubtedly represents a limitation to our interpretation. Despite this, the finding of several fossilised footprints of sloths along with others made by human beings could provide a potential context to our interpretation (Bustos et al., 2018). The authors argue that the sloth trackway suggests evasion and defensive behaviour, probably indicating humans stalked and harassed sloths during hunts. Evidence of these kinds of hunting activities would include close-quarter encounters and the use of close-range weapons. Further studies focusing on similar modifications on limb bones of fossil South American Late Pleistocene megafauna could offer additional evidence for such activities.

Conclusion

The indentation on a ~ 33 cal kyBP calcaneus of a *Lest-0don armatus* individual from the Arroyo del Vizcaíno site was possibly caused by human agency. The presence of wood fibre residues, indentation morphology, and microwear traces are interpreted in the context of a penetrating object, potentially a wooden shaft with an attached conical tip produced in a harder material such as bone and ivory, although other hard materials should not be ruled out. Alternative, natural agents are less likely as thorough explanations of the morphology and location of the indentation.

The angle of penetration, indentation features and the type of tool used would suggest a fast, very close-range attack hunting strategy. The possible use of a bone, ivory or hardwood tip instead of a lithic could indicate that early hunters benefited from any readily available material for the construction of tools while keeping lithic tools for butchering and other tasks, avoiding the risk of loss during hunting. Finally, the relatively high proportion of cut-marks on *Lestodon armatus* bones compared to those of other taxa registered at the site, along with the evidence presented here, is useful in giving scenarios of hunting prey preference and strategies.

Supplementary Information

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Supplementary material 1.

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Author contributions

R.A.F.: conceptualization, funding acquisition, investigation, supervision, writing-original draft, writing-review and editing; E.H.: usewear/residue analysis, writing original draft and editing, image acquisition; L.A.L: indentation/mark analysis using CAT Scan images, definition of weapon's shape, materials and attack range, writing original draft and editing; R.F: usewear/residue analysis, editing; P.S.T.: 3D reconstructions and visualization, writing-review and editing, and L.V.: writing-review and editing.

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Availability of data and materials

All data generated or analysed during this study are included in this published article.The 3D model of the fossil specimen is deposited at the MorphoSource database within the project: Megafauna3D: Late Pleistocene megafauna fossils from Uruguay (ID: 000670061; Varela et al. 2025).

Declarations

Ethics approval and consent to participate

Not applicable.

Competing interests

The authors declare no competing interests.

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