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A tale of many tracks: An overview of fossil proboscidean footprints at Paleolithic sites around the world, with a particular focus on Schöningen, in Germany

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ABSTRACT - Modern elephants shape the habitats they live in to such an extent that they are referred to as ecosystem engineers; their ancient counterparts seem to have done the same. The most frequent and visible traces left by proboscideans past and present are footprints. However, while their tracks are not uncommon in the world trace fossil record, as far as we know they are relatively rare in the prehistoric archeological record. This paper provides a concise overview of the most important Plio-Pleistocene archeological sites – in Africa, Asia, North America, and Europe – which also contain fossil proboscidean tracks. Particular attention is given to the site of Schöningen, in Germany (Lower Saxony), dated at about 300 ka ago, where recent research has brought to light the largest assemblage of fossilized straight-tusked elephant (*Palaeoloxodon antiquus*) footprints ever found at a Paleolithic excavation. In one of the many instances in which ichnology is increasingly used to aid the reconstruction of the environmental, biological, and cultural features of prehistoric sites, these tracks make it possible to expand our knowledge of the ecology of Plio-Pleistocene proboscideans and gather clues on their ecological, spatial and behavioral interactions with hominin groups.

Keywords: Vertebrate ichnology; elephant; mammoth; fossil footprint; archeological sites; hominin-elephant interaction.

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1. INTRODUCTION

Starting about 1.8 Ma ago, interactions between hominins and proboscideans are well attested to by the many ancient butchering sites discovered around the world and the large number of disarticulated fossil elephant and mammoth bones found bearing marks of anthropic activity and/or spatially associated with stone tools and areas occupied by humans (e.g., Leakey, 1971; Isaac and Crader, 1981; Cavarretta et al., 2001; Domínguez-Rodrigo et al., 2007, 2012; Panera et al., 2014; Waters et al., 2015; Moreno et al., 2019; Yravedra et al., 2019; Konidaris et al., 2021; Haynes, 2022; Gaudzinski-Windheuser et al., 2023). This recurrent association indicates that proboscidean and hominin species long shared certain habitats and ecological spaces.

Because of their size, elephants certainly cannot - and usually need not - conceal themselves. Their habitual routes are easy to locate in any habitat, and, as other animals do, hominins of the past probably used them as highways for their own movements (Haynes, 2012; Agam and Barkai, 2018). Moreover, their carcasses were a huge source of food, bones, fat, tendons, and hides, hence it is most likely that hominins would generally have paid great attention to these pachyderms.

The biological activities of present-day elephants produce a variety of bioturbations that affect the habitats they live in to such an extent that these animals are referred to as ecosystem engineers. Neoichnological studies on the present-day species *Loxodonta africana* (African bush elephant) and *Elephas maximus* (Asian elephant) have shown that these pachyderms dig up or move sediments with their bodies, trunks, tusks, and feet, leaving behind pits, depressions, and trunk-drag grooves (Haynes, 2012; Engvall, 2014). Besides bioturbations originating from direct contact with the elephants' bodily parts, there are also those caused by other activities such as spraying water, urinating, and defecating. Elephants flatten the ground they lie down on, and cause depressions or piles of heavily reworked earth to form in the muddy or wet areas they wallow in. They are attracted to watering holes, ponds, or other bodies of water for more than just drinking; for instance, if the water is deep enough, they will submerge themselves in it completely (Haynes, 2012;

van den Heever et al., 2017; Platt and Hasiotis, 2014).

As is the case with other pachyderms, such as extant and extinct hippopotamuses (Altamura et al., 2017), frequently used elephant trails are easily recognizable; over time, due to repeated trampling, they deepen trench-like into the ground (Haynes, 2012; van den Heever et al., 2017). Most African bush elephants travel in herds ranging from a single family of about a dozen individuals to clans comprising a hundred animals or so. Adult males are usually solitary, while females, calves, and juveniles form groups headed by a matriarch that leads them to water and food. Elephants are able to memorize the spatial distribution of these resources in the landscape and range over areas from 200 to 11,000 km^2 (Hooper, 2020).

Hence, it is not surprising that biological traces left on substrates by ancient proboscideans have often survived in fossil form. Worldwide, the fossil track record of the ichnospecies *Proboscipeda panfamilia* consists mainly of footprints, trails and undertracks (e.g., McDonald et al., 2007; Milàn et al., 2007, 2015; Neto de Carvalho, 2009; Pillola and Zoboli, 2017; Bennett et al., 2019; Mũniz et al., 2019; Urban et al., 2019; Helm et al., 2021, 2022; Neto de Carvalho et al., 2021). A modern adult elephant can weigh up to 6 metric tons, and the downward pressure exercised by its feet at each step can reach 660 g per square centimeter (Michilsens et al., 2009; Haynes, 2012; Panagiotopoulou et al., 2016; Guru et al., 2020). An adult male straight-tusked elephant (*Palaeoloxodon antiquus*) weighed up to 13 tons (Gaudzinski-Windheuser et al., 2023), hence the pressure exercised by its feet would have been much greater. If the substrate's features allow it, this pressure compresses the trampled sediment and causes a footprint to be excavated. The outline of the track left by the hind foot (*pes*) of an adult male African bush elephant is usually oval-shaped and measures about 56x35 cm, while that of the forefoot (*manus*) is almost circular and measures about 50x47 cm. The short front toenails of adults leave little or no impression (Liebenberg, 1990; Pasenko, 2017; van den Heever et al., 2017).

While the number of fossilized footprints found worldwide is relatively high, other types of proboscidean fossil traces are few; pits and other traces of digging activities have been found at several Paleolithic sites in Spain (Silva et al., 2013; Panera et al., 2014) and in the United States (Haynes, 2007; Haynes, 2012), and snakelike trunk-drag grooves have been discovered in South Africa (Helm et al., 2022).

Similarly to what emerges from paleontological and archeozoological evidence, the ichnological record shows a recurring association and coexistence of fossil elephant tracks with archeological sites and with track sites that include hominin footprints, as attested to in several Plio-Pleistocene deposits worldwide. Ichnology is being increasingly used to complement prehistoric studies, providing researchers with accurate information on the paleoecological and paleoenvironmental features of a given site, as well as on the physical, social, and behavioral characteristics of prehistoric human groups (e.g., Bennett and Morse, 2014; Bennett, 2018; Pastoors and Lenssen-Erz, 2021; Hatala et al., 2023). In this paper, we shall consider the scientific implications of the presence of proboscidean tracks in prehistoric contexts, the most important of which are briefly described below, in chronological order (Fig. 1). We shall also devote a whole chapter to the 300,000-year-old site of Schöningen, in Germany, which has been the focus of much of our most recent research.

Fig. 1 - Locations of Plio-Pleistocene archeological sites containing fossil proboscidean tracks.

2. PLIO-PLEISTOCENE ARCHEOLOGICAL SITES CONTAINING PROBOSCIDEAN TRACKS

2.1. LAETOLI, TANZANIA

The oldest known site of paleoanthropological interest associated with fossilized proboscidean footprints is Laetoli, south of the Olduvai Gorge, in Tanzania's Arusha Region. This renowned track site, which was discovered in the mid-1970s, comprises eighteen large ichnosurfaces containing thousands of tracks that were impressed over the course of a few weeks on the surface of a tuff deposit formed 3.66 Ma ago by volcanic ash that was probably ejected by the nearby Sadiman volcano or by other volcanic centers in the area (Leakey and Hay, 1979; Leakey and Harris, 1987; Zaitsev et al., 2011).

The five hominin trackways discovered here, attributed to *Australopithecus afarensis* (sites G and S, Leakey and Harris, 1987; Masao et al., 2016), as well as a number of footprints that may have been made by other hominins (site A, McNutt et al., 2021), have provided many clues and scientific knowledge about the biomechanical capabilities, sexual dimorphism and social structure of these species (Hatala et al., 2023).

The so-called "Footprint Tuffs" contain about 10,000 exposed tracks made by animals of many different species, from insects to birds to mammals (Leakey, 1987; Musiba et al., 2008). The localities bearing animal tracks have generally received much less scientific attention than those with hominin footprints, and they are now subject to major preservation issues (Musiba et al., 2008).

Trackways and individual tracks of proboscideans (88 footprints in total) have been found on the paleosurfaces of sites A, C, D, N West (Leakey, 1987), J, L2, and R (Musiba et al., 2008). They are not in direct spatial association with the *Australopithecus afarensis* trackways found at sites G and S, but several of them are close to a trackway in site A that was recently attributed to a hominin (Fig. 2) (Leakey and Harris, 1987; McNutt et al., 2021). The Laetoli site consists of a series of exposed surfaces spread over an area of 100 km^2, hence the presence of a relatively abundant number of proboscidean footprints in its track record bears witness to a certain degree of coexistence between elephants and hominins in that area. Elephant footprints at Laetoli are mostly rather shallow, with axial lengths ranging between 28 and 65 cm. They appear to have two main shapes, both elliptical: one is longer than it is wide, and the other is the opposite. Mary Leakey attributed the first kind, which is more numerous, to *Loxodonta exoptata*, whose legs were thicker and more massive than those of modern elephants, and the second to *Deinotherium bozasi* (Leakey, 1987).

2.2. ILERET, KENYA

Several track-bearing paleosurfaces have been found at Ileret, in the Turkana Basin in northern Kenya (Marsabit County). Seven contain trackways and individual footprints of hominins and animals, and another twenty only animal tracks. All these surfaces pertain to the Okote Member of the Koobi Fora Formation and are sandwiched between tuff layers dating back to 1.53 and 1.51 Ma ago (Bennett et al., 2009; Roach et al., 2016, 2018; Hatala et al., 2017, 2023). The ichnological levels, which

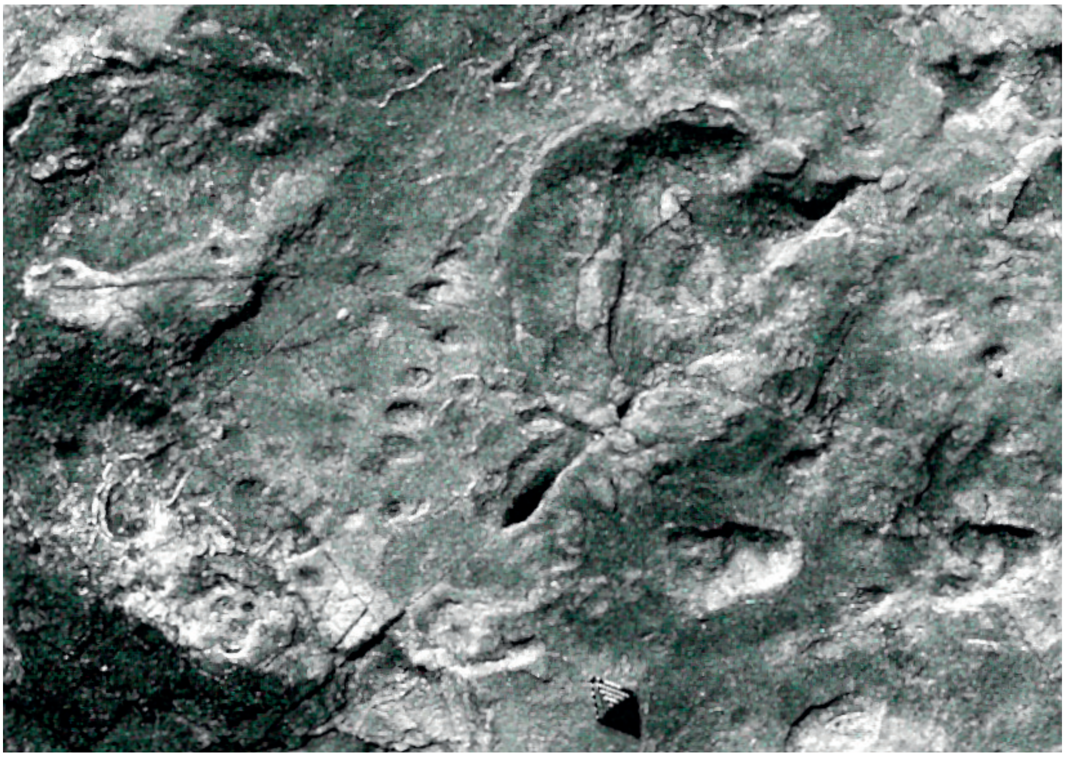

Fig. 2 - Laetoli, Footprint Tuff, site A (3.6 Ma). Proboscidean tracks associated with possible hominin footprints (after Leakey, 1987).

were exposed by natural causes or by stratigraphic test excavations within a 1.5 km radius from the first site that was discovered (FwJj14E), are located at various heights of the stratigraphic sequence. The ichnosurfaces consist of layers of silts and fine sands, typical of low-energy lacustrine or deltaic deposits.

Besides about a hundred human footprints (attributed to *Homo erectus*) and tracks made by birds, reptiles and many different species of mammals, the Ileret fossil track assemblage includes a single *Elephas* or *Loxodonta* footprint (Roach et al., 2016). This is a crater-like, pseudo-circular depression, about 40 cm in diameter, with no diagnostic features. Numerous non-human skeletal remains, including seven proboscidean bone fragments, were found in the same area (Roach et al., 2018).

2.3. MELKA KUNTURE, ETHIOPIA

The archeological complex of Melka Kunture is located on the Ethiopian highlands, about 2,000 m a.s.l., and comprises dozens of outcrops covering an area of about 100 km^2 along the Upper Awash River. Excavations carried out since 1963 have brought to light an archeological sequence comprising Early, Middle, and Late Stone Age horizons, i.e., dated at about 2 Ma to 5 ka ago (Mussi et al., 2022). Many ichnosurfaces have been documented in recent years (Altamura et al., 2017, 2018, 2020a).

For instance, a track-bearing surface was recently discovered beneath a volcanic deposit at the Gombore II-2 site (Fig. 3a). About 35 square meters of this layer - a fine silty-sandy sediment dating to about 0.75 Ma ago - have been investigated to date (Altamura et al., 2018; Perini et al., 2021). The deposit (which is partly sealed by a layer of sand and one of volcanic ash) formed

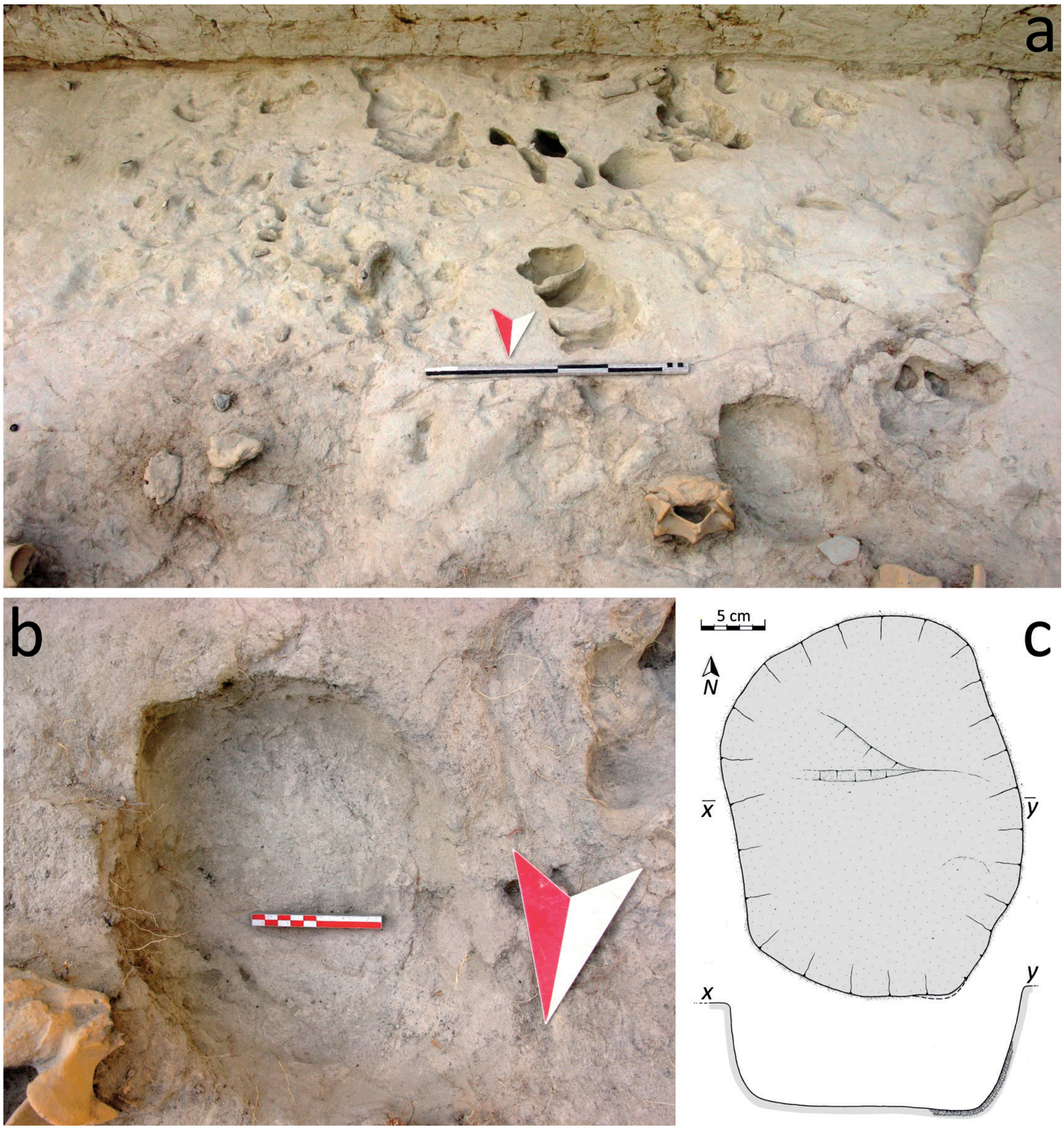

Fig. 3 - Melka Kunture, Gombore II-2 (0.75 Ma). The ichnosurface (a); detail of the possible proboscidean footprint on the track-bearing surface (b); planimetry and profile of the footprint (c), drawing by N. Tomei.

in a moist environment, probably in the proximity of a shallow body of water. The hundreds of fossil tracks on its surface - pertaining to hippopotamuses, bovids, suids, equids, birds, and perhaps several smaller mammals - include a dozen human footprints, some of which are made by children. Based on the chronology of the deposit and on the hominin remains found elsewhere at Melka Kunture, the hominin track-makers seem to have belonged to an early form of *Homo heidelbergensis* (Altamura et al., 2018). As is usual at sites where animals congregate, such as watering holes, the footprints found here do not form trackways or any significant alignment.

One of the megafauna footprints (which straddles squares D5 and E5 of the exposed level) may have been made by a proboscidean (Fig. 3 b,c). It has an elliptical outline, measuring 30x23 cm along its axes, and a rather uniform concave shape, 9.5 cm deep, with no diagnostic features. It is consistent with the footprint of a young elephant, though it may be a badly preserved track of a hippopotamus or rhinoceros. Moreover, the elephant remains at Melka Kunture are very scarce; a few fragments of *Elephas recki recki* bones were found in the Oldowan levels of Garba IV, dated 1.5 Ma ago (Geraads et al., 2004), while photos in the Italian archeological mission's archive show that a tusk was retrieved in 1966 from a Pleistocene level at the nearby Kella area. The single rhinoceros bone remain that was found at Gombore II comes from an older level than the one with the footprint (Gombore II Open Air Museum, ca. 1 Ma; Gallotti et al., 2010; Perini et al., 2021). Hippopotamus remains, on the other hand, are rather common. They were found on the track-bearing paleosurface - some of them with butchering marks - associated with other animal bones and lithic implements (Altamura et al., 2018, 2020b).

2.4. ATELLA, ITALY

The approximately 600,000-year-old site located next to the cemetery of Atella (Basilicata region, southern Italy) contains a sequence that formed at the edge of a Pleistocene lake with sediments originated by the Vulture volcanic complex (Rocca et al., 2022, 2023). The surface of Layer I, in the top portion of the Pleistocene sequence, contains several possible fossil tracks that were excavated in the 1990s (Fabiano and Zucchelli, 2003). At the time this layer, which is characterized by desiccation cracks, was described as a sandy-silty lacustrine deposit about 15 cm thick that probably bore witness to a shrinking of the ancient lake caused by the volcanic activity attested to by the overlying Layer L, which consists of reworked volcanic products. However, a recent multidisciplinary analysis ascertained that it is a tuff formed, according to $^{40}Ar/^{39}Ar$ dating, sometime between 715 and 575 ka ago (Rocca et al., 2023).

The deformations exposed on the surface of Layer I consist of a series of hollows and at least four large sub-elliptical depressions whose axial lengths measure several decimeters. Although they do not have any diagnostic features nor well-defined outlines, their size and general shape, and the presence of load structures (undertracks, raised rims, and sediment displacement), suggest that they could be footprints of straight-tusked elephants (*Palaeoloxodon antiquus*). This attribution is corroborated by the many bone remains of this species that have been found here, especially in the lower part of the Pleistocene sequence (e.g., Ciolli, 1997; Rocca et al., 2023). The passage of at least one elephant would have caused the fragmentation and partial displacement of the surface crust of Layer I, making it subside into the substrate, which at the time must have been still plastic and moist enough for this to happen. While Layer I is archeologically sterile, stone artifacts and osteological remains were found above it (Layer L); hence, it could have been a walking surface. After having been exposed by the archeological excavations, the potential track-bearing surface started to deteriorate badly, so a resin cast was made of a portion of it. New fieldwork is currently underway to determine whether the nature of the deformations is indeed ichnological (Rocca et al., 2023).

2.5. FORESTA, ITALY

The fossil ichnosite known as "Ciampate del Diavolo" (the "Devil's Trails") is located on the north-eastern slope of the Roccamonfina volcano, near the village of Foresta, in the township of Tora e Piccilli (Campania region, southern Italy). To date, the exposed portion extends over about 2,000 m^2. At least four human trackways have been identified on the surface of an ignimbrite radiometrically dated at 349±3 ka ago, i.e., during the glacial phase of MIS 10 (Santello, 2010; Palombo and Panarello, 2023); they were probably made by *H. heidelbergensis* individuals making their way down (at least some of them) from a path that ran further up the slope. The 81 human traces recorded to date are mostly footprints, but there are also impressions left by hands and other body parts as the trackmakers descended the steep slope. Several stone implements have been found associated with this surface (Mietto et al., 2003, 2022; Panarello et al., 2017a, 2017b, 2020, 2023; Avanzini et al., 2020).

This surface also contains footprints of other vertebrates - an indeterminate medium-sized ruminant artiodactyl, a horse (*Equus* sp.), a bear (*Ursus* sp.), and an elephant, probably *Palaeoloxodon antiquus*. The elephant footprints (*manus* and *pes* impressions) form a short trackway, not fully discernible, made by a young animal. The outlines of the better-preserved tracks are round or oval, with a displacement rim and faint impressions of the front toenails. Their diameters measure from 27.7 cm to 33.4 cm, consistent with a juvenile or adolescent elephant weighing between 2.35 and 2.6 metric tons (Palombo et al., 2018; Pillola et al., 2020; Palombo, 2022).

2.6. CASAL DE' PAZZI, ITALY

Several fossil bird tracks, plus one made by a large mammal, were recently studied at the Casal de' Pazzi site, in the eastern suburb of Rome (Latium Region, central Italy) (Altamura, 2020a; Altamura and Gioia, 2020).

Discovered in 1981, this archeological site, well-known for the great number of finds unearthed there (faunal bone remains, stone implements, and the fragment of a human skull), consists of fluvial sediments that, according to relative dating performed via geological correlation, accumulated 200-250 ka ago (or perhaps about 270 ka ago) in a paleo riverbed that had eroded a Lionato Tuff deposit radiometrically dated at 353 ka ago (Gioia et al., 2014; Marra et al., 2017; Gioia, 2020). The presence of possible bioturbation in these sediments was recently detected at the interface between gravel, sand, and silt fluvial-lacustrine deposits (Level 5 in Anzidei et al., 1984). This structure, which had been sectioned vertically and partly removed by past archeological digs, is preserved in a stratigraphic balk that was left intact in the excavated area, which was eventually musealized (Fig. 4).

A small sideways excavation was performed on the balk to ascertain the ichnological nature of the deformation which, once the infill was removed, turned out to be a depression, 36 cm wide and 31 cm deep, with a curved horizontal outline and a bell-shaped vertical one. It had been clearly produced by a downward compression force exercised on a surface consisting of a thin silt lens and gravel layer, sinking it into an underlying silt layer. The vacuum created by the load structure had been filled by a coarse sand deposit that had eventually covered the surface. The interface between the substrate and the infill is well-defined. The marked load fractures (undertracks) in the compressed and deformed silt beneath the depression, and in the underlying gravel, point to the biogenic nature of this structure. Embedded at an angle in the track's sole surface is a small bone fragment that was probably pressed down by the trackmaker's foot.

Although this track has no diagnostic morphological features, its diameter (which would have measured at least 36 cm) is consistent with that of a large mammal, such as an elephant, rhinoceros, or hippopotamus. Since there are no toe or toenail impressions, which are typical of rhino and hippo tracks, this footprint was likely made by a straight-tusked elephant; this identification is corroborated by the large number of *Palaeoloxodon antiquus* remains present in the site's archeozoological record (Pandolfi et al., 2023).

A review of the archival documentation of past excavations showed that this site may have contained other vertebrate tracks (Altamura and Gioia, 2020), such as those documented at other Upper and Middle Pleistocene sites of the Rome area (Altamura, 2020b; Altamura et al., 2020c; Cerilli et al., 2020).

2.7. MATALASCAÑAS, SPAIN

Along the beach of Matalascañas, about 45 km southeast of Huelva, in southern Spain (Andalucía autonomous community), coastal erosion at the base of a cliff exposed

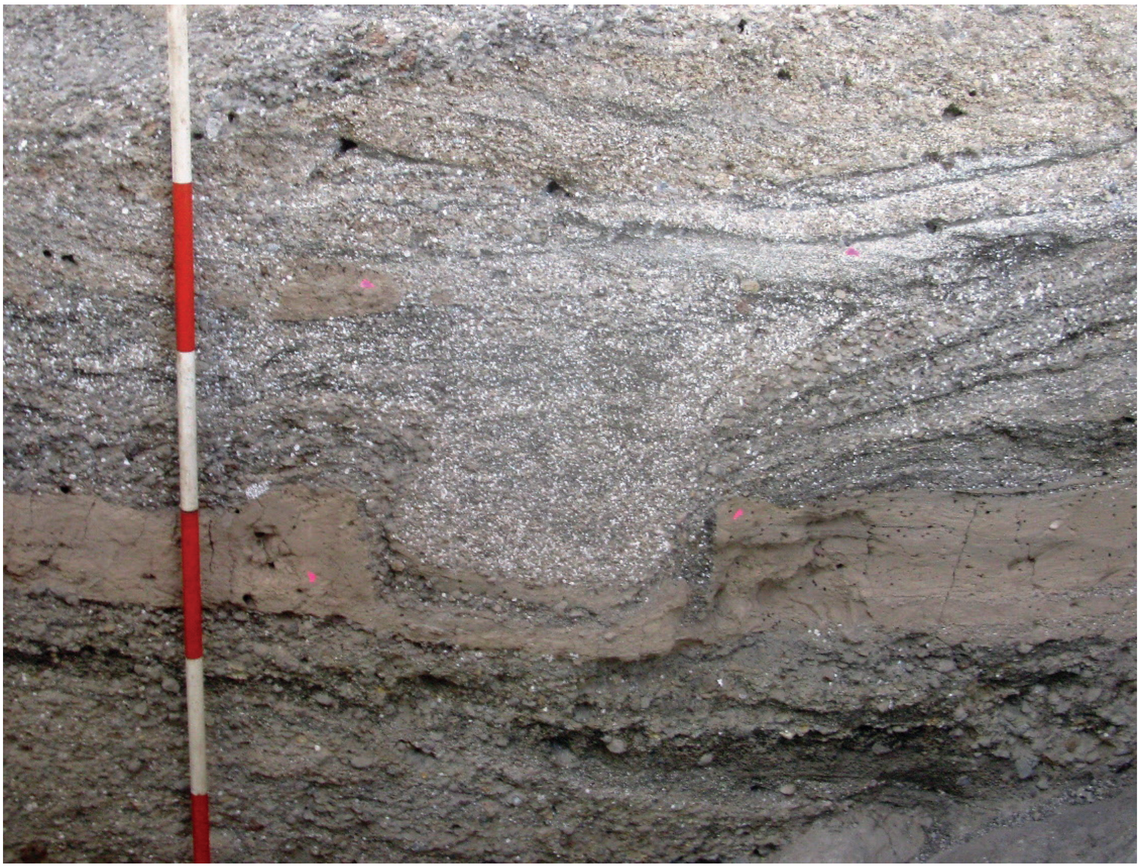

Fig. 4 - Casal de' Pazzi, stratigraphic balk (ca. 270-200 ka). Probable proboscidean footprint cut through by the excavation.

surfaces bearing human and animal fossil tracks. The silty-sandy pedogenized sediments on which the tracks had been impressed contain rhizoliths, indicating that the area was once covered by dense vegetation, most likely growing around a freshwater interdunal pond (Neto de Carvalho et al., 2020a, 2021). The Matalascañas Trampled Surface (MTS) bears many tracks made by vertebrates such as water birds, artiodactyls, canids, and elephants (Neto de Carvalho et al., 2020a, 2021, 2023). Bordering the western and southern edges of the MTS is an area that Mayoral et al. (2021) dubbed Matalascañas Hominin Trampled Surface (HTS) for the numerous human footprints found impressed on it (87 so far), which came to light following the recent erosion of a portion of the MTS (Neto de Carvalho et al., 2023). At first, the track-bearing deposit was attributed to MIS 5, but absolute dating obtained via optically stimulated luminescence (OSL) later suggested that it was older, going back to 295.8±17.8 ka ago (Mayoral et al., 2022). However, both an in-depth study of the lithic assemblage associated with the trampled layers - which includes several typical Levallois tools - and new OSL dating indicate that the site formed around 150 ka ago, i.e., during the MIS 6-5 transition (García Rincón et al., 2022; Neto de Carvalho et al., 2023).

The elephant footprints found on the MTS are numerous; while most of them are isolated tracks, there are at least eight trackways made by single individuals. Ascribed to the straight-tusked elephant *Palaeoloxodon antiquus*, the tracks are round or elliptical, with the axial length of the hindfoot (*pes*) tracks ranging from 9.6 to 54.5 cm; in some cases, marginal ridges and possible redeposition of the substrate (*ejecta*) were observed. The age of the various trackmakers was determined based on footprint size; tracks of calves (under 2 years old), juveniles (2-7 years old) and adolescents (8 to 15 years old) are predominant, while those of adults (both male and female) are fewer, indicating that this wetland was a major environmental resource for elephant herds, a place where they gave birth to and reared their young (Neto de Carvalho et al., 2021).

This environment attracted hominins as well (*Homo neanderthalensis*), as shown not only by their footprints but also by the stone implements found here (Mayoral et al., 2021; Neto de Carvalho et al., 2021, 2023). Besides Matalascañas, other Pleistocene aeolianites and coastal dune deposits in the southern Iberian Peninsula have been found to contain vertebrate tracks (e.g., Neto de Carvalho, 2009; Neto de Carvalho et al., 2016, 2020a, 2020b, 2022). For instance, a single possible Neanderthal footprint associated with elephant and other mammal tracks was discovered at Gibraltar (Mũniz et al., 2019). Other ichnosites containing tracks that may have been made by elephants have occasionally been unearthed during archeological digs at various Paleolithic sites near Madrid, such as Arriaga IIa, where, besides *Palaeoloxodon antiquus* remains and stone artifacts, traces possibly pertaining to elephants - several footprints (ranging from 17 to 22 cm in diameter) and a pit - have been documented (Álvarez Catalán et al., 2009; Silva et al., 2013; Panera et al., 2014).

2.8. ALATHAR, SAUDI ARABIA

A track-bearing surface was discovered at Alathar, in the Nefud Desert (north-western Arabian Peninsula, Saudi Arabia), on the sandy-silty diatomite deposits of a freshwater paleolake (Stewart et al., 2020). Seven possible *Homo sapiens* footprints, plus several hundred animal tracks, were found on an outcrop dated via optically stimulated luminescence (OSL) between 120 ka and 110 ka ago (MIS 5). These footprints appear to be the earliest evidence of the presence of anatomically modern humans in the Arabian Peninsula, predating by about 25 ka the oldest known modern human fossils in the area. Most of the animal tracks were made by camelids, bovids, and elephants; a single equid track was also recorded.

The 43 elephant tracks found to date are concentrated in two main groups of trackways located in the proximity of the human footprints. These round or slightly elliptical impressions, with diameters measuring from 19 to 63 cm, have almost no diagnostic features; displacement rims, fractures and load structures have been observed in the trampled sediments under or around them. The tracks found on the ancient lakeshore bear witness to the passage of herds of elephants of various ages. This same paleoenvironment may also have been used as an ecological corridor by groups of humans. The track-bearing deposit also yielded faunal fossil remains, including two bones of taxonomically indeterminate elephants that may have been the actual trackmakers.

2.9. LAKE NOJIRI, JAPAN

The Tategahana Paleolithic site, located at about 650 m asl on the shore of Lake Nojiri (Nojiri-ko), on Honshu, the main island of Japan (Nagano prefecture), has been systematically excavated since the early 1960s. The stratigraphy consists of Upper Pleistocene and Holocene deposits made up of lacustrine sediments alternating with volcanic ash layers.

Over the years, the excavations have brought to light bone remains pertaining to at least 46 Naumann's elephants (*Palaeoloxodon naumanni*). This species lived in the area from about 60 to 38 ka BP, and accounts for over 90% of the bone remains found at the site. The bones were often found in clusters, and in several cases seem to have been associated with lithics, bone and wooden artifacts, and archeozoological bone remains with traces of human-made fractures. Researchers have suggested that all these elements point to the existence of elephant kill sites along the shore of the paleolake (Kondo et al., 2001, 2018).

Thirty-five elephant tracks have been found in levels pertaining to the Lower Member of the Nojiri-ko Formation and dated at between 53 and 41 ka ago (Kondo et al., 2001; Matsukawa and Shibata, 2015). The footprints - which include three trackways made by single individuals - are from 39 to 49 cm long. The site has also yielded artiodactyl tracks (Matsukawa and Shibata, 2015).

2.10. JEJU ISLAND, SOUTH KOREA

Several ichnological outcrops have been found at Sagaeri, on the north-eastern slope of Mt. Songak, on the volcanic island of Jeju (Jeju Province, about 90 km south of the Korean Peninsula). According to the paleoenvironmental reconstruction, this area was once a coastal wetland, like a semi-enclosed lagoon or an intertidal mudflat, where the reworked volcanoclastic sand or mud shoreline sediments had been intermittently exposed or submerged.

Thousands of trace fossils have been documented on multiple surfaces positioned at different levels of the stratigraphic sequence. Mammal tracks include about 500 human footprints (on two stratigraphic horizons) and more than one thousand deer-like artiodactyl tracks, as well as a few carnivore and proboscidean footprints. About a hundred bird tracks, plus several fish trails and invertebrate trace fossils, have also been recorded. Together with the gastropod, bivalve, crab, and plant body fossils found here, these tracks provide an accurate picture of the ancient shoreline's paleocommunity and paleoecology (Kim et al., 2009).

Two of the track-bearing levels contain several large circular or irregularly shaped footprints attributed to woolly mammoths (*Mammuthus primigenius*) by the scientists who discovered them. Eight footprints are positioned two-by-two (compound tracks) to form a short trackway made by a single individual; the *manus* tracks are 40 cm long and about 36 cm wide. Although these tracks are not on the same surfaces that contain human footprints, they nonetheless indicate that proboscideans and hominins occupied the same paleoenvironment (Kim et al., 2009, 2010). The dating of the track-bearing horizons is a matter of dispute. The researchers who discovered the footprints set them at the late Upper Pleistocene, i.e., between 25 and 19 cal ka BP (Kim et al., 2010), but scientists who subsequently reexamined the stratigraphy and performed new radiocarbon dating place them in the mid- to late Holocene (Sohn et al., 2015).

2.11. MURRAY SPRINGS, ARIZONA, USA

The Murray Springs Clovis site, in the upper San Pedro River valley in Arizona, has yielded an important archeological sequence dated at the late Pleistocene (about 13 ka BP). Excavations carried out from 1967 to 1971 brought to light levels of human occupation, stone and bone artifacts, and a large quantity of mammoth, bison, equid, camelid, canid, and rodent bones. Five kill sites were also discovered; they contained bone remains left by the butchering and processing of animal carcasses, including bones of Columbian mammoths (*Mammuthus columbi*), associated with projectile points and other stone artifacts. The paleoenvironment featured a spring field that fed a stream.

Tracks imprinted in sand or mud sediments by mammoths and other large mammals (e.g., equids and bovids) were documented in several parts of the sequence; they were detected either exposed on paleosurfaces or sectioned by excavation cuts. The mammoth footprints were found mostly in Areas 1 and 3. Of particular interest is a paleosurface bearing thickly overlapping circular stratigraphic deformations consistent with heavy trampling by mammoths at the edge of a watering hole. The skeleton of an adult female mammoth was also found here, as well as other bones, which in some cases were associated with stone implements. Scrape trace fossils discovered in the bed of a then-dry stream were probably made by mammoths searching for water. In many instances, mammoths tread upon archeological fragments that had been lying on the surface, displacing them and/or sinking them into the substrate (Haynes, 2007; Haynes, 2012).

2.12. ST. MARY RESERVOIR, CANADA

Skeletal remains of bovids and equids were discovered at the St. Mary Reservoir in southwestern Alberta (Canada), together with tracks of camelids, bovids, equids, cervids, and mammoths imprinted in aeolian silts and medium-fine-grained sands. The site is about 1.5 km long and 0.5 km wide and runs along the bank of the paleo river channel, adjacent to present-day Wally's Beach. The track-bearing horizons are dated at the late Pleistocene and contain hundreds of proboscidean tracks and trackways. The footprints - which were probably made by woolly mammoths (*Mammuthus primigenius*) - had been imprinted into soft, muddy sediments and often have diagnostic features.

Based on the tracks, this particular mammoth population was dominated by adults, with a far smaller proportion of juveniles and calves than would be expected in a stable or expanding population at such a site. This suggests that at the end of the Pleistocene, this species was stressed and undergoing a demographic crisis. This decline was shared by all North American megafauna prior to its extinction, which was probably brought about by multiple causes, including overhunting by humans (McNeil et al., 2002). The St. Mary Reservoir population, for instance, was likely to have been affected by human presence, as can be inferred by the many stone artifacts found here, as well as evidence of killing and butchering of horses and camels during a human occupation that the most recent research has dated at about 13 cal ka BP (Waters et al., 2015).

2.13. WHITE SANDS, NEW MEXICO, USA

Numerous horizons bearing human footprints dating to the late Pleistocene have been found at White Sands National Monument in New Mexico; the tracks had been impressed in gypsum-rich sand and silt sediments along the edge of a drying-up lake. Some of the many ichnosites discovered here are of exceptional interest, such as a surface bearing 60 human footprints dated between 23 and 21 ka ago, i.e., the earliest known evidence of human presence in North America (Bennett et al., 2021). Another surface bears a trackway consisting of 26 human footprints (dating to between 16 and 10 ka ago) directly associated with one made by a giant ground sloth; based on track analysis, the animal was being stalked by the human, presumably a hunter (Bustos et al., 2018).

One of the most important discoveries in the area is that of a double trackway, about 10 ka old, comprising over 400 human footprints. At least 1.5 km long, this is the longest known fossil human trackway in the world. The two parallel trails head in opposite directions and were made by the same individual, probably a young woman, carrying a child in one direction but not in the other (Bennet et al., 2020).

The trail made by the woman and child was still fresh when it was crossed at different points by a giant sloth and at least three proboscideans, most likely Columbian mammoths (*Mammuthus columbi*). The animals' trackways were in turn crossed by the other trail, indicating that the woman made it on her return journey, this time alone. The fact that the ground was moist enough to retain all these footprints before it dried out completely indicates that the time span between the two human passages and the various animal ones was very short, probably no more than a few hours in all. At one point of the outbound trackway, the human footprints were deformed by a mammoth track, which in turn was stepped into by the woman on her way back.

Columbian mammoth footprints are very abundant in the White Sands area (e.g., Lucas et al., 2007; Urban et al., 2018; Bennett et al., 2019). The ones that cross the human trackway are circular or elliptical, with diameters measuring from 35 to 75 cm. While the giant sloth appears to have stopped abruptly upon coming upon the human trail, shuffling around a few steps before quickly moving on, the pachyderms seem to have been totally unconcerned as they crossed it, most likely because they did not perceive humans - at least these ones - as a threat (Bennet et al., 2020).

3. ICHNOLOGICAL RESEARCH AT A PALEOLITHIC SITE: SCHÖNINGEN

Schöningen is a well-known Paleolithic complex in Lower Saxony (northern Germany). The archeological sequence formed during the Middle Pleistocene on the shore of a paleolake that had filled a glacial depression. The twenty or so single occupation occurrences of archeological interest that have been recorded to date - some of which in a peaty environment, others in one rich in calcareous mud - have yielded stone artifacts, bone and wood implements, vertebrate and plant remains, and many types of microfossils. The stratigraphic sequence, the artifacts, the paleobotanical and paleofaunal analysis, and the absolute datings that set them at about 320-300 ka ago, all indicate that the archeological deposits pertain to MIS 9 (see the overview on the site in Serangeli et al., 2023).

Schöningen's paleoenvironmental conditions made it possible for sediment surfaces to receive, retain and preserve tracks. Starting in 2018, a specific line of research has focused on old and new ichnological discoveries, most of which have occurred at two sites - Schöningen 13 I and Schöningen 13 II-2 Untere Berme - located at

Fig. 5 - Schöningen, view of the Speersockel, with the abandoned lignite quarry in the background.

the western edge of the large lignite quarry that exposed the Pleistocene sequence (Fig. 5) (Serangeli et al., 2020; Altamura et al., 2020d, 2023). Other possible fossil tracks have been identified at Schöningen 13 II-2, Schöningen 13 II-2-1 and Schöningen 13 II-4.

The fossil tracks found at these sites include many proboscidean footprints which were certainly made by Eurasian straight-tusked elephants (*Palaeoloxodon antiquus*), the only elephant species documented here in the interglacial levels, in various parts of the sequence. The remains of at least ten elephants have been excavated to date, including those of two juveniles and the almost complete skeleton of an older female, approximately 50 years old, which was associated with stone and bone implements (Serangeli et al., 2020, 2023; Venditti et al., 2022).

3.1. SCHÖNINGEN 13 I

In the summer of 1994, an archeological investigation of the Schöningen 13 I site - about 200 m north of Schöningen 13 II, or Speersockel ("area with the spears"), where the famous Schöningen wooden spears were discovered - included a 325-square-meter area of Layer 2, which seems to have been muddy shore sediment that was exposed when the waters of the paleolake receded for some time, ca. 320 ka ago (Altamura et al., 2023). On the surface of this layer, archeologists found and documented dozens of fossil tracks spread over a 65-square-meter area (Fig. 6), but they were not studied in depth and their discovery was only mentioned briefly in a few German-language publications on the Schöningen excavations (e.g., Thieme and Maier, 1995; Thieme, 2007; Mania and Altermann, 2015). These tracks have now been reviewed by examining the relevant archival documentation (sketches and photographs), as well as the six plaster casts made of them when they were discovered (Altamura et al., 2023).

The paleosurface contained about 70 footprints of large and medium-sized vertebrates, including bovids and cervids; about half of them featured morphometric characteristics typical of elephants (Fig. 6). The tracks - most of which were in a poor state of preservation - were distributed rather uniformly on the surface, though a few of them were aligned, probably as part of single trackways. The elephant footprints - some sub-circular, some elliptical - were clustered in a few areas of

Fig. 6 - Schöningen 13 I, Level 2 (ca. 320 ka). View of the ichnosurface excavated in 1994 and detail of two proboscidean tracks.

the north-western portion of the surface, many of them overlapping each other or aligned. The ones that could be measured have diameters ranging from 27 to 60 cm and were probably made by small groups of elephants of various ages, including many young individuals, walking along the muddy lakeshore. The track-bearing surface also yielded a few bone fragments pertaining to an equid and a large bovid, but no stone implements nor any other human trace (Altamura et al., 2023).

3.2. SCHÖNINGEN 13 II-2 UNTERE BERME

In 2002, archeological excavations began at the Schöningen 13 II-2 Untere Berme site, a few dozen meters south of the Speersockel site. A total area of 450 m^2 has been explored since then, yielding about 520 finds, including faunal remains, lithic artifacts, and carbonized wood (Serangeli et al., 2015). In 2018, a large track-bearing surface was discovered, 68 m^2 of which have been exposed and studied to date. The tracks had been impressed on a layer of calcareous mud with a clay-silt matrix and were eventually covered up by sandy-silty and peaty sediments (Figs. 7 and 8). Paleobotanical and sedimentological studies indicate that this surface, which was located on the shore of the paleolake, had been frequented at a time when the waters of the lake were receding during a climate phase that favored the growth of an open, grass-rich woodland (Altamura et al., 2023).

The track-bearing surface has been exposed on an excavated area measuring about 20x5 m and oriented in an NW-SE direction; it is mostly sub-horizontal,

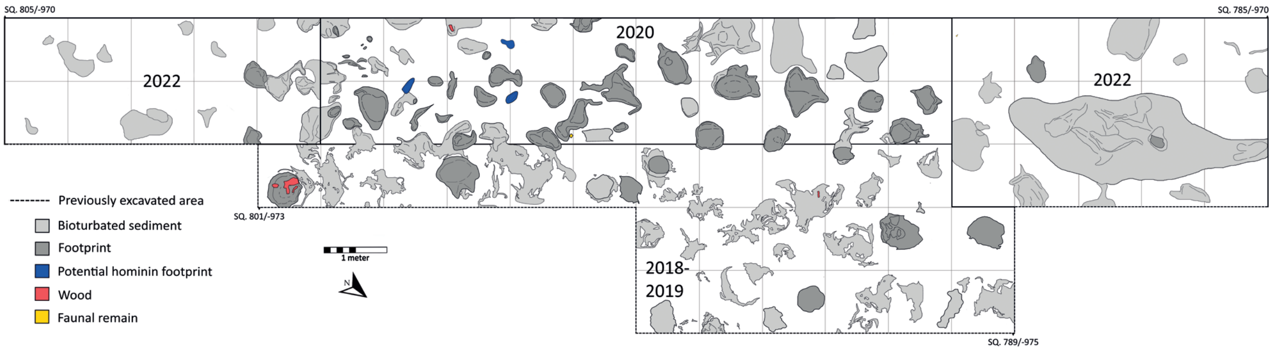

Fig. 7 - Schöningen 13 II-2 Untere Berme (ca. 300 ka). Planimetric map of the ichnosurface excavated between 2018 and 2022.

Fig. 8 - Schöningen 13 II-2 Untere Berme. View of the ichnosurface excavated between 2018 and 2020.

with irregularities and ripples that typically form on submerged mud deposits (Fig. 8). In 2022, a shallow channel-like depression, about 4 m long, was found in the north-western side of the investigated area; as yet it is unclear whether it was formed by water erosion or by biological agents. Fragments of wood were found in the sediments that filled the depression, as well as in some of the track infills (Fig. 9), but not on the rest of the surface. While the surface of the lacustrine clay layer is intensely bioturbated, especially in the center of the excavated area, the number of stratigraphic disturbances appears to decrease at the NW and SE ends (Fig. 7).

While some of the bioturbations are load structures with well-defined outlines and peat infills, others - especially those in the north-eastern part of the excavation – are hard to make out, with infills consisting of peat sediments mixed with the reworked substrate deposit (Fig. 7). This difference is probably due to the tracks having been impressed at different times. At first, the deposit was waterlogged, and the overlying peat layer was still rather thin, so that trampling reworked the sediments in depth, resulting in large bioturbations with no diagnostic features. Later, when the lakeshore had dried out more and the peat layer had become thicker, mammals walking on the surface did not sink into it as much as they had done before, hence their tracks were better defined, and their infills, consisting of the most part of sediments from the overlying peat layer, more homogeneous (Altamura et al., 2023).

Most of the footprints were made by elephants, and only a very few by bovids, equids, or other indeterminate vertebrates. Three footprints appear to have been made by juvenile or adult hominins; since the context is dated about 300 ka ago, they probably belonged to a late form of *Homo heidelbergensis* that was evolving into *Homo neanderthalensis* (on this topic, see, e.g., Di Vincenzo and Manzi, 2023, in this volume, and references therein).

The better-preserved bioturbations are for the most part elliptical or round impressions, with axial diameters ranging from 31 to 75 cm (Fig. 9). The true tracks (*sensu* Bennett and Morse, 2014) that could be identified are 31 to 55 cm long, with concave walls and bottoms, and deformed and raised rims (Fig. 10). In the case of tracks sectioned by excavation cuts, undertracks, and micro-faults are present in the substrate sediments beneath them, indicating the biogenic nature of these load structures (Fig. 11) (e.g., see Bennett et al., 2019; Altamura and Gioia, 2020). The larger tracks are consistent with juvenile and adult straight-tusked elephants (*Palaeoloxodon antiquus*). Fragments of wood have been found in the infill of several tracks, crushed into the sole of the footprint by the animal's weight (Fig. 9). There is also a megafaunal footprint with three lobe-shaped appendixes on one side, a shape consistent with rhinocerotoidean tracks (Altamura et al., 2023).

Although only four small faunal remains have been found in direct association with the tracks, several bone fragments and lithic artifacts were discovered during

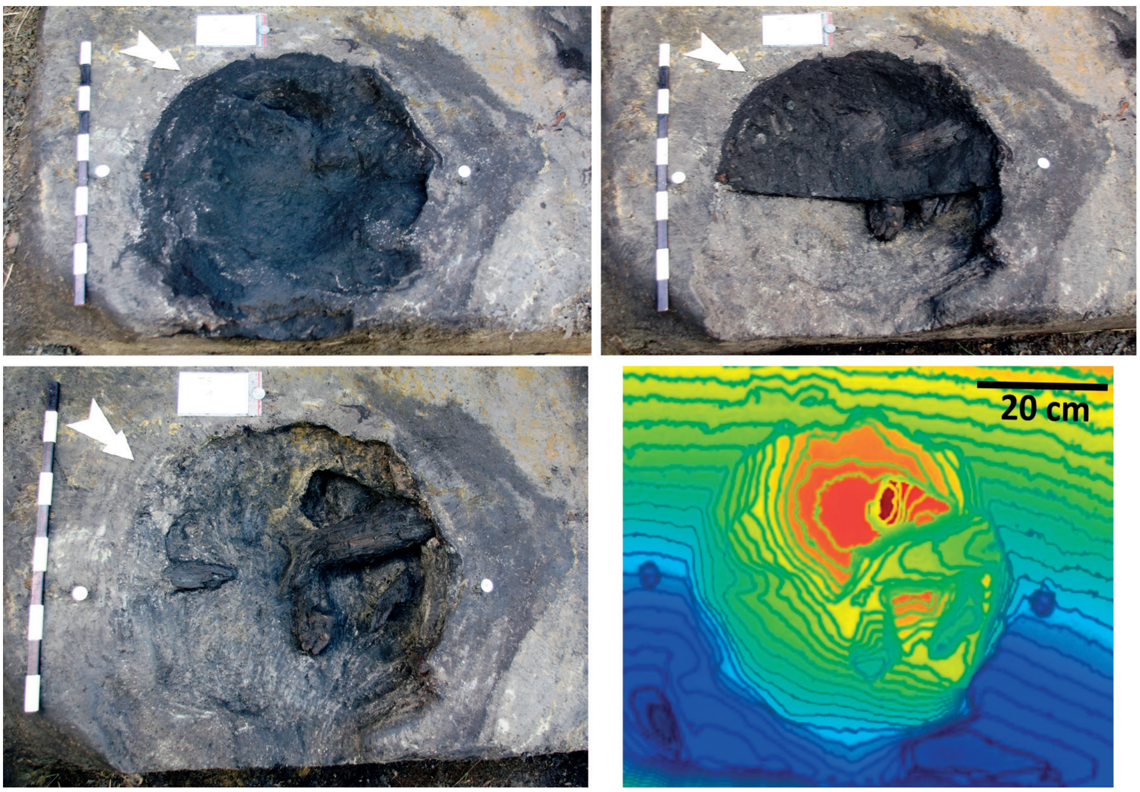

Fig. 9 - Schöningen 13 II-2 Untere Berme. Proboscidean footprint before, during, and after infill removal, and 1cm-contour map of the emptied track. Note the large fragments of wood at the bottom.

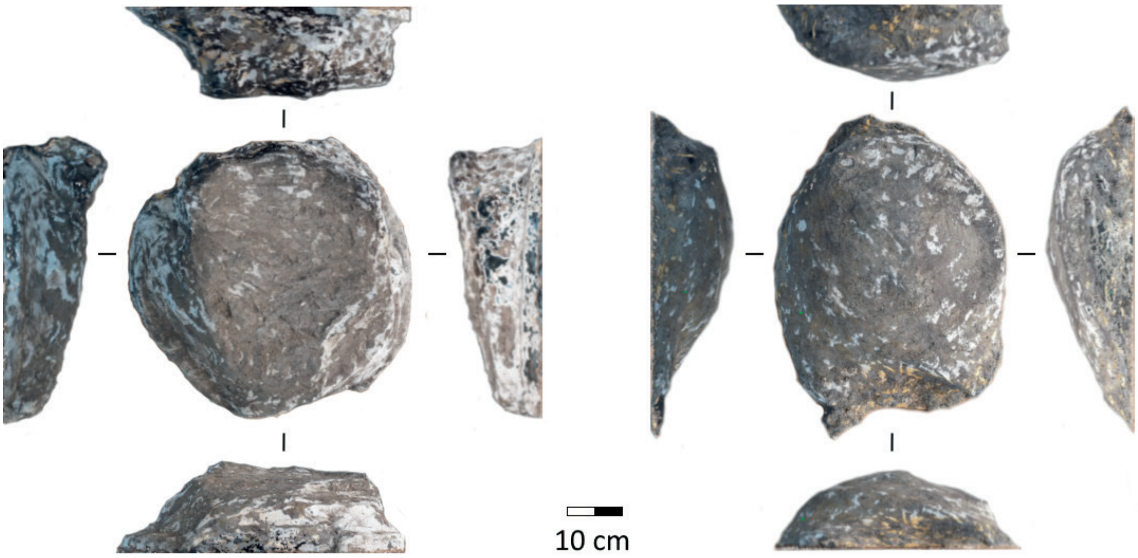

Fig. 10 - Schöningen 13 II-2 Untere Berme. 3D reconstructions of the positive plaster casts of two proboscidean footprints, showing the soles and walls of the tracks.

Fig. 11 - Schöningen 13 II-2 Untere Berme, 2022 excavation, south-east sector. Large bioturbations cut through vertically by the excavation. Note the stratigraphic deformations of the substrate (undertracks).

earlier excavations in archeological levels associated with the frequentation phase of the ichnosurface. Various large and medium-sized mammal remains are attested here, but no proboscideans (Altamura et al., 2023). A flint side-scraper was found on the edge of the infill of what appeared to be a bioturbation and has since been identified as a probable elephant track (Fig. 12).

The tracks were recorded with drawings, photographs, and 3D software. Moreover, plaster casts were made of several diagnostic tracks (Fig. 10), while others were

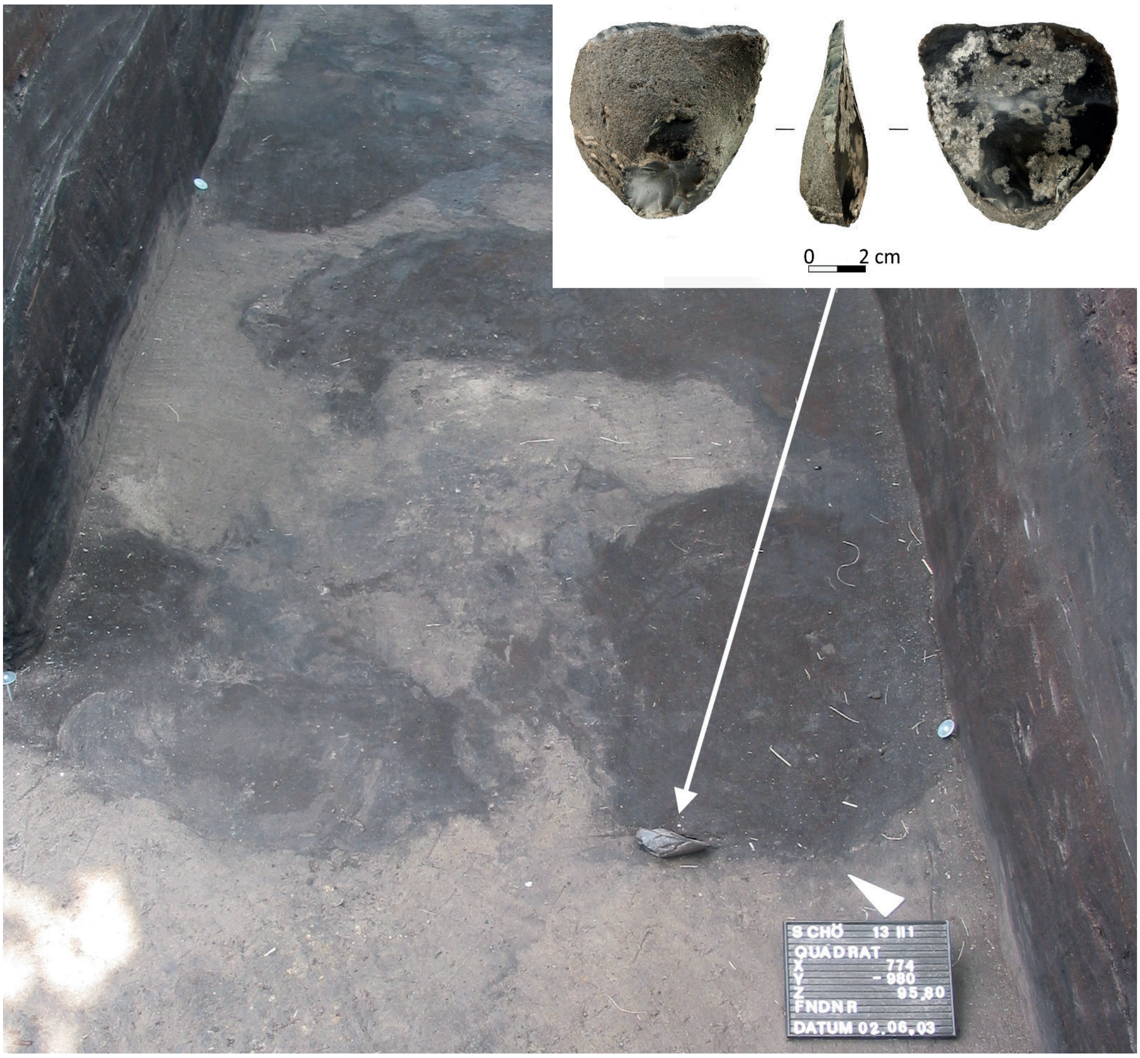

Fig. 12 - Schöningen 13 II-2. Side-scraper unearthed within the infill of a possible bioturbation.

removed from the site with the slab of sediment that contained them.

3.3. OTHER ICHNOLOGICAL FINDS AT SCHÖNINGEN

Other probable ichnological traces have been detected thanks to the preliminary review of part of the graphic and photographic documentation relating to the archeological excavations carried out at Schöningen before 2018. Several erosion or load structures have been recorded, but they have not yet been studied nor interpreted as being vertebrate and invertebrate fossil tracks, hence they are a potential subject of future research.

Based on the relevant excavation records, proboscidean tracks may be present at the Schöningen 13 II-2 (Fig. 13), Schöningen 13 II-2-1, and Schöningen 13 II-4 (Fig. 14) sites, in sequences located near the Speersockel area. These ichnites are elliptical, with diameters measuring about 25 to 40 cm. The ones that were cross-sectioned by the excavation show a marked boundary between substrate and infill, both along the walls and the bottom of the erosion structures, and an underlying deformation of the substrate sediments.

The absence of footprints where one would expect them to be is also noteworthy. We are referring to the almost complete skeleton of an adult female straight-tusked elephant recently found at the Schöningen 13 II-3 site (Serangeli et al., 2020, 2023; Venditti et al., 2022). For instance, one of its legs was almost complete, with well-preserved, articulated bones. The stratigraphy under it, however, consists of laminar, sub-horizontal peaty sediments with no noticeable - at least for now - signs of bioturbation or load-caused deformation (Fig. 15). This could mean that the elephant did not stand on that precise spot when it was still alive, in which case its leg could have ended up in that position after its death, displaced by decomposition processes or other natural, biological, or even human agents.

In this case, the absence of footprints can tell us where the animal did not walk before reaching the place where its carcass was found, or, conversely, where the heavy

Fig. 13 - Schöningen 13 II-2. Possible proboscidean footprint sectioned by the excavation cut.

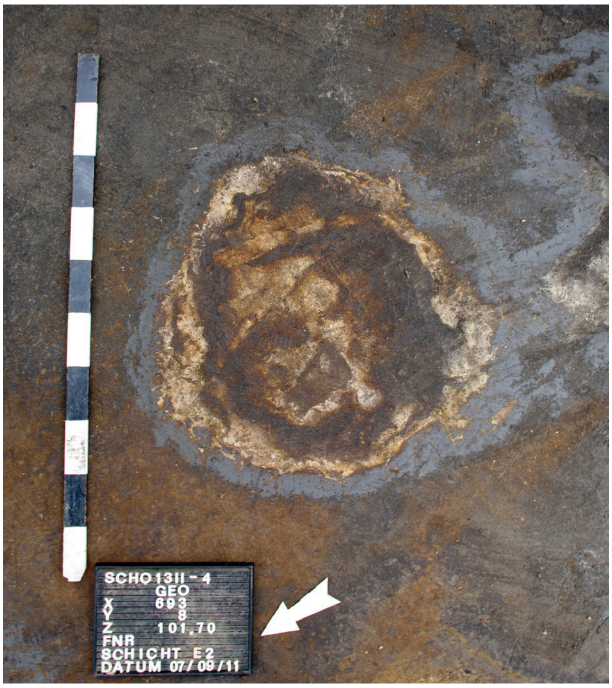

Fig. 14 - Schöningen 13 II-4. Excavation of a possible proboscidean footprint.

body of the dying or dead animal lay, flattening out the underwater peat deposit and erasing any deformation its trampling may have previously caused to be formed in the sediment. Hopefully, the studies now underway will be able to shed light on this aspect (cf. Serangeli et al., 2023).

4. DISCUSSION AND CONCLUSIONS

The contribution of ichnological research to the study of prehistoric sites is a major one. Fossil tracks have been documented on outcrops exposed by erosion (e.g., aeolianites, tuffs, evaporites), discovered in sand, silt, or clay deposits during stratigraphic excavations, or identified in archival photos and drawings. At the sites described above, the very presence - or absence - of tracks entails the identification of walking and frequentation surfaces, not a foregone occurrence in geoarcheological contexts. Tracks are formed and retained only when a number of favorable factors occur at the same time, hence their presence and morphological features provide further information (sediment composition, moisture content, sedimentation and lithification rate, and extent of biological presence) on the state of the substrate and of the environment at the time the trackmaker walked on that particular surface (Laporte and Behrensmeyer, 1980; Cohen et al., 1993; Ashley and Liutkus, 2003; Bennett and Morse, 2014; Pasenko, 2017; Altamura, 2019; Bennett et al., 2019).

Lithics and bones are usually quite resistant to taphonomic processes and before burial they may be subjected to displacement, transportation, fragmentation, or deterioration. For instance, an elephant bone can lie exposed on the ground for 40 years or so before disintegrating, and even be carried over great distances by natural or biological agents (Haynes, 2015). When this is the case, such a find can constitute only a generic

Fig. 15 - Schöningen 13 II-3. Excavation of the articulated leg bones of a straight-tusked elephant lying on top of peat sediments that do not contain any load deformations.

element in the reconstruction of the background of an archeological or paleontological context. Hence, the integrity and autochthony of an archeological deposit need to be carefully evaluated to assess the chronological and ecological reliability of the finds, and therefore be able to reconstruct the communities that lived in the area when that deposit was formed (e.g., Méndez-Quintas et al., 2023, in this volume, and references therein). Tracks, on the other hand, are anchored to the place where they were made and do not survive long when exposed to taphonomic, meteorological and/or biological agents (Bennett and Morse, 2014; Roach et al., 2016); hence, they provide reliable snapshots of who was present at a site at a specific moment in time, bearing witness in situ to a particular episode of frequentation of that surface even when remains are scarce or totally absent.

Their tracks can be the only indication that proboscideans were once present at a particular location. This is the case with most of the sites described in this paper, where generally very few or no proboscidean skeletal remains have been found and ichnology plays a major role in complementing paleontological data to reconstruct ancient faunal complexes.

The recurring presence of fossil proboscidean tracks at Plio-Pleistocene archeological sites around the world further demonstrates that various species of hominins and proboscideans long coexisted and often shared the same paleoenvironments. The elephant tracks discovered at Laetoli, Atella, and Foresta had been impressed on the surface of volcanic deposits; this offers interesting insights on the behavior of these large animals during catastrophic events, and their reaction and resilience capacities, a subject rarely addressed in literature (e.g., Altamura et al., 2017). Generally speaking, however, fossilized elephant and mammoth tracks are usually found in places where the paleoenvironment consists of wetlands, such as lakeshores, marshes, spring fields, riverbanks, and coastlines. The reasons for this are both ethological and taphonomic: on the one hand, proboscideans, like most mammals, were and are attracted to bodies of water; on the other, liminal environments positioned between dry and submerged areas favor track formation and preservation (e.g., Cohen, et al., 1993).

Besides the mere spatial sharing of moist or wet environments, where food resources usually abound, the frequent association of fossil proboscidean tracks with human presence could point to behavioral and economic interactions. In some cases (e.g., at Laetoli, Foresta, Alathar, and White Sands), elephants/mammoths seem to have just passed through areas (transit sites) that happened to be frequented by hominins as well. At other sites, however, it appears that hominins could have been engaging in specific subsistence strategies. At Ileret, for instance, the trackways made by human adults walking along the shore of an ancient lake may indicate the existence of groups of hunters searching for prey (Roach et al., 2016). The elephant footprints at Atella sink deep into what was once a muddy substrate, indicating that the animals may have become stuck in the mud, a circumstance that would have made it easy for human groups to kill or scavenge them (Fabiano and Zucchelli, 2003), as has been documented, for example, at the Polledrara di Cecanibbio site (Santucci et al., 2015).

The tracks found at Gombore II-2, Schöningen 13 II-2 Untere Berme and Matalascañas show that these were animal congregation sites that were also frequented by small, mixed-age groups of hominins engaged in various functional activities (Altamura et al., 2018, 2020b, 2023; Neto de Carvalho et al., 2023), for whom the attractiveness of these sites would have been enhanced by the possibility of finding carcasses of large animals to scavenge. At the Murray Springs and the St. Mary Reservoir sites in North America, and at Lake Nojiri in Japan, several proboscidean tracks have been found associated with specialized kill sites (McNeil et al., 2005; Haynes, 2007; Kondo et al., 2001, 2018; Matsukawa and Shibata, 2015).

Now and then, surfaces with proboscidean footprints have also yielded lithics and other kinds of tools (e.g., Gombore II-2, Atella, Foresta, Schöningen, Matalascañas, Casal de' Pazzi, Murray Springs, St. Mary Reservoir), thus confirming that hominins were not simply passing through these locations but were also engaged in functional or subsistence activities; at older sites, however, we are still unable to draw with certainty a connection between these human activities and the passage of elephants. Conversely, at Pilauco, a late-Pleistocene site in Chile, it is a human ichnite, together with lithic artifacts, that indicates that this may have been a *Notiomastodon platensis* butchering site (Moreno et al., 2019), similar to the 0.75-million-year-old hippo butchering site at Gombore II-2 (Altamura et al., 2018, 2020b). At White Sands, however, the fact that the mammoth trackways do not indicate any reaction to the human trail they crossed suggests that - at least at that time and place - these animals did not perceive humans as particularly dangerous predators. Conversely, the mammoth tracks at the St. Mary Reservoir site point to a population decline that researchers believe could be due in part to hunting by humans. Ichnological evidence has thus added an interesting element to the debate about whether Pleistocene hominins were hunters or scavengers vis-à-vis of proboscideans.

There are other methodological implications for which the presence of proboscidean fossil tracks at archeological sites needs to be taken in due account. For instance, elephants/mammoths could have displaced surface materials, including archeological ones, both horizontally, by hitting them with their feet as they walked, and vertically, by pressing them underfoot into the ground (Eren et al., 2010; Haynes, 2012). For example, stone implements, and bone fragments were found sunk into the sediments under several pachyderm tracks at Melka Kunture and Murray Springs (Haynes, 2007; Altamura et al., 2018, 2020a), and a bone fragment was stuck in the bottom of the track found at Casal de' Pazzi (Altamura and Gioia, 2020). At Schöningen 13 II-2 Untere Berme, wood, bone fragments, and possibly stone artifacts and pollen from the overlying layers, were found both in the trampled sediment of the ichnosurface and in the track infills (Altamura et al., 2023). Moreover, when trodden upon by large animals, stone, bone, and wood materials (both natural and archeological) can end up bearing marks - fractures, abrasions, polishes, pseudo-retouches, and so forth - that can be very similar to those made by humans (Haynes, 2012; Yravedra et al., 2019; Domínguez-Solera et al., 2021). Hence, any spatial, taphonomic, paleobotanical, technological, or traceological study of a prehistoric site which also contains bioturbations made by ancient proboscideans must take them into consideration to evaluate the impact that these animals may have had on that site.

As noted above, when reconstructing an archeological context, tracks are highly significant but very fragile elements. We would therefore like to end this paper with a note on the preservation of fossilized proboscidean tracks. At many of the sites we mentioned, the tracks were exposed to degradation, whether by erosion or destroyed by the archeological excavations themselves. Even when the track-bearing surfaces are lithified, like the pyroclastic deposits at Laetoli and Foresta, once the tracks have been exposed to the elements they start to deteriorate, albeit at a slower rate than others thanks to the surfaces' geological features. Hence, their preservation continues to be a major issue (e.g., Dalton, 2008; Musiba et al., 2008), which needs to be addressed through conservation, the building of protective structures over them or even reburial using previously excavated sediments or artificial material. The problem is even more urgent when the tracks were impressed on soft sediments: all it takes is a rainy day to erase tracks that had survived intact underground for hundreds of thousands of years. Unfortunately, in this case, a permanent solution has yet to be found. All that can be done for now is to document the tracks before they disappear, via old and new techniques - sketches, photographs, ground-penetrating radar images, and 3D software (using 3D photogrammetry, laser scans, and so forth to obtain 3D models and prints). At the most, if a certain degree of invasiveness is admissible, casts can be made (using plaster, silicone, resins, or other substances), and blocks of track-bearing deposits can be consolidated and removed for safekeeping, transferring them to a protected environment.

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