**Ichnological and archaeological evidence from Gombore II OAM,
Melka Kunture, Ethiopia: An integrated approach to reconstruct local
environments and biological presences between 1.2 and 0.85 Ma**

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Ichnological evidence from Gombore II OAM, Melka Kunture, Ethiopia: an integrated approach to reconstruct Pleistocene environments and 'ghost' biological presences between 1.2-0.85 Ma

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Abstract
New ichnological data are available at the prehistoric site of Melka Kunture, Upper Awash valley in Ethiopia. Excavation of new test pits enabled us to explore the volcanic and fluvio-lacustrine sequence at the Gombore II Open Air Museum archaeological site (ca. 0.85 Ma). This has allowed a detailed reconstruction of the palaeoenvironment and of the fauna present in the time interval between >1.2 and 0.85 Ma. Various-sized mammals, birds, molluscs as well as hominins left tracks throughout the sequence, and document a varied fauna and associated behaviours. The hominin tracks add to those already reported for the site. The mollusc traces document the presence and orientation of water streams which, according to the associated traces, were visited by hominins, mammals and birds. Most of these traces were found within levels traditionally considered barren for archaeology, they all document life activity and are obviously always *in situ*. This confirms the potential of the ichnological research as an important complementary tool for archaeological investigations.
Keywords: Melka Kunture, Pleistocene, Gombore, Archaeology, Fossil footprints, Ichnology, Palaeoenvironment

1 Introduction

In the last decade, ichnology has emerged as a powerful tool for reconstructing past landscapes and the ecology of sites relevant to our understand of human evolution. While the record of fossil Plio-Pleistocene hominin footprints is constantly increasing (e.g., Bennett and Morse, 2014; Masao et al., 2016; Hatala et al., 2017; Bustos et al., 2018; Helm et al., 2018; McLaren et al., 2018; Duveau et al., 2019; Muñiz et al., 2019), the integrated analysis of footprints, lithostratigraphy, palaeontology and archaeology is less common (but cfr. Fabiano and Zucchelli, 2003; Mastrolorenzo et al., 2006; Silva et al., 2013; Bennett and Morse, 2014; Pastoors et al., 2015; Mussi et al., 2016; Ledoux et al., 2017; Panarello et al., 2017, 2020; Altamura et al., 2018; Moreno et al., 2019; Romano et al., 2019).

Melka Kunture, consists of a cluster of Pleistocene sites, that spread over 100 sq. km on the Ethiopian Highland at about 2,000-2,200 m a.s.l.. It is located along the Upper Awash river, some 60 km south of Addis Ababa (Fig. 1). French researchers started their investigations in 1960s (Bailloud, 1965; Chavaillon and Piperno, 2004), and in 1999 the activity was taken over by an Italian Archaeological Mission, currently under the direction of one of the authors of this study (MM).Melka Kunture is a complex accumulation of Pleistocene fluvial and lacustrine deposits, interbedded with volcanic units from eruptive centres a few dozens of kilometres away. Absolute radiometric dating (K-Ar and $^{40}Ar/^{39}Ar$), and magnetostratigraphic analyses give dates that start at 1.8 Ma (Chavaillon and Piperno, 2004; Morgan et al., 2012; Tamrat et al., 2014). A range of archaeological artefacts have been recovered over the years (Chavaillon and Piperno, 2004). On this plateau, the hominins would have faced a challenging environment, with a cold and high-mountain ecosystem characterized by vegetation of the dry evergreen Afromontane forest and grassland complex, with variable high-altitude forests and grasslands (Mussi et al., 2016; Bonnefille et al., 2018). Accordingly, Melka Kunture could be viewed as a testing ground for the hominin survival and adaptative capabilities during the earliest Out of Africa episodes.

Recently, the Pleistocene record has been enriched by the discovery of ichnological surfaces. The fossil footprints were not reported, nor described, during the previous 50 years of research. Since 2013, bioturbated surfaces were identified during fieldwork, and more were spotted during a review of the archival documentation of past excavations. They occur in the localities Kella Gully (1.8-1.7 Ma), Garba IVD (1.6 Ma), Garba XII (1.3-1.1 Ma) and elsewhere in the Garba Gully (1.3-1 Ma), Simbiro III (1.2 Ma) and Garba I (0.6 Ma) (Altamura, 2017, 2019). In the Gombore Gully, trampled layers were documented both by surveys (Gombore I and Gombore Iγ, ca. 1.5-1.2 Ma; Gombore X, ca. 0.7 Ma; Gombore III, ca. 0.6-0.4 Ma), and by extensive excavations and test pits. A wellpreserved trackway and some isolated footprints made by a hippopotamus community were discovered at Gombore II-2 just above a tuff dated to 0.7 Ma (Altamura et al., 2017). Just below the same tuff, an ichnosurface exposed over ca. 35 m^2 hundreds of hippopotamus, bovid, equid, bird and other small mammals footprints. Eleven hominin footprints were identified on this surface, some of them belonging to potentially young individuals (1-3 years old). They were associated with rich archaeological and faunal evidence, including fossil bones of hippos butchered by the multi-age hominin group, suggesting activities conducted directly on the spot (Altamura et al., 2018).

Five metres below this ichnosurface, in the final units of the Lower Pleistocene sequence, lies Gombore II, a large Middle Acheulean site with several sub-sites, dated at ca. 0.85 Ma. Surface bioturbations at the interface between fluvial and lacustrine deposits were identified at one of these sites (Gombore II OAM). The excavation of fossil footprints started there in 2015 and continued in the following years focused on the final Lower Pleistocene deposits which date from between 1.2 and 0.85 Ma. Most of the recorded ichnosurfaces show signs of bioturbation. Footprints are associated with lithic and faunal remains, but in many cases, they provide the only hint of any biological activity. New hominin footprints were also recorded from these units. We present this new ichnological evidence in association with a compendium of associated lithostratigraphy, archaeology and palaeontology data. By combining these different lines of evidence we are able to build a detailed reconstruction of the palaeoenvironments in which these units were deposited. More over this work points to the potential promise for further ichnological work in this area.

1.1 The Gombore Gully

Gombore is one of the small gullies on the right side of the Upper Awash River. During the Holocene, and up to present times, a seasonal stream has eroded the Lower and Middle Pleistocene beds exposing archaeological horizons. The Pleistocene deposit (ca. 20 m thick) are formed of fluvial and lacustrine sediments (sand, clay, gravel) interbedded with either primary, or reworked, volcanic tephras (Taieb, 1974; Kieffer et al., 2004; Raynal et al., 2004; Morgan et al., 2012; Mussi et al., 2016).

The area was first spotted by Bailloud in the early 1960s (Bailloud, 1965) and became the focus of both the French and the Italian expeditions (e.g., Chavaillon and Berthelet, 2004; Gallotti et al., 2010; Gallotti and Mussi, 2016, 2018; Mendez-Quintas et al., 2019). The stratigraphic sequence starts with Gombore I, a multilayered site with Oldowan and Early Acheulean evidence dated between 1.8 and 1.2 Ma (Chavaillon and Piperno, 2004; Morgan et al., 2012; Gallotti and Mussi, 2018). Higher up in the gully, an impressive Middle Acheulean layer, the so-called “main level”, spreads over some 1,000 m^2 and directly overlies a tuff dated to 0.87 Ma (Morgan et al., 2012; Mussi et al., 2016). The site was explored by various parcels: Gombore II-1 (70 m^2), Gombore II-3 (8 m^2), Gombore II-4 (13 m^2) and Gombore II-5 (9 m^2). In 2001, further 35 m^2 were exposed, fenced, protected with a thatched roof, left in full view for visitors and eventually called Gombore II Open Air Museum, or Gombore II OAM for short (SI Fig. 1). Overall, the main archaeological layer is a dense accumulation of cobbles mixed with thousands of lithic and faunal remains. The layer is ca. 0.15 m thick and locally split into two superimposed lenses (Chavaillon and Piperno, 2004; Gallotti et al., 2010). Mendez-Quintas et al. (2019) evidenced a direct anthropogenic contribution on top of the lag deposit of Gombore II OAM.

As elsewhere all over the Pleistocene sequence of Melka Kunture, the taxon *Hippopotamus* cfr. *amphibius* is abundant, representing a third of the whole faunal assemblage. The palaeoenvironment was suitable for hippos. Marshes and ponds along a meandering palaeo-Awash offered appropriate residential areas, with grazing surfaces nearby (Altamura et al., 2017). *Bovidae* are attested by a number of subfamilies such as Bovinae, Alcelaphinae, Reduncinae and Antilopinae. This suggests the co-existence of both open and humid spaces. Suidae, Giraffidae, Rhinocerontidae and Equidae are also documented, while carnivores (Hyaenidae and Canidae) are extremely rare. Only two bird remains are recorded (Pichon, 1979; Chavaillon and Berthelet, 2004; Gallotti et al., 2010). At Gombore II sub-sites hominins are well documented by thousands of lithic implements, obtained both by debitage and by shaping flaking methods. Typical Middle Acheulean implements, as handaxes and cleavers, are common. Furthermore, two hominin cranial fragments were discovered at Gombore II-1 (Chavaillon et al., 1974; Chavaillon and Coppens, 1986) and recently attributed to an early form of *Homo heidelbergensis* (Profico et al., 2016).

Above the main archaeological layer, a sandy and sandy-silty fluvio-lacustrine unit accumulated and is followed by a ca. 2 m-thick lacustrine deposit of clays and silty-clays. On the top of this unit, another sandy and sandy-silty interval includes the Matuyama-Bruhnes magnetostratigraphic boundary (0.78 Ma). The fossil footprints and archaeological traces of the Gombore II-2 site, the socalled
hippo butchering site, post-date the palaeomagnetic reversal (Chavaillon and Berthelet, 2004; Tamrat et al., 2014; Mussi et al., 2016; Altamura et al., 2018, 2019). A 1 m thick distal volcanic tuff sealed the palaeolandscape at 0.7 Ma (Morgan et al., 2010; Altamura et al., 2018). The fluvial environment and the fauna quickly recovered, allowing mammals and eventually hominins to repopulate the area (Altamura et al., 2017, 2019). In the uppermost Gombore Gully, late Acheulean evidence is found *in situ* at Gombore III, which is dated to between 0.6 and 0.4 Ma site (Mussi et al., 2016). MSA and LSA implements were collected on the surface by Bailloud (1965) and Taieb (1974).

1.2 Ichnological record adjacent to Gombore II OAM

In the sedimentary sequence of the area pre-dating the Matuyama-Brunhes reversal, archival and published pictures and sketches of past excavations, provide hints of possible footprints (see e.g., Mussi et al., 2016; Altamura and Mussi, 2017; Altamura, 2019). These had previously gone unnoticed, or their significance was not recognized. More potential tracks and bioturbations were spotted along the standing excavation walls of Gombore II-1 and Gombore II OAM. This consist of sharp undulations and deformation at the interface of silty and sandy layers. They penetrated a few cm into the underlying layer giving a visible true track in cross-section below which further deformation is visible, presumably the undertrack. The true tracks are infilled by the overlying sediment. Along the standing walls of Gombore II OAM, some potential tracks have rounded bases and are up to 23 cm wide. Due to their size these have been tentatively attributed to hippos or to large-sized ungulates (Mussi et al., 2016).

In 2015 erosion revealed the surface of a Pleistocene silty layer, just north of the Gombore II OAM. Several sandy spots were noticed on this surface. A small test of 1 m^2 was opened, called Gombore II OAM North Footprint test (henceforward Test Pit A, Fig. 2). Many vertebrate footprints were recorded, including small hominin tracks (SI Fig. 1) and a preliminary report was published (Altamura and Mussi, 2017).

In 2017, a second test pit was opened (2 m^2) outside the southwestern corner of the open-air museum (Gombore II OAM South-West Footprint test, henceforward Test Pit B, Fig. 2). Here, the alternating silts and fine sands that capped the main archaeological layer were preserved for an interval of around 1.6 m. This part of the sequence was thought to be sterile, since previous excavations had found no bones or lithics in this layer. However, along the excavation walls of Gombore II OAM, just 2.5 m away, a fluvial channel bank with bioturbations were visible. The test pit was stopped when we reached the main archaeological layer. Twelve bioturbated layers were documented throughout the sequence, but no archaeological remain above the rich Acheulean level at the bottom were identified.

In 2018 and 2019, we made a third test (6 m^2) along the north-western corner of Gombore II OAM

(Gombore II OAM North-West Footprint test, henceforward Test Pit C, Fig. 2). In this area the seasonal stream had already eroded the Pleistocene deposits overlying the main archaeological layer, as well as the archaeological layer itself. We found the remains of the latter re-deposited within the modern clayey soil (Black Cotton Soil). The new excavation started from the 0.87 Ma tuff layer (Morgan et al., 2012) at the base of the main archaeological deposit. The underlying sequence was explored through a depth of 1.8 m. Lithic and faunal remains were unearthed in association with five trampled layers. Another tuff, in the lower part of the test, corresponds to the "former B tuff" of the Gombore I Gully, described by Raynal et al. (2004) and dated by Morgan et al. (2012) to 1.2 ± 0.07 Ma. At the base of the test, two sandy layers and a sandy/gravel layer below the deepest trampled silt were brought to light over 1 m^2 and excavated over a sample area of 0.5x0.5 m.

2 Materials and Methods

The excavations were led by the first author of this contribution (FA) under the direction of the head of the Mission (MM), removing the layers through *décapage horizontal*, that is excavating progressively one thin layer at a time. This method allowed us to follow, expose and examine each layer for tracks in turn. Eighteen different bioturbated surfaces were identified within the Test Pits A, B and C and are numbered progressively from the top to the bottom. Different colour, consistence and composition allowed us to identify these bioturbations and discriminate between substrate and track infill. Sand or silty sand usually filled the deformed silty or silty-sandy substrate. Each track was emptied using lancettes and small brushes. In some cases, however, the track infill and the substrate were so similar to each other that it was impossible to distinguish them properly. In this case (e.g., Layer 8), we simply noted the presence of bioturbation rather than try to explore its 3D form, or we excavated small sample areas.

Each palaeosurface was recorded graphically and photographically, and by photogrammetry to produce 3D models with the software Agisoft Photoscan Professional. Once emptied of their infill, artificial plaster casts were produced for seven hippo tracks of Level-14 and for the hominin footprint of Level-17 (Test Pit C), whereas the hominin footprints of Level-5 (Test Pit B) and of Test Pit A were removed in a consolidated block of sediment (SI Fig. 2, 3). All the archaeological materials and the casts are kept in the Authority for Research and Conservation of Cultural Heritage storehouse at Addis Ababa, Ethiopia. The 3D models where scaled and auto-rectified such that the plane of the surface was perpendicular to the viewer using Digtrace (www.digtrace.co.uk). Contour maps were produced in Digtrace and colour rendered images using Cloudcompare (https://www.danielgm.net/cc/). Ages were calculated with reference to a standard growth curve for modern humans (de Onis, 2006), accepting that this has clear limitations when making inferences above extinct hominins.

3 Results

3.1 Litho-stratigraphic sequence

The assembled evidence from the Gombore II OAM section, and from the new excavations of Gombore II OAM allowed to reconstruct a continuous 3.2 m-thick litho-stratigraphic sequence (Fig. 3, 4). The documented sequence extends below and above the main archaeological layer. While the overlying stratigraphy is fairly well-known from previous studies (e.g., Kieffer et al., 2004; Raynal et al., 2004; Gallotti et al., 2010), the underlying section has not been well documented before. Overall, the deposits formed in a fluvial environment and are generally composed of fine-grained overbank deposits with distal ash fall events. Two coarse deposits interpreted as lag deposits indicate higher energy flows that accumulated cobbles, pebbles and archaeological remains mixed with fine and coarse sands. These lag horizons are rich in archaeological artefacts (the main archaeological layer) and are partially exposed in Test Pit C at the base of the sequence. Although the origin of these layers is related to fluvial dynamics concentrating artefacts Mendez-Quintaz et

al. (2019) have argued for a limited direct anthropogenic contribution to the uppermost layer.
Two primary, although distal, ash falls are found below the main archaeological layer in Test Pit C. One lies underneath the main archaeological layer of Gombore II OAM, while the second occurs almost at the base of the excavation. In Test Pit B, the overbank deposit overlying the main archaeological layer is cross-cut obliquely (N-S) by a palaeo-channel. This channel is also visible in Gombore II OAM standing walls, just 2.5 m away. Raynal et al. (2004: 161) interpreted this as the northern bank of the palaeochannel (Fig. 4; SI Fig. 4). The fluvial sedimentation continues with sandy sediments inter-bedded with reworked ash fall.
Detailed description of the Tests Pits A and C stratigraphy is reported below from bottom to top (Fig. 3):
-sandy layer with volcanic gravel, up to 0.05 m thick, partially excavated over 0.5x0.5 m. It yielded fourteen lithic implements and a single faunal remain;
-gravel layer with obsidian pebbles included in a sandy matrix, more than 0.1 m-thick, partially exposed at the bottom of Test Pit C and excavated over 0.5x0.5 m. The layer is rich in archaeological remains: fifty lithic implements, including a small bifacial tool, and sixteen faunal fragments were found;
-sandy layer, up to 0.04 m thick, partially overlying the previous one. It was similarly explored on a limited area, yielding six lithic implements and a faunal remain;
-silt layer, 0.02 m thick. It was explored as the overlying ones over the whole Test Pit C (6 m^2). Sterile, but showing signs of bioturbation (Level-17), including possible hominin footprints. This layer formed in a low-energy fluvial environment;
-grey tuff level, 0.3 m-thick, compact and poorly sorted, probably a distal ashfall. A bone fragment was recovered at the base. We correlate this layer with the “former B tuff” or tuff 9978/9986 of the Gombore I gully, described by Raynal et al. (2004) and Kieffer et al. (2004) as a 1 m-thick volcanic deposit with lenses of various granulometry and content, mostly originated by a distal ash fall linked to a rhyolitic magma. The altitudinal position of tuff 9978/9986, of ca. 2019.5/2021 m asl (Raynal et al., 2004; Kieffer et al., 2004), is consistent with the altitude of the tuff documented within the test (ca. 2019.3/2019.6 m asl). The layer is dated to 1.2 Ma by Morgan et al. (2012)
-mud deposit, compact and with sub-horizontal grey to brown lenses. The surface of the layer, 0.4 m thick, is bioturbated (Level-16). Sterile; the granulometry shows relatively calm conditions of deposition in a probable floodplain pond environment;
-sands mixed with pumices and mud chips coming from erosion of underlying layer, 0.1 m thick. Eleven lithic finds and a bone fragment were recovered;
-silty-sandy lenses, locally interbedded with sands and sparse obsidian gravels, overall 0.15 m thick. Fifty-six finds, both obsidian implements (N=42) and faunal remains (N=14), were documented in Test Pit C. The layer is bioturbated (Level-15). The silty layer exposed in Test Pit A (1 m^2) is stratigraphically correlated with this level, since both overlay a layer of sand mixed with pumices; furthermore, considering the overall N-S inclination of the sequence, they are at similar altitude (2,020.9 and 2,020.3 m a.s.l. respectively). From Test Pit A, a single small mammal remain was found within a footprint infill;
-silt with a bioturbated surface (Level-14), ca. 0.1 m thick. Two obsidian implements were recovered from this layer;
-sands with mud chips, ca. 0.2 m thick. Sterile, but potential bioturbations were noticed on the surface (Level-13);
-partially eroded silty-sandy deposit, 0.9 m-thick. This is the dacitic tuff 9951/2151 with vegetal imprints reported by Kieffer et al. (2004) and Raynal et al. (2004). This layer was originated by an ash fall deposited in a watery environment. Morgan et al. (2012) dated it to 0.875 ± 0.01 Ma.
Above the 0.875 Ma tuff, we found the main archaeological layer of Gombore II subsectors. It

consists of a channel-floor lag deposit, 0.1/0.2 m-thick, composed by coarse volcanic pebbles and archaeological and faunal remains included in a well-sorted sandy matrix (Raynal et al., 2004; Gallotti et al., 2010; Mendez-Quintaz et al., 2019). The overlying sequence was documented both at Gombore II OAM and within Test Pit B (2 m^2). We interpret it as a resulting from channel migration and reworked volcanic products. From bottom to top we brought to light: -silty-sandy compact deposits, overall 0.8 m-thick, alternating with thin (up to 0.05 m-thick) silt lenses. The planar-bedding silty lenses, slightly inclined toward north, are probably ashfalls reworked by water, i.e. the so-called Tuff C in Raynal et al. (2004). The surface of the deposit was deeply eroded toward south by a channel stream, that cuts obliquely the pre-existing layers up to a 0.4 m (SI Fig. 4). Sterile, but many lenses are bioturbated (Levels-9/12);

-deposit made up by alternating sandy-silty and silty-sandy lenses, 0.8 m-thick, in planar bedding and generally slightly inclined toward south. This probably is the infill of the channel bed that eroded the underlying sequence. Sterile, but many lenses are bioturbated (Levels-1/8). The upper part of the deposit is partially disturbed by Holocene erosion and pedogenesis.

The stratigraphic sequence suggests a fluvial setting influenced by volcanic ash fall material. The sedimentation took place mainly in an overbank environment affected by the migration of the paleo-Awash River and by crevasse splay/channel deposits.

3.2 Ichnosurfaces

We recorded 18 bioturbated surfaces (Fig. 5-8; SI Detailed description of footprint layers; SI Fig. 5-18). The tracks were left by various animal species and by hominins as well (Table 1). On the palaeo-surfaces were occasionally evidenced ripple marks from water stream activity or desiccation cracks from sediment exposure and drying.

3.2.1 Bivalves

Almond-like impressions are ubiquitous in Test Pit B Level-3 to -12, and common in Test Pit C Level-14 and -17 (Fig. 9). They are 5 to 40 mm long, 5 to 20 mm wide and up to 10 to 20 mm deep. They are often accompanied by 5 to 20 mm wide elongated, continuous furrows which are either straight, curvilinear, meandering or irregular. Almond-like impressions and furrows are often superimposed to each other, as in Test Pit B Level-11, and clear transitions between these two morphotypes (compound traces) are also observed, as in Test Pit B Level-4. These traces display in some layers a marked preferential orientation.

We interpret the almond-like impressions and the furrows as respectively resting and grazing traces of invertebrates such as bivalves (e.g., Ekdale and Bromley, 2001; Lawfield and Pickerill, 2006; Monaco et al., 2016). In some instances, a complete U-turn was probably produced by the invertebrate moving around in grazing behaviour. The identification of natural casts of shells, as in Test Pit B Level-4, provide weight to our interpretation (SI Fig. 19). They most probably belong to unionid clams. In Test Pit B Level-10, even the impression of shell ornaments happens to be preserved.

3.2.2 Hippos

On Level-14, hippo footprints, belonging to at least 5 individuals, are preserved and show clear anatomical details such as the four fingers and the plantar pad (Fig. 10; e.g., Bennett et al., 2014; Altamura et al., 2017, 2018). On the palaeo-surface at least four discrete trackways are present, as well as other isolated tracks (SI Fig. 2 and 14). The largest elliptical depressions are up to 40 cm long and belong to adults, while few prints are smaller, ca. 27 cm long, and are likely related to babies or young animals (see comparisons in Altamura et al., 2017). Alternatively, the smaller tracks can be attributed to the pygmy *Hippopotamus aethiopicus*. However, this is much less likely, as this species has a single tentative identification at Melka Kunture in much earlier layers, at ca. 1.7 Ma (Geraads et al., 2004).

Level-13, -15 and -17 yielded big-sized elliptical imprints as well, but they lack any diagnostic feature and cannot be attributed with certainty to hippos.

3.2.3 Herbivores

Herbivore traces consist of bipartite depressions, produced by split hooves, ranging from the size of those of large bovids (up to 20x20 cm), as *Connochaetes taurinus*, to those of suids and small antelopes (4-12 cm wide) (Fig. 10; e.g., Leakey, 1987; Liebenberg, 1990; Roach et al., 2016; Altamura et al., 2018). Middle- and small-sized ungulates have been documented in Level-3, -5 to -7, - 14, 15 and-17; they are usually represented by isolated tracks, but they sometimes occur in larger number, suggesting possible trackways, as in Test Pit A. Big-sized ungulates left their traces, up to 20 cm long, in Level-6, -15 to -17.

3.2.4 Varia

In Level 1 of the Test Pit B there is a cluster of four sub-elliptical depressions, 7 to 12 cm in diameter. Each is a circular depression with smaller impressions on a side, consistent with carnivore impressions (e.g., Leakey, 1987) and resembling modern-day hyena tracks (Liebenberg, 1990). We surmise that the circular depression is the central foot pad, while the smaller impression on the side (often numbering four) are finger imprints (Fig. 10).

On Level-3, we evidenced few tracks that are possibly both isolated traces and part of a trackway of a tridactyl animal (Fig. 10). There is an elongated digit III impression and two well-divergent, lateral, shorter digit II and IV impressions of the same length, consistent with the morphology of a small bird track (e.g., Aramayo et al., 2015). In Level-3 and -6, slightly oblique burrows of about 3-5 cm of diameter were observed, showing meniscate structures typical of backfilled invertebrate burrows (e.g., Buatois and Mangano, 2011)

3.2.4 Hominins

Eight potential hominin footprints are documented, but more partial or poorly-preserved tracks were also recorded, which could not be positively recognized as of human origin. The oldest stratigraphically of these (F1-2, Fig. 11) occur on Level-17 in Test Pit C and are directly overlain by the 1.2 Ma tuff. Two more footprints (F3-4, Fig. 11), in Test Pit A, were imprinted on a silty layer that we correlate with Level-15, and accordingly are 1.2 to 0.87 million-years old. The most recent traces (F5-8, Fig. 11) occur on Level-5 of Test Pit B, overlying the 0.87 Ma tuff and well below the Matuyama-Brunhes magnetostratigraphic boundary at 0.78 Ma. This boundary occurs ca. 2.5 m higher up in the Gombore gully sequence (Gallotti et al., 2010; Morgan et al., 2012; Mussi et al., 2016; Mendez-Quintas et al., 2019). The suggested age of the hominin traces is therefore in the range of 0.85 Ma.

On the three surfaces identified with possible hominin footprints the following observations can be made (Fig. 11 and Table 2). The first track on Level-17 (F1, Fig. 11, a-b) has strong anatomical properties of a footprint in terms of clear heel, well defined toe impressions. The hallux is strongly divergent which may reflect slippage during foot placement. The dimensions are typical of either a post 16 sub-adult male or a female (Table 2). The second track on Level 17 (F2, Fig. 11, c-e) is poorly defined and not definitively identified here as being of hominin origin. There are a number of heel-like impressions on this surface, but a lack of clearly defined anatomical toe impressions. In Test Pit A there is one clear hominin footprint (F3, Fig. 11, f-g) with good anatomical detail for the toes that are typical of deeply impressed human tracks. There is also a smaller potential hominin track (F4, Fig. 11, f) which has some hominin-like characteristics, however with a maximum length of only 87 mm this would give the track-maker of around 6 months old based on the modern human growth curve. Level-5 contains a range of footprints partially superimposed. At least four tracks are visible, labeled F5-F8 in Figure 11. Perhaps the best developed anatomically of these is F7 which is also the largest in terms of length at 174 mm. The smallest is F8 which is just 133 mm long. Using a modern growth curve as first approximation this would place the track-makers age 4 to 6 years old. They are deeply impressed tracks showing poor anatomical definition and in the case of F5 and F6 are superimposed in almost directions. A minimum of two individuals is suggested with a maximum of four.

3.3 Archaeological material

No archaeological material was discovered in Test Pit B in the 1.6 m thick sequence overlaying the main archaeological layer. This Acheulean layer was exposed over just 0.6 x 0.4 m at the feet of the eastern standing wall of the pit (SI Fig. 4).

In Test Pits C and A a total of 159 finds were recovered (Table 3). Actually, the three gravel and sandy layers at the bottom of Test Pit C were rich in archaeological material (88 finds, i.e. the 55.3% of the total). However, not many finds are recorded as only surface cleaning and a 0.5 x 0.5 m excavation were performed over the lowest part of this sequence. Moreover, the finds from the three lowermost layers of Test Pit C show abraded and rounded surfaces, suggesting water transport over some distance, while the remains collected elsewhere in the sequence were better preserved with lithics often retaining sharp and 'fresh' cutting edges. Overall, we collected 124 modified and unmodified stone remains and 35 bone fragments (Fig. 12). Obsidian pebbles (max. 50 mm in length) were abundant in the lowermost layers, but were not collected since they are the outcome of water stream deposition. We sampled a single natural basalt pebble (80 mm in length) that could be a manuport.

The lithic industry includes 123 pieces. The hominins appear to have mostly selected obsidian (N=75), while basalt and other volcanic rock make the remaining of the sample (N=48). Most obsidian implements are either flakes or flake fragments (N=46), which frequently are debitage debris. The knapping method attested by flake dorsal scars and technological features point to simple debitage methods as the unipolar, centripetal or multidirectional exploitation of striking platforms. Seven small obsidian cores (max. 49 mm in length) were retrieved from the lowermost archaeological levels. They mostly confirm debitage by centripetal exploitation, both unifacial and bifacial (Fig. 12, no. 6). Three sidescrapers and 16 flakes with some marginal retouch were also discovered (Fig. 12, no.1-5). Overall, the flakes are relatively small, in average just 21.8 mm in length. An elongated flake (63 mm) was produced by the shaping of a handaxe (Fig. 12, no.7). Among shaping products, obsidian was exploited to produce a small bifacial tool (64x42x20 mm) and a tiny chopping tool (36x28x18 mm) (Fig. 12, no.8-9).

The 33 unretouched and 6 retouched basalt flakes and flake fragments (Fig. 12, no.10-11) are larger than the obsidian ones (length average = 36.1 mm); they are the outcome of simple or centripetal flaking methods, as a single basalt core also suggests. Basalt and tuffaceous pebbles were also used as percussors and heavy duty tools (N=8). The faunal assemblage is quite limited (N=35). The bone fragments are mostly small and undiagnostic pieces (50 mm-long in average). Few specimens are long bone fragments or trabecular ones. There are three hippo tooth fragments, a small-sized herbivore and an equid tooth (Fig. 12, no.12-13). A small rodent lower jaw is the only find from Test Pit A (Fig. 12, no.14).

In Level-14 of Test Pit C, two obsidian flakes were almost in contact with two hippo footprints (SI Fig. 20). They were lying obliquely as pushed downward by a heavy load and probably by the hippo feet pressure. In Level-16 and -17, and mostly so in Level-15, the finds were either lying on the surface or stuck either in the footprint sandy infill or in the covering sands, providing more direct association with the trampled palaeo-surfaces.

4 Discussion

The ichnological tests pits next to Gombore II OAM provide detailed information allowing to reconstruct the general environment as well as the archaeological and faunal presences in this part of the landscape. The 3.2 m thick sequence formed between 1.2 and 0.85 million-years ago, therefore recording changes in the landscape over a relatively long time span. Sands, silts and clays were the prevailing sediments during this time. As described in previous research (Raynal et al., 2004; Mussi et al., 2016; Mendez-Quintas et al., 2019), these were deposited in a low-energy environment, perhaps as part of a meandering river system characterized by ponds, marshes and floodplains, interrupted periodically by volcanic activity. Nevertheless, there were occasional episodes of faster flow as indicated by the lag deposits and the preservation of the tracks themselves. To be preserved they had to be relatively quickly buried by fine-grained sediments. The track infilling was not an erosive process, so while occurring rapidly it is still consistent with a low energy environment. The only coarse-grained laterally-extensive level is the main Middle Acheulean surface, left in full view at Gombore II OAM, discovered at the bottom of Test Pit B and found eroded at the top of Test Pit C. It is a thick accumulation by fluvial transport, at the bottom of a channel, of pebbles, lithics and faunal remains, partly iso-oriented, and later settled by hominins (Mendez-Quintas et al., 2019).

A notable feature is the recurring presence of bivalve resting and/or grazing traces on many of the bioturbated layers within Test Pits B and C. Some palaeosurfaces (Level-9, -10, -11, -12) show only bivalve traces, while in other levels (Level-3, -4, -5, -6, -7, -8, -14, -17) the latter ones are associated with hominin or other animal footprints. The bivalve traces discovered are consistent with the morphological and behavioural features of unionoids (e.g., Ekdale and Bromley, 2001; Lawfield and Pickerill, 2006; Monaco et al., 2016; Knoll et al., 2017; Carmona et al., 2018) and are tentatively assigned to unionoid clams. These clams still populate the Upper Awash River at Melka Kunture (A. Girod pers. comm. to MM in 2019) (SI Fig. 19). Unionoid shell fossils or endocasts have been recovered elsewhere at Garba III, Unit II, c. 0.6 Ma (Chavaillon and Berthelet, 2004; Mussi et al., 2014); within the Gombore Gully in the sequence between Gombore Iδ and Gombore II, >0.875 Ma (Mendez-Quintas et al., 2019), and at Gombore III, 0.6-0.4 Ma (SI Fig. 19) (Altamura, 2017). At these sites the shell valves are mainly paired and still joined in life position. The molluscs died *in situ* after having been buried by the sediment load without managing to escape, or after having experienced a severe ecological stress (e.g., Knoll et al., 2017). On the opposite, in the ichnological test pits at Gombore II-OAM, the traces appear to belong to a living community that was apparently able to easily leave. As a consequence there is no fossil shell, which prevents us from directly inferring a species. Acidic waters and other local factors could also have hampered shell preservation.

Freshwater mussels and other molluscs are useful indicators in bio-geographic and archaeological reconstruction (e.g., Girod, 2005; Ashkenazi et al., 2010; Wolverton et al., 2010; Mienis and Ashkenazi, 2011; Urban and Bigga, 2015; Shchelinsky et al., 2016; Van Bocxlaer, 2017; Lundquist et al., 2019; Lyubas et al., 2019). Widespread worldwide and in Africa (Bacci,1948; Daget, 1998; Van Damme and Van Bocxlaer, 2009; Graf and Cummings, 2011; Lopes-Lima et al., 2017), these molluscs provide detailed information, since they have developed specific living, reproductive and feeding habits (Vaughn et al., 2008; Zając et al., 2016). Unionoids are sessile and filter-feeding bivalves that need clear, well-oxygenated running water (Vaughn et al., 2008). Usually these molluscs live in permanent rivers, not in ephemeral ones. This suggests that the bivalve-rich trace layers of Test Pits B and C probably experienced clean, running water. Since in Level-3, -4, -5, -6, -7, -8, -14 and -17 unionids were associated with bird and mammal footprints and desiccation cracks, we surmise that at the time the water was relatively shallow, or that seasonal fluctuations in water level and sediment exposure occurred before new deposits sealed the palaeo-surfaces.

The occurrence of invertebrate meniscate burrows (Layer-3 and -6) is consistent with a stable substrate. On the opposite, Level-9, -10, -11, -12, where part of the deposit was eventually eroded as a channel bank, show only molluscs traces. Even if most freshwater mussels usually do not colonize the bottom of channels deeper than 2 m, this suggests all the same that they lived at the bottom of a slightly deeper water course, where mammals and birds had no access and where seasonal water fluctuations could not expose the sediment to the air, except for short time intervals such as in Layer-9 (incipient mud cracks). In these levels many traces are iso-oriented NW-SE. This probably was the direction of the water flow for a consistent amount of time, as the same orientation is also suggested by ripple marks in the underlying Level-14 and -16. Alternatively, the isoorientation of the molluscs could have been the outcome of palaeoenvironmental changes that led to population movements in a specific direction (e.g. Knoll et al., 2017).

The reproductive cycle of unionoids provides further information. Unionoid clams pass through a larval stage during their reproductive cycle. The larvae are obligate parasites of fish, using them as a mean of transport to spread through the drainage systems. Accordingly, unionoid and fish abundance are correlated and co-occur (Graf and Cummings, 2011). Fish are not unexpected at Melka Kunture, but they are not, so far, part of the fossil record and this is the first positive indicator of fish in the upper palaeo-Awash. Furthermore, the association between unionoids and mammals (in Level-3, -4, -5, -6, -7, -8, -14, -17) provides evidence that animals and occasionally young hominins were walking through shallow, clear and streaming water. This happened either while walking through the area, or/and when drinking clear water or washing themselves.

A close association between hominins and lake or river shores was already evidenced by the 1.5 Ma hominin footprints of Ileret, in Kenya (Roach et al., 2016), and by the 1.4 Ma hominin trail associated to bird and hippo footprints at Koobi Fora (Behrensemeyer and Laporte, 1981; Bennett et al., 2009). Shallow freshwater could also have been accessed in search of food, perhaps to capture fish or molluscs. The earliest recorded exploitation of aquatic animals by hominins dates back to almost 2 Ma (Braun et al., 2010), and the evidence increases throughout the Middle and Upper Pleistocene (Bosch et al., 2018). In later prehistoric times, unionoids are well recorded as part of hominin diet (e.g. Girod, 2005; Rabett et al., 2011; Szabó and Amesbury, 2011; Peres et al., 2016; Merzoug, 2017). They possibly were a small but valuable resource for the Pleistocene hominins of Melka Kunture.

The best-preserved hominin footprints are dated respectively to just before 1.2 million-years (Level-17 of Test Pit C); between 1.2 and 0.87 million-years (Level-15 of Test Pit A); and between 0.87 and 0.78 million-years (Level-5 of Test Pit B). They appear to mostly belong to young individuals, and while the anatomical details is relatively poor, the presence of heel and forefoot impressions allow them to be recognized definitively and they are consistent with other hominin traces in soft substrates (Bennett and Morse, 2014). They are one of a relatively few early ichnological sites currently, with older sites at Laetoli in Tanzania (3.6 Ma; Leakey and Hay, 1979; Leakey and Harris, 1987; Masao et al., 2016); Koobi Fora and Ileret in Kenya (1.5-1.4 Ma; Behrensmeyer and Laporte, 1981; Bennett et al., 2009; Hatala et al., 2017); and Happisburgh in the UK at 1-0.78 Ma (Ashton et al., 2014). The new data from the Gombore II OAM, confirms that juveniles are the most common trace in the Melka Kunture ichnological record, as has already been seen at the 0.7 Ma site of Gombore II-2 (Altamura et al., 2018). Children were free to move around in this marshy paleolandscape,

while the rest of the group, including adults, was presumably not far away.

Carnivores and birds are extremely rare all over the Pleistocene faunal record of Melka Kunture. The possible carnivore (hyena?) track of Test Pit B Level-1 is consistent with the discovery at Gombore II of remains of either *Hyaena* or *Crocuta* (Geraads et al., in press). Overall, the fauna of the ichnological record mirrors the fauna of the coeval archaeological layers of Melka Kunture, as the main level of Gombore II OAM. However, the fossil tracks reveal a substantial component of small- and middle-sized animal while hominins and hippos were scarcely present. Accordingly, ichnology is complementary to the archaeological and palaeontological record but also overturns it at Gombore II. As it is easier for big bones rather than for those small animals to preserve and enter the archaeological record, and the same holds true for lithics, due to taphonomic and formation processes both the hominin and hippo population are overestimated.

5 Conclusions

The combined lithostratigraphical, ichnological and archaeological records allow a detailed palaeoenvironmental reconstruction. The lithostratigraphic deposits, and the ubiquitous unionid traces, show that the research area was part of a hydrographical system that we tentatively call palaeo-Awash. Eruptive products periodically impacted the area, primarily in the form of distal ash falls (Kieffer et al., 2004). More volcanic deposits occur as reworked ones above the main archaeological level (Kieffer et al., 2004; Raynal et al., 2004; Gallotti et al., 2010; Mendez-Quintas et al., 2019). Even if the registered volcanic episodes were mainly distal ash falls, we surmise that an ash layer up to 1 m-thick strongly impacted on the palaeoenvironment, covering grass and even bushes (Altamura et al., 2017). As the sequence above the 1.2 Ma tuff at the base of Test Pit C documents, the record of hominin and herbivorous presence is interrupted after the eruption, but they soon recovered and repopulated the area (Level-16 and -15).

Below the 0.87 Ma ignimbrite, in Test Pit C and Test Pit A, a few dozens of lithic artifacts and faunal remains were discovered, mostly from the basal layers where a relatively high-energy water stream accumulated gravels and coarse sands. As the remaining layers formed in a low energy environment, preserving footprints, whereas the lithics have sharp edges, excluding long-distance transport, those sporadic archaeological remains likely reflect an autochthonous or paraautochthonous assemblage. Centripetal debitage and the small bifacial tool quite similar to a small handaxe at the base of the sequence, which pre-dates 1.2 million years; later on a shaping flake from Test Pit C, and eventually at ca. 0.85 million-years the ample record of the main archaeological layer of Gombore II, all provide evidence that the lithic industry belongs to the Acheulean technocomplex. The layers were wet and the surface often muddy, as in Level-15 and -16. Hominins occasionally walked through (Level-15 of Test Pit A and Level-17 of Test Pit C), and knapped stone nearby, as evidenced by the lithic implements ending at that spot. Variously-sized mammals, mostly ungulates, roamed in the same area. In Level-14 the footprints show that the hippos were ubiquitous, as always at Melka Kunture. The area had to be relatively close to the occupation areas, the hippo pools, as they produced trails on a wet, unconsolidated silt. Hominins were not far from these dangerous animals, as small obsidian implements were over trampled and sunk under the animal feet (SI Fig. 20), suggesting coexistence. Hominin-hippo coexistence and interaction is evidenced again in full later on, 700,000 years ago, at Gombore II-2, another archaeological and ichnological site of Gombore gully (Altamura et al., 2018, 2019).

The 0.87 Ma ignimbrite, almost 1m-thick, sealed this landscape and the record described above, filling meanders, ponds and other depressed areas. A palaeochannel developed, as part of the resulting hydrographical changes. Cobbles, as well as faunal and lithic remains accumulated in this channel forming the stone-rich surface of the main middle Acheulean layer (Gallotti et al., 2010; Mendez-Quintas et al., 2019). Later, in a low-energy environment, alternated silts and fine sands accumulated over 0.8 m, filling in this watercourse. Freshwater bivalve traces are exclusively recorded, evidencing that the silts and sands deposited underwater. The palaeochannel appears to have then migrated and the infilling deposits were eroded obliquely along the new channel banks (Raynal et al., 2004; Gallotti et al., 2010). In turn, this channel was filled in by alternating sands and silts, more 0.8 m-thick. Ungulates, birds, young hominins (Test Pit B, Level-5) and eventually a carnivore produced new sets of tracks which were often in association with freshwater bivalves and mud cracks, suggesting intermittent or shallow water. Neither bones nor lithics occur and only the footprints are the only evidence of biological activity.

While the ichnological record is rich and complex, artifacts and palaeontological remains were not unearthed above the main archaeological level. This was seen when excavating Test Pit B and similarly recorded at Gombore OAM by Gallotti et al. (2010). The sequence had been deemed “sterile” by previous workers who did not document the easily-destroyed traces and this ‘ghost evidence' was simply overlooked. The integration of archaeology, lithostratigraphy and ichnology, allows to reconstruct in much greater detail what happened between 1.2 and 0.78 Ma in the Gombore Gully. The area was characterized by a fluvio-lacustrine environment which was subaerial or at times covered by deep and shallow waters. It was cyclically invested by eruptions that impacted in different ways on the local hydrography, landscape evolution, and animal peopling. Young hominins were attracted by watery environments along river or pond shores, entering shallow waters just as other mammals and birds did. The recurrent association with water clams suggests that fish and freshwater molluscs possibly were a welcome supplement to the diet of these final Lower Pleistocene hominins.

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Author contributions

FA: conceptualization, excavations, archaeological and ichnological (vertebrate) analysis; MM: funding acquisition, project administration, scientific supervision of the investigations; MRB and SCR analysis of hominin ichnology; LM ichnological analysis (vertebrates and invertebrates); RTM lithostratigraphy and sedimentology. FA wrote the paper with MM, LM, RTM, MRB; all the authors reviewed and edited the manuscript.

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Captions

Fig. 1 Location map of Melka Kunture

Fig. 2 Location of Gombore II OAM and of Test Pits A, B and C.

Fig. 3 Stratigraphic log of the Gombore Gully with details of the sequence of the ichnological Test Pits at Gombore II OAM

Fig. 4 Stratigraphic and altimetric correlation of the standing walls of Gombore II OAM and of Test Pits A, B and C.

Fig. 5 Planimetries of Test Pit B: Levels -1/-6

Fig. 6 Planimetry of Test Pit B: Levels -7/-12

Fig. 7 Planimetry of Test Pit A (top left), and of Test Pit C: Levels -13/-14

Fig. 8 Planimetry of Test Pit C: Levels -15/-17

Fig. 9 Unionoids traces at Test Pit B: Level-10 before and after the excavations (a-b); Level-11 (c); excavated portion of Level-11 at the NE corner of the test pit (d); Level-12 (e).

Fig. 10 Footprints found in the ichnological Test Pits B and C: hippo footprints of Level-14 before (a) and after the excavation (b-e), including an hippo track overtrampled by a small-sized ungulate (e); big-sized ungulate footprints of Level-17 (f) and of Level-5 (g), the last one associated with mollusc and small-sized ungulate tracks; small-sized ungulate, mollusc and bird tracks (white arrow) of Level-3 (h); possible carnivore footprint of Level-1 (i).

Fig. 11 Pictures and elaboration of hominin footprints: contour map (a) and picture (b) of the track cast from Level-17, Test Pit C; contour map (c) and picture before (d) and after (e) the excavation of the second footprint from Level-17, Test Pit C; contour map (f) and picture (g) of the tracks found at Test Pit A; contour map (h) and picture (i) of the tracks from Level-5, Test Pit B.

Fig. 12 Archaeological materials from the excavations. Obsidian implements: retouched flakes (1-4), side-scraper (5), centripetal core (6), flake from handaxe shaping (7), bifacial tool (8) and chopper (9). Basalt implements: retouched flakes (10-11). Faunal remains: hippo (12) and equid (13) tooth, rodent jaw (14).

Tab.1 Attribution to species of the ichnological evidence divided per level, with association of lithic and faunal remains.

Tab. 2 Measures and age attribution of the hominin footprints F1-8.

Tab. 3 Typological characterization of the lithic industry and attribution of the faunal remains found in Test Pits A and C.

Declaration of interests

X The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

1

Ichnological evidence from Gombore II OAM, Melka Kunture, Ethiopia: an integrated approach to reconstruct Pleistocene environments and ‘ghost’ biological presences between 1.2-0.85 Ma

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Supplementary Information

SI 1 Detailed description of footprint layers

We recorded 18 bioturbated layers (SI Fig. 5-18). We describe below layer by layer the ichnological evidence, subdivided by excavation areas.

Test Pit B

Level-1. A bioturbated surface is preserved over a strip of 120 x 40 cm along the SE corner of the test. On the residual surface, made up by silty-sandy sediments, few traces can be seen in concave epirelief. Most of the tracks, 3 to 22 cm in length, are poorly diagnostic features. In the central part of the paleo-surface there is a cluster of four sub-elliptical depressions. Each track, 7 to 12 cm in diameter, is a circular depression with smaller impressions on a side. They are consistent with carnivore impressions (e.g. Leakey, 1987) and resemble modern-day hyenas tracks (Liebenberg, 1990). We surmise that the circular depression is the central foot pad, while the smaller impression on the side (often numbering four) are finger imprints.

Level-2. A small bioturbated sandy-silty lens is preserved over 60 x 50 cm in the SE corner of the test. The few concave traces do not allow a straightforward interpretation. The two central ones are wider, up to 32 x 25 cm, and a few cm deep.

Level-3.The traces are preserved as a concave epirelief over150 x 50 cm. Part of the bioturbated surface displays intense mud-cracking, sometimes starting from the traces themselves. A single 5x1 cm track with two slightly diverging and separated, oval, elongated and tapering impressions was likely produced by an ungulate (e.g., Aramayo et al., 2015). Two tracks are possibly part of a trackway and an isolated one are tridactyl. There is an elongated digit III impression and two welldivergent,
lateral, shorter digit II and IV impressions of the same length. These are likely bird tracks (e.g., Aramayo et al., 2015). The commonest traces, discovered at the center of the bioturbated surface, are almond-like impressions generally less than 2 cm-long. They are accompanied by 0.5 to1cm-wide elongated, continuous furrows which are either straight, or sinuous or irregular. The furrows happen to overlap each other and do not show any preferential orientation. We interpret the almond-like impressions and the furrows as respectively resting and grazing traces of invertebrates

such as bivalves (e.g., Ekdale and Bromley, 2001; Lawfield and Pickerill, 2006). More traces can be seen in the upper right corner of the bioturbated surface. Those are burrows with meniscate structures, about 3 cm wide, also produced by invertebrates (e.g., Buatois and Mangano, 2011).
Level-4. The traces are preserved in concave epirelief over 150 x 100 cm in the NE part of the excavation. The NW part of the bioturbated surface is interested by intense mud-cracking. A single

poorly-preserved track about 10 cm-long and 5 cm-wide shows a very long heel impression with a possible concave medial margin. It possibly was a human child track (e.g., Altamura et al., 2018). This surface also shows the usual almond-shaped and elongate furrows that we interpret as produced by bivalves, with a preferential NW-SE orientation. The transition between the morphotypes is clear. The furrow width varies from 0.5 to 2 cm while the almond-shaped traces have a maximum length of 3 cm. Natural casts of shells were also discovered, probably belonging to unionid clams, which gives more weight to our interpretation.
Level-5. Many tracks are preserved in concave epirelief all over the surface. Most are the shallow almond-shaped structures assumedly produced by unionid clams. In the central and south-eastern part of the excavation, larger tracks, mostly sub-elliptical in shape, could be the tracks of mediumand small-sized vertebrates, although no diagnostic feature is preserved. In the north-western corner of the test, four elongated impressions occur. They are consistent with hominin footprints, partially superimposed (F5-8).
Level-6. The traces are preserved in concave epirelief over the whole excavated surface. No sedimentary structures were observed. Four-five isolated tracks with two elongated parallel and separated imprints about 3-4 cm long were probably produced by small ungulates (e.g., Aramayo et al., 2015). A single track is about 15 cm wide and 15 cm long with two separated tapering impressions and was probably a big-sized ungulate. Small almond-like poorly-preserved traces are the resting traces of bivalves. More are invertebrate burrows. Two of them are parallel to each other and enter obliquely into the sediment, showing meniscate structures (e.g., Buatois and Mangano, 2011). Some more burrows are probably bivalve resting traces.
Level-7. The traces are preserved in concave epirelief in the NE and S parts of the excavated surface. No sedimentary structures were observed. Several poorly-preserved almond-like tracks could have been bivalve resting traces; a single footprint in the SW corner likely is a mammal track.
Level-8. This sandy silty lever showed traces of possible bioturbation, but the infill matrix was almost identical to the substrate, so that it was not possible to properly isolate discrete footprints. Maybe in the first instance the substrate was too wet to hold any track. A small strip (80 x 20 cm) was explored on the southern side of the test, and many poorly diagnostic features were brought to light. Those are shallow traces, mostly NW-SE oriented, consistent with bivalve resting traces and burrows. An isolated circular depression in the western part of the investigated area might have been of a middle-sized mammal.
Level-9. The traces are preserved in the northern side of the excavation, while on the remaining area of the test they have been eroded by the channel bank. The surface is densely bioturbated. There is are superposed resting and grazing traces of bivalves, with a clear preferential orientation, although the details are not visible because the surface was not completely prepared (NW-SE).
Level-10. The traces are only preserved in concave epirelief over the northern part of the excavation due to channel bank erosion. Sedimentary structures include some incipient and thin mud cracks. The traces are well preserved, especially so in the middle part of the bioturbated surface. The

common almond-like impressions, sometimes clustering in groups, are the usual resting traces of bivalves. They are 2-4 cm long and 0.5-2 cm wide, with a maximum depth of 1-2 cm.The impression of the shell ornaments is sometimes preserved. These traces are associated with unornamented furrows, 0.5 to 2 cm-wide, that have a straight, curve or meandering course. In some instances a complete U-turn was probably produced by bivalves moving around in grazing behavior (e.g. Lawfield and Pickerill, 2006). In three instances or more, the almond-like traces are superimposed to the furrows. Overall, there is no preferential orientation.

Level-11. The traces are preserved all over the excavated surface but southward where they have been eroded by the channel bank.. The surface is intensely bioturbated, a large quantity of resting and grazing traces of bivalves occur. They show a clear preferential NW-SE orientation. Only a small portion of the surface was completely prepared and shows linear furrows, which are curve, straight or meandering and are associated to almond-like structures. These traces are commonly superimposed to each other.

Level-12. The surface is intensely bioturbated and the traces are preserved over most of the excavated surface, but not on the southern side where they have been eroded by the channel bank. Many are resting (almond-like) and grazing (linear, mostly curved and straight) traces of bivalves. They show a clear NW-SE preferential orientation and occur in decreasing numbers from north to south. The surface was not completely prepared.

Test Pit C

Level-13. The paleosurface of the sands with redeposited silt fragments, found just below the 0.87 Ma tuff, possibly shows bioturbations. The evidence was documented along the 2 southernmost squares of the test, while in the remaining northern 4 m^2 the layer surface was already altered by Holocene erosion. Potential tracks are represented by concave depressions, elliptical in shape, ranging from 12 up to 38 cm in length, and up to 10 cm deep. The features were filled by the overlying tuff deposit, hence they were empty and exposed at the surface at the time of the eruption. They do not show any diagnostic feature, but the shape and dimensions suggest that they are tracks left by medium and large-sized vertebrates.

Level-14. This silty layer is one of the best preserved trampled surfaces, showing many big-sized sub-circular concave epireliefs. A minimum of 24 discrete impressions were recognized, which were whole or partial tracks produced by large mammals. Eleven of them are complete and display diagnostic features. The entirely preserved specimens measure from 27x18 cm to 36x28 cm. They are characterized by a big rounded depression encircled on a side by four smaller digit-like impressions. The size and anatomical features are perfectly consistent with tracks left by hippos, usually formed by the rounded plantar pad and by the four load-bearing fingers, the last ones often underlined by sub-vertical walls of sediment between them (Behrensmeyer and Laporte, 1981; Bennett et al., 2014; Altamura et al., 2017, 2018). At least one of the tracks seems to have been overtrampled by an ungulate, since along the wall there is a vertical channel-like structure ending at the bottom in a bipartite impression resembling an ungulate split hoof. The hippo footprints suggest different individuals, both adults and young ones, that produced at least 4 discrete trails. Based on

the relative overlap of the tracks, at first a young individual (3) walked toward south-west; then an adult hippo (2) moved in the opposite direction, i.e. toward north-east; lastly two adult hippos (1, 4) moved toward south/south-east, overtrampling some of the preexistent footprints. Moreover, in the central-northern part of the test many resting and grazing traces of bivalves were evidenced, together with some shallow elliptical imprints, undetermined. In the same area, sub-parallel and SW-NE iso-oriented shallow linear depression are probably ripple-marks, suggesting a water flow with a N-NW/S-SE drainage.

Level-15. The layer is a silty-sandy sediment a few cm thick sandwiched between fine sand deposits. During the excavation, in the central part the sandy and silty lenses were churned and was difficult to isolate discrete bioturbations, while in the northern and southern areas the trampled level was fairly well preserved. The paleo-surface shows dozens of sub-circular and elliptical concave epireliefs. None is well defined and diagnostic, even if many tracks are formed by two flanked elliptical depressions that are consistent with the tracks left by small- and middle-sized ungulates, such as bovids or suids. In the southern side of the excavation, five big bioturbations aligned in a curved line penetrated the silty layer into the underlying sands, dragging down silt fragments. Big sub-circular depressions on the south and south-eastern sides of the test were apparently produced by big mammals like hippos. Mud ripples occur on the south-western corner of the paleosurface, suggesting that the substrate was quite wet when trampled.

Level-16. The top of this 0.4 m-thick consolidated silty-clayey deposit is bioturbated. The paleosurface is characterized by ripple marks, usually sub-parallel and SW-NE iso-oriented, but more irregular and with curvilinear trends in the eastern side of the test. Four distinct clusters of footprints were recorded. Three are present in the southern part of the surface, each with a welldelineated large bipartite impression, up to 20x20 cm in diameter and up to 9 cm deep. These tracks were produced by big-sized ungulates, as adult bovids. The track in the south-western corner probably overtrampled another ungulate footprint, suggesting a pes-manus compound track. The fourth trampling evidence is in the central-western part of the surface and is a elliptical depression, 32x24 cm wide and 4 cm deep, with concave walls and possibly a bipartite bottom.

Level-17. The lowest trampled layer is a 2cm-thick silt layer almost at the bottom of the test excavation. In its southern portion, three very shallow possible tracks are documented in the centraleastern part of the layer. Two are poorly diagnostic, while the third one displays a clear toe-like impression and continues with a concave depression towards south-east. The general shape suggests a hominin (F1). In the central-northern part of the surface, many cobbles and pebbles, covered by the thin silty layer, are outcropping from the underlying gravel deposit. Many potential footprints are present on the thin silty paleosurface, but their shape and deepness was conditioned by such hard substrate. Three big elliptical imprints are aligned in a NE-SW row in the nort-western part of the excavation. Being 30-40 in diameter, they could be related to big-sized animal as hippos. In the central-eastern part of the surface a couple of shallow bipartite impressions could have been left by middle- or big-sized ungulates. In the northern part of the excavation, two elongated tracks resemble hominin imprints aligned in a S-SW/N-NE direction. The westernmost footprint has a human-like shape (F2), although it is very shallow and show poorly diagnostic features, also because the gravel substrate prevented a complete and deep impression. Almond-like impression,

related to resting traces of unionoids are common especially in the north-western and centraleastern side of the surface.

Test Pit A

The trampled surface of Test Pit A is correlated with the above-mentioned Level-15. A silty-sandy layer was exposed by erosion and subsequently excavated over ca. 1 m^2. Dozens of tracks in concave epirelief were documented. In the central-western part of the test, those are elliptical or irregularly-shaped features, up to 5-10 cm in diameter, and no more than 8 cm-deep. In the western part of the surface, there were some bigger traces, up to 20 in diameter and 10 cm-deep. The diagnostic ones are few, since the layer laid exposed to erosion for a while and the preservation is not optimal. Many of the smaller tracks are made by two flanked depressions, consistent with middle- or small-sized ungulates. More elliptical tracks, very shallow and only 2 cm wide, resemble a micro-mammal trail, being aligned East-West in the southern part of the test. Some of the bigger depressions, moreover, show at the bottom a bipartite structure suggesting a large-sized ungulates. In the central-southern part of the layer, two potential hominin footprints were found (F3-4).

SI Fig. 1 The North Footprint Test (Test Pit A) is located in front of the tourist entrance at the Gombore II OAM (1). After the trampled silt outcropped for erosion, it was cleaned (2) and the sand-filled footprints were excavated and documented (3).
7
SI Fig. 2 Realization of chalk casts of the hippo footprints of Level-14 at Test Pit C. Chalk filling of the emptied tracks; extraction of the cast; cleaning of the molded footprint from the substrate matrix. Below: 3D rendering of the plantar surfaces of the hippo footprint casts (forefoot up).
8
SI Fig. 3 Extraction of hominin footprints from Level-5 of Test Pit B (1) and at Test Pit A (2): a rectangular trench was excavated into the substrate; the sediment block was consolidated and encased with chalk bendages; removal of the block.
9
SI Fig. 4 Channel bank erosion at Test Pit B and at Gombore II OAM. Top: The erosion surface (arrows) visible along the eastern standing wall of the test; at the bottom of the excavation is the main archaeological layer cleaned on a 0.6x0.4 m area. Bottom left: the erosion surface (arrows) along the western standing wall of Gombore II OAM. Bottom right: the erosion surface in plantar view at Test Pit B, with the Level-9 in view in the inner (northern) part of the excavation.
10
SI Fig. 5 Photogrammetry of Test Pit B: Levels -1 (top) and -2 (bottom).
11
SI Fig. 6 Photogrammetry of Test Pit B: Levels -3 (top) and -4 (bottom).
12
SI Fig. 7 Photogrammetry of Test Pit B: Levels -5 (top) and -6 (bottom).
13
SI Fig. 8 Photogrammetry and picture of Test Pit B: Level-7 (top) and picture of Level-8 (bottom).
14
SI Fig. 9 Photogrammetry of Test Pit B: Levels -9 (top) and -10 (bottom).
15
SI Fig. 10 Photogrammetry of Test Pit B: Levels -11 (top) and -12 (bottom).
16
SI Fig. 11 Photogrammetry of Level-13 in the southern part of Test Pit C (top) and picture of the Level-13 in the central-northern part of the test, where it was partially eroded during the Holocene (bottom).
17
SI Fig. 12 Photogrammetry of Test Pit C: Level-14 in the central-northern part of the excavation (top) and in the southern part of the test (bottom).
18
SI Fig. 13 Photogrammetry of Test Pit C: Level-14 in the central-northern part of the excavation (top) and in the southern part of the test (bottom), before the excavation of the footprints. Note that the footprints are still filled by sands mixed with pumices.
19
SI Fig. 14 3D rendering of Level-14 at Test Pit C, with the attribution of footprints and trails to hippo individuals (1-4).
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SI Fig. 15 Photogrammetry of Test Pit C: Level-15 in the northern part of the excavation (top) and in the southern part of the test (bottom). In the central part of the surface the footprints were poorly preserved.
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SI Fig. 16 Photogrammetry of Test Pit C: Level-16 in the central-northern part of the excavation (top) and in the southern part of the test (bottom).
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SI Fig. 17 Photogrammetry of Test Pit C: Level-17 in the central-northern part of the excavation (top) and in the southern part of the test (bottom).

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SI Fig. 18 Photogrammetry of the footprint layer of Test Pit A.

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SI Fig. 19 Top left: Modern-day unionoid mussels collected on the shores of the Awash river near Melka Kunture (Awash Gorge). The specimens probably belong to the species *Unio dembeae* Reeve 1865 (Bacci, 1948; Daget, 1998). Top right: Fossil shells of *Unio* sp. from the Gombore Gully. The specimens were included in a fluvial-lacustrine silty-sandy deposit overlying the Acheulean level of Gombore III (0.6-0.4 Ma), ca. 90 m south of Gombore II OAM. Bottom: Profiles of the consolidated infill (natural track cast) of two unionoid resting traces from Level-4 of Test Pit B (ca. 0.85 Ma). The infills document the shape of the halfburied shells: they have an almond-like shape in planar view, while in profile they have a double-convex outline that ends with a basal thickening, probably derived from the impression of the mollusk's foot.