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The Middle Pleistocene footprints of Foresta (Southern-Central Italy): research activities, achievements, and perspectives

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ABSTRACT - The Foresta "Devil's Trails" ichnosite (Roccamonfina volcano, Caserta, Central Italy) is famous throughout the world for the abundance of its human ichnological evidence, preserved on the very steep slope surface of an ignimbritic deposit dated at 349±3 ka. An impressive amount of data has been collected during approximately twenty years of research activities (2001-2018). The field and laboratory research led to the recognition of at least 81 hominin footprints, most of them arranged in four trackways, as well as a few mammal footprints only partially studied to date [*Proboscipeda panfamilia,* Pecoripeda (?Cervipeda, *Bifidipes* sp., and two badly preserved hypothetically impressed by a bear, ? *Ursichnus* cf. *U. europaeus*)]. Some investigations are now underway and others, dedicated to the deepening of knowledge of the site in the context of the evolutionary dynamics of Middle Pleistocene humans and fauna, and paleoenvironment evolution, will be conducted in the near future based on the already collected data.

In this paper we provide a synthesis of the research activities carried out in the period 2001-2018 by a research team originally composed of geologists and ichnologists and progressively expanded to include archaeologists, vertebrate paleontologists, and volcanologists; we highlight the main results achieved during this period by means of increasingly developed and advanced techniques of collection, analysis and interpretation of ichnological and geochronological data; we briefly illustrate the ongoing studies and recommend future activities; and finally we emphasize the dramatic problem related to the preservation of this unique ichnosite, seriously threatened by progressive degradation.

Keywords: "Devil's Trails"; Roccamonfina volcano; hominin footprints; mammal footprints; research chronicle; chronology; paleoenvironment.

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1. INTRODUCTION

The unique human Foresta "Devil's Trails" ichnosite (hereinon F/DT), located on the north-eastern slopes of the extinct Roccamonfina volcano (Municipality of Tora and Piccilli, Caserta, Central Italy) (Fig. 1) is worldwide known for the richness of its human ichnological evidence, preserved on a very steep slope (Fig. 2) (Mietto et al., 2003; Avanzini et al., 2008; Panarello et al., 2022 a,b,c). Peculiar diagenetic, depositional and erosive geological processes preserved them through time till historical times.

Since the XIX century, people frequenting the area noted these strange tracks, arranged along the inclined surface as if someone had climbed down along a steep slope walking on burning volcanic ashes if not lava. Since no man would be able to do it without ending up in ashes, the legend of a supernatural trackmaker emerged. As a result, some fanciful, completely implausible or hardly conceivable hypotheses developed. The site became famous, and people for a long time believed that the traces were left by the Devil, so the trackways became popular as "Ciampate del diavolo" ("Devil's Trails"), the name still used to indicate the site (e.g., Iulianis, 1986, 2002; AA.VV., 1996; Caputi, 2000; Bernasconi et al., 2002).

This folkloric hypothesis was discredited only in 2001, when, on August the 4th, two researchers living in the same area (the archaeologist Adolfo Panarello and the historian Marco De Angelis) visited the site and realized the actual significance and paleontological potential of such peculiar

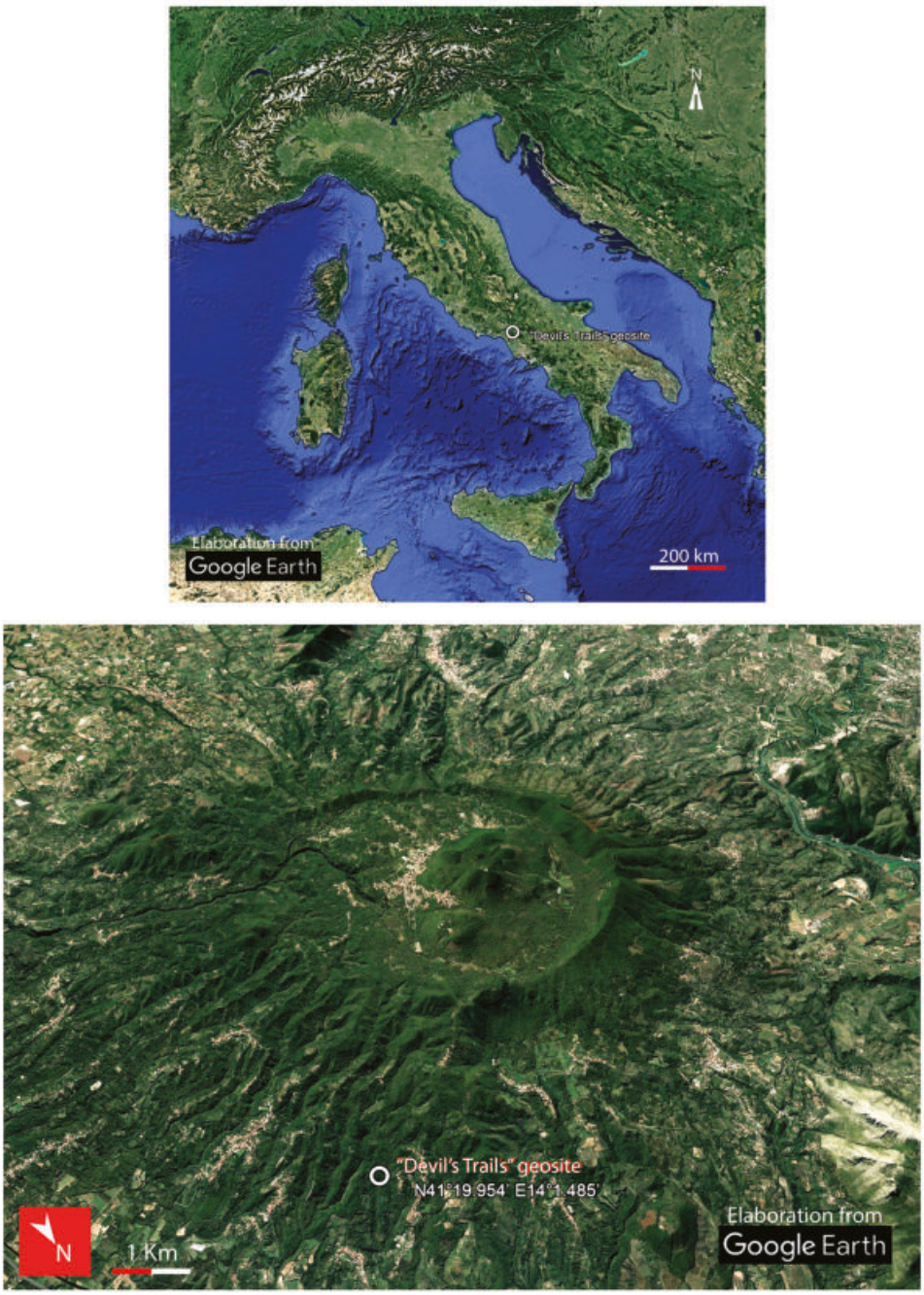

Fig. 1 - Localization of the area surrounding the Foresta/"Devils Trails" (upper image); Aerial panoramic view of the Roccamonfina Volcano, the white circle indicates the Foresta/"Devils Trails" site (lower image) (modified from Google Earth).

traces. Therefore, they contacted Professor Paolo Mietto, a paleoichnologist working at Padua University, asking him to come and provide his trustworthy opinion on the putative human footprints. His first inspection of the site confirmed that prehistorical humans left the footprints, preserved on the lithified surface of the Roccamonfina volcano pyroclastic flow, impressed following a regular scheme and a bipedal pattern.

An initial round of non-invasive examinations of the trampled surface started after the formation of a study team led by P. Mietto, which included renowned scholars in the research activity. The progressively expanded research team surveyed the site under the direction of P. Mietto for about twenty years (2001-2018). The study of the collected material has been carried forward until 2021, leading to the publication of a detailed and critical description of the results in a ponderous monography in early 2022, published by the Italian National Institute of Geophysics and Volcanology (Mietto et al., 2022).

This paper aims to: i) provide a synthesis of the research activities carried out over the last twenty years by the progressively expanded research team, which currently includes ichnologists, archaeologists, vertebrate paleontologists, geologists, and volcanologists;

Fig. 2 - View from the West of the ignimbrititic slope (Brown Leucite Tuff's unit LS7) where the Foresta/"Devils Trails" hominin trackways and some mammalian footprints are impressed.

ii) highlight the principal results achieved by means of increasingly developed and advanced techniques of collection, analysis, and interpretation of ichnological and geochronological data; iii) provide information of ongoing studies and the outlook for future activities devoted to further increasing knowledge about the site in the context of the evolutionary dynamics of Middle Pleistocene human and fauna, and paleoenvironment evolution; iv) highlight the dramatic problem related to the preservation of this unique site, seriously threatened by progressive degradation.

2. CHRONICLE OF RESEARCHE UNDERTAKEN FROM 2002 TO 2018

The research activities, carried out during these years under the direction of P. Mietto, led to new discoveries and to the construction of extremely detailed datasets useful for the correct interpretation of the nature and significance of the F/DT footprints and trackways, as well as of their chronology.

2.1. PRELIMINARY INSPECTION AND SUCCESSIVE SURVEYS (2002-2004)

P. Mietto carried out the first inspection at the site on February 28th, 2002, together with A. Panarello and M. De Angelis. The survey confirmed the real nature of the fossil footprints, arranged in two clearly discernible trackways. The footprints were originally impressed by hominins on a soft substrate, then lithified and preserved by overlapping deposits successively removed by the action of erosive processes.

The three researchers visited for the second time the site on April 5th and 6th, 2002 together with Dr. Marco Avanzini (Museo Tridentino di Scienze Naturali), and, soon after, P. Mietto reported the discovery to the competent archaeological Sopraintendence. The initial fieldwork started as soon as the research team got all the required permissions.

The research detected and recorded for the first time a great number of human footprints left by bare feet, along with rare other animal footprints, as well as a few intriguing ichno-structures, such as the imprint of a long slide, some prints left by hands that were rested on the ground during the slide for balancing walking, and a calf muscle-print. Moreover, P. Mietto and his research team, examining the biped footprints of the "zed-shaped" trackway located further west (successively named Trackway A), recognized in some the medial longitudinal arch typical of human footprints (Fig. 3).

The first analysis of the ichnological patterns was carried out by directly drawing the recognized tracks on polyethylene sheets and by extensive photographic surveys under natural and controlled light. In addition, to

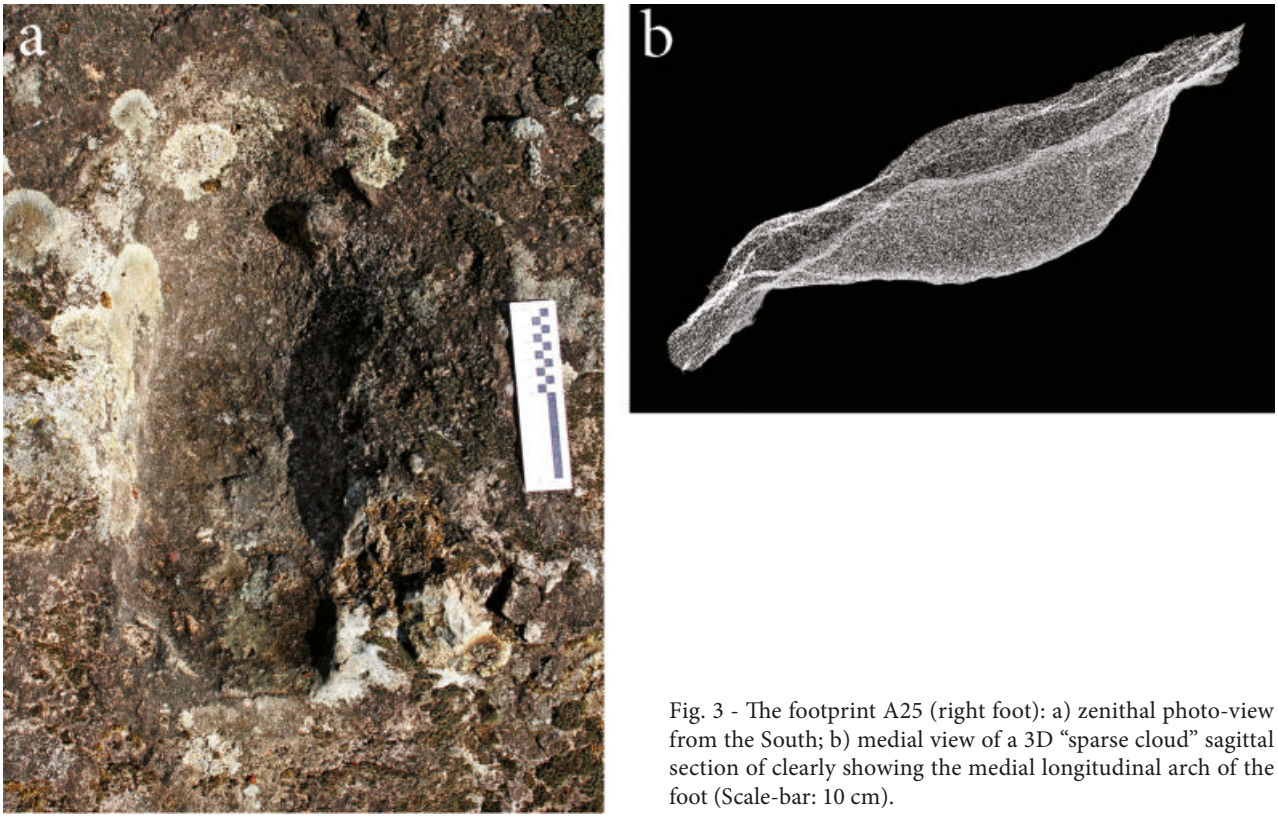

Fig. 3 - The footprint A25 (right foot): a) zenithal photo-view from the South; b) medial view of a 3D "sparse cloud" sagittal section of clearly showing the medial longitudinal arch of the foot (Scale-bar: 10 cm).

two long trackways (named Trackway A and Trackway B) and a third one (Trackway C), divided into two segments by a break in the slope, were also recognized. The survey confirmed the presence in Trackway B of a cavity compatible with the palm print of a left hand, associated with a depression that seemed referable to a long slide (Fig. 4). The compatibility with human footprints of all the depressions was verified and recorded. Researchers noticed a few other footprints, somehow attributable to other animals, flanking the hominin tracks at some points.

Ascertained that all the depressions compatible with footprints were located at the top of a single stratigraphic layer, and that most of them were attributable to bipedal trackmakers, researchers recorded all the morphologies of the tracks, confirming their real ichnological nature (i.e., the displacement rims and structures due to progressive sinking and lateral and frontal stabilization of the limbs in accordance with the geomorphological constraints imposed by the steeply inclined tuff slope). These structures are fully visible on most of the best-preserved footprints. The presence of clear and indisputable human features in the footprints, such as the narrow and elongated shape longer than wide, the regular alternation of a medial concavity in consecutive footprints, as well as the impressions of the heel, big toe, and medial longitudinal arch in most of the best preserved footprints, allowed researchers to preliminary attribute the ichnites to at least one or more hominin individuals.

Given the significance of the discovery, P. Mietto involved the volcanologist Giuseppe Rolandi (University of Naples "Federico II"), who during a survey on site carried out on June 5th, 2002, confirmed the pyroclastic nature of the imprinted deposit, referring it to one of the units of Brown Leucitic Tuff (BLT), deposited during the second eruptive phase of the Roccamonfina volcano, dated at about 385-325 ka (De Rita and Giordano, 1996).

With the support of the volcanological team led by G. Rolandi, a study of the processes that permitted humans and animals to walk on the pyroclastic flow and led to footprint preservation started. After the diffractometric analysis of samples taken at various points, volcanologists could assert that hominins and animals had been able to walk on the surface of the deposit originated by a pyroclastic eruption because the zeolitization process was at its beginning, so the surface was cooling but still plastic enough to record even quite deep footprints. Then, during the eruptive 'fall-out', a shower of light materials of varying granulometry filled and covered the footprints, allowing them to dry and not be destroyed by the subsequent pyroclastic flow, preserving them for hundreds of thousands of years.

The same team successively noted that the consolidation process of the ignimbritic deposit had not been uniform, leading to a few breakdowns in the footprint impressions (Panarello et al., 2022a and references therein). Finally, the team decided to conduct some research to find an answer to the question of when and how long the re-exposure might have occurred. This research included examining surface-found epilithic lichens.

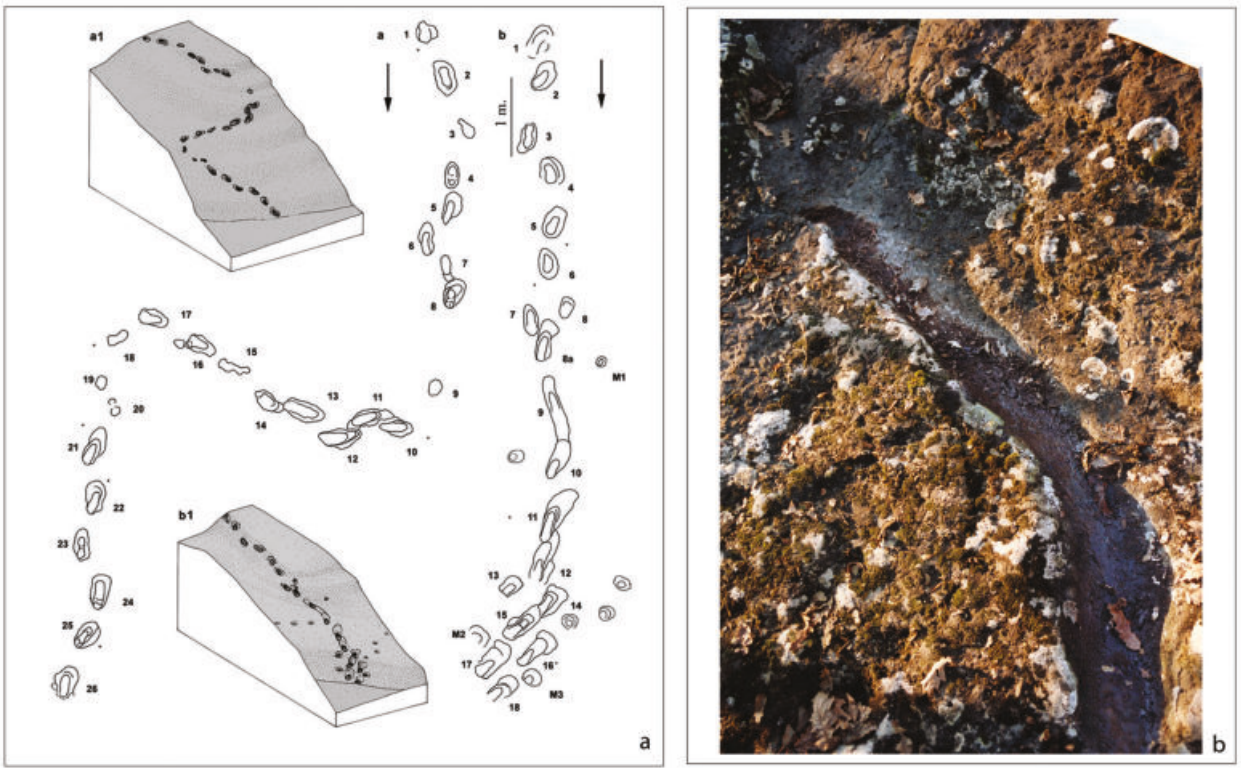

Fig. 4 - The trackways A and B: a) Trackways A and B Block diagrams and graphical sketches of (from Avanzini et al., 2008); b) Trackway B photographic view from south-east of the long slide called B09.

The evidence resulting from the first surveys and the K/Ar chronological range of the trampled deposit (385-325 ka) led to a first communication, presenting in *Nature* the "Devil's Trails" as the oldest ascertained human footprints (Mietto et al., 2003).

2.2. RESEARCH ACTIVITY IN 2005

Intense field work activities continued between 2005 and 2010 under the direction of P. Mietto.

In July and October 2005, the research team carried out two campaigns, carefully removing the cover of debris to obtain new scientific information about the footprints and to verify the feasibility of installing a metal walkway that would permit the observation of the footprints on the slope without walking on the slope surface (mounting the metal walkway where no fossil prints were present).

The researchers aimed to better understand and contextualize the footprints already detected and analyzed during the first non-invasive surveys and to look for new footprints or trackways and possible extensions of the trackways, in particular of trackways B and C. Fortunately, the survey brought to light new ichnological evidence, permitting a better understanding of their arrangement. Another possible direction of walking has been detected (first named Trackway F and then Trackway E), oriented to the West and, consequently, in a direction opposed to that of other trackways. Moreover, new six footprints have been detected, prolonging upstream the Trackway C. Sample casts were also made of footprints A21-A22-A23 and A25 (the best preserved of Trackway A), using fast-catalyzing silicone rubber; in addition, two partial footprints, consisting only of the heel impressions, were also identified in Trackway A (A27, A26). The latter were assumed to be in continuity with the others of Trackway A purely on a geometric basis, even though they were located quite far from the end of the trackway. Moreover, an attempt was made to identify the complete pattern of Trackway E, leading to the discovery of a well-preserved new footprint (later named E03), larger than all the F/DT human footprints. The removal of the debris also revealed that Trackway E, consisting of 4 footprints, was abruptly interrupted by a quarry cut in the tuffaceous deposit.

Finally, the research team identified two other possible handprints in Trackway B, whereas a succession of depressions at its end, in correspondence with the break in the slope, was first considered compatible with human footprints, but successive studies demonstrated that they are traces generated in historical times by anthropic cutting activity and then altered by the action of natural agents and repeated passages of humans and animals (Mietto and Panarello, 2022b).

The second fieldwork, carried out in the autumn of 2005, was equally rich in results. It was almost entirely dedicated to the cleaning of the apical part of the slope and, in particular, the ledge from which Trackways A, B, and possibly Trackway C start. All removed debris materials were carefully recorded and sieved. This showed that none of them were in primary deposits. Moreover,

ceramic fragments were found, documenting that people had visited the site in historical times, at least since the second half of the 18th century.

The excavation of the fairly plane apical part of the ignimbritic surface revealed the presence of long serpentine grooves that intersected each other at various points before converging into a single, wider furrow. Within the grooves, some putative human and animal ichnites were identified, together with signs of anthropic activities made in historical times. The context of this finding suggested great caution in interpreting the nature of this new evidence.

2.3. RESEARCH ACTIVITY IN 2008-2010

The amount of ichnological evidence found at F/DT suggested to the research team that these footprints could not have been an isolated case and that the frequentation of Palaeolithic humans could have spread on a wider area. Consequently, the exploration of all the BLT outcrops started in 2005 was continued and expanded. Pseudo-ichnite successions were found in the two localities of Carangi (Marzano Appio Municipality) and Ponte (Sessa Aurunca Municipality). A series of prospections and samplings were conducted at Carangi in 2008, but subsequent studies and surveys revealed that the identified track successions were generated in historical times by human and animal activities, and by erosive processes (Panarello et al., 2017c). The Ponte outcrops have been only photographically surveyed as they show enough evident signs of human historical cuts to demonstrate that the footprint-like structures do not have prehistoric origins.

In 2008 and 2010, the volcanologist Lisa Santello (University of Padua), in the course of her Ph.D. research, analyzed in-depth the imprinted ignimbritic deposit in the contest of the volcanic formations of Roccamonfina volcano, present in the F/DT and other areas located in its vicinity (Santello, 2010). The volcanologist revised the stratigraphic setting of the BLT Formation deposits, arranging them in a sequence of eight units (from LS1 at the bottom to LS8 at the top), where LS7 is the layer that preserved prehistoric human and other animal footprints and LS8 is the overlapping one. New accurate $^{40}Ar/^{39}Ar$ radiometric dating of the volcanic outcropping layers have been proposed, attributing to LS7 an age of 349±3 ka (Santello, 2010) (Fig. 5).

New research activities took place in the period October 12-17, 2009, mainly focusing on the still unexplored easternmost part of the imprinted slope. Researchers exhumed another section of the apical prehistoric pathway (Fig. 6) and the debris covering the east of Trackway B was removed. The removed debris was carefully sieved, and a few but important remains were found, extending the frequentation of the site to the early Middle Ages (12th-13th centuries), as supported by some ceramic sherds and by the characteristics of some signs of the slope structure anthropic alterations (Fig. 7) (Mietto and Panarello, 2022a).

Moreover, a large impression in the trackway B was analyzed, then interpreted as the print of trackmaker B right gluteus (Panarello, 2020), as well as the adjacent heel-strike print of a right footprint (B22).

During the 2008-2010, the Geotop society (Ancona) executed a laser scanning survey of the entire "Devil's Trails". Moreover, the research team made silicone casts of a few other well-preserved footprints of Trackway B and took various low-resolution shots of the entire site and high-resolution shots of Trackway A and Trackway B. A rich night-time photographic shoot was also carried out in order to have maximum control over the light sources for the most accurate morphological interpretations of the slope and the ichnites. Finally, an accurate interpretation of the hitherto exhumed ichnological evidence was attempted, carried out separately by each of the team's ichnologists.

From 4 to 9 October 2010, the cleaning work on the easternmost part of the slope was completed. This permitted to define the total extension of the prehistoric pathway equal to 53.19 m and to individuate some other depressions compatible with human and other animal footprints, still under study. The easternmost pathway sector shows signs of alteration due to recent anthropic cuts, but it is preserved for large stretches. The research team surveyed the sector by tracing it on polyethylene sheets and taking pictures under natural and controlled light. Furthermore, it was subjected to high-detail photogrammetry, which allowed for the generation of various 3D models in the years that followed (Panarello, 2016; Panarello and Mietto, 2022 a,b; Mietto and Panarello, 2022a).

2.4. RESEARCH ACTIVITY IN 2013-2015

During the period 2013-2015, the activity at the site was primarily related to the doctoral study of archaeologist and ichnologist Adolfo Panarello (University of Cassino and of Southern Latium). The activity included an exhaustive study of the already collected data along with new extensive surveys of the site. More specifically, a complete photogrammetric survey was performed and perfected with the help of a drone. A highly detailed 3D model was elaborated, enabling to study even in the future all the ichnological evidence identified on the ignimbrite surface.

During the A. Panarello Ph.D research, some other evidence were also noted, such as the footprints called F01 and F02, located on the same ledge on which the handprint TP_M1 is preserved (Fig. 8). During the photogrammetric reconstruction of the segment P1_15 a basalt core was noticed in a clastic layer, interbedded between the LS07 and LS08 units (Panarello et al., 2017 a,b, 2020; Biddittu and Panarello, 2022). The finding of this lithic artifact encouraged the exploration of areas surrounding the site, where Italo Biddittu (see below) and A. Panarello found a few reworked lithic tools. Their study is still in progress, though some preliminary reports have been published (see below) (Panarello et al., 2017b, 2020;

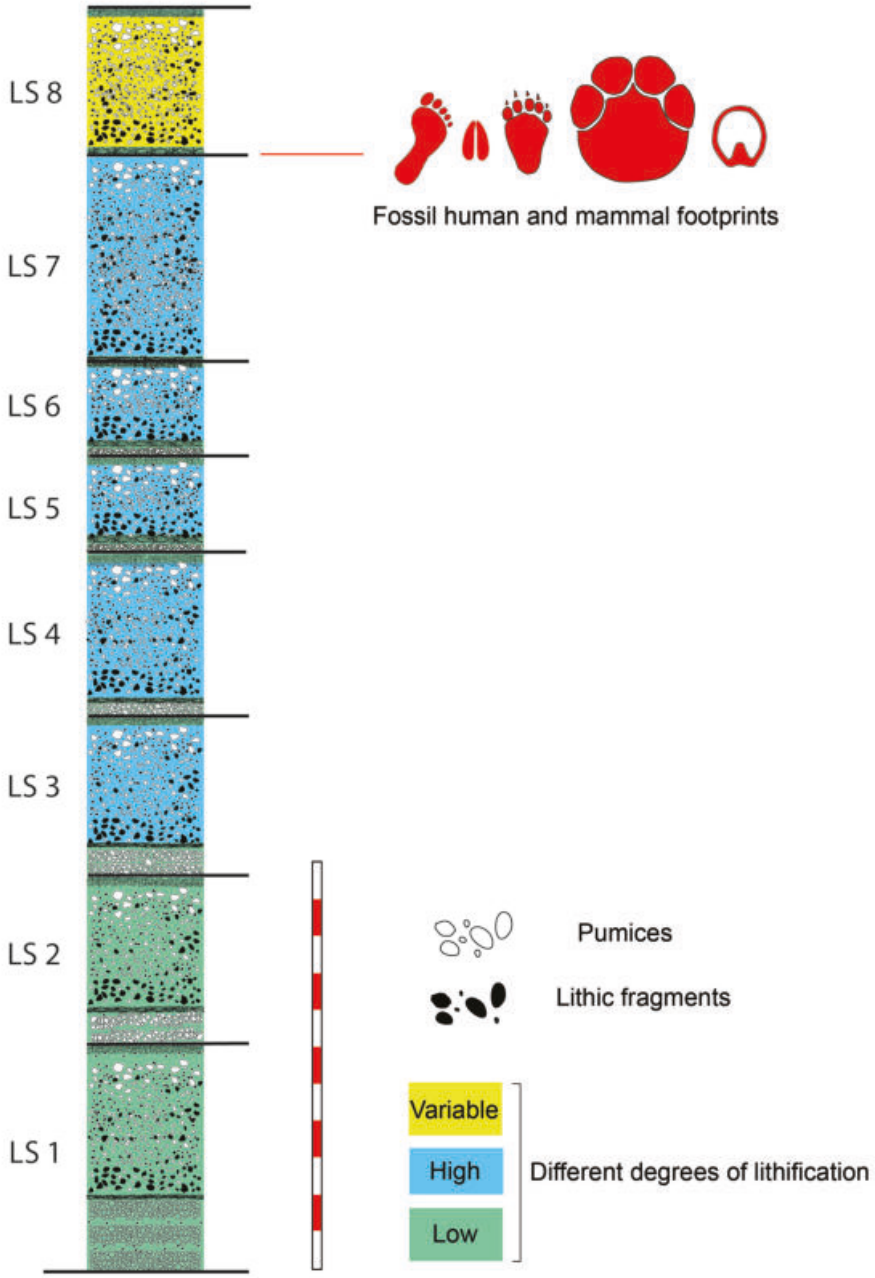

Fig. 5 - Stratigraphical setting of F/DT BLT deposits with an indication of the relations between the single geological units and localization of the imprinted surface (1 bar=1 m) (modified from Santello, 2010 and Di Vito, 2022).

Biddittu and Panarello, 2022 and references therein).

Between 2013 and 2015, A. Panarello analysed, in the context of his Ph.D. research, the geomorphology of the site and of its surroundings, with particular attention to the anthropic contamination of the sites during historical ages. The entire site was photogrammetrically reconstructed and, in particular, the structure that had been first recorded in 2005 and that turned out to be the oldest known human fossil pathway in the world so far. Moreover, recent anthropogenic cuts were classified, distinguishing them from prehistoric morpho-structures (Panarello, 2016).

In June 2014, the archaeologist Italo Biddittu (Istituto Italiano di Paleontologia Umana) joined the research group and undertook an extensive territorial surface survey with A. Panarello in both the wide Roccamonfina volcanic area and in the alluvial plane surrounding it. The exploration's goal was to find some traces of material culture and indications that would help to better contextualize the F/DT prehistoric trackmakers in the complex scenario of Paleolithic Italian human populations.

2.5. RESEARCH ACTIVITY IN 2016-2020

The vertebrate paleontologist Maria Rita Palombo (Sapienza, University of Rome) was asked to join

Fig. 6 - Western and eastern photographic views of the P1_Pathway as it appeared in 2005 (modified from Panarello and Mietto, 2022a).

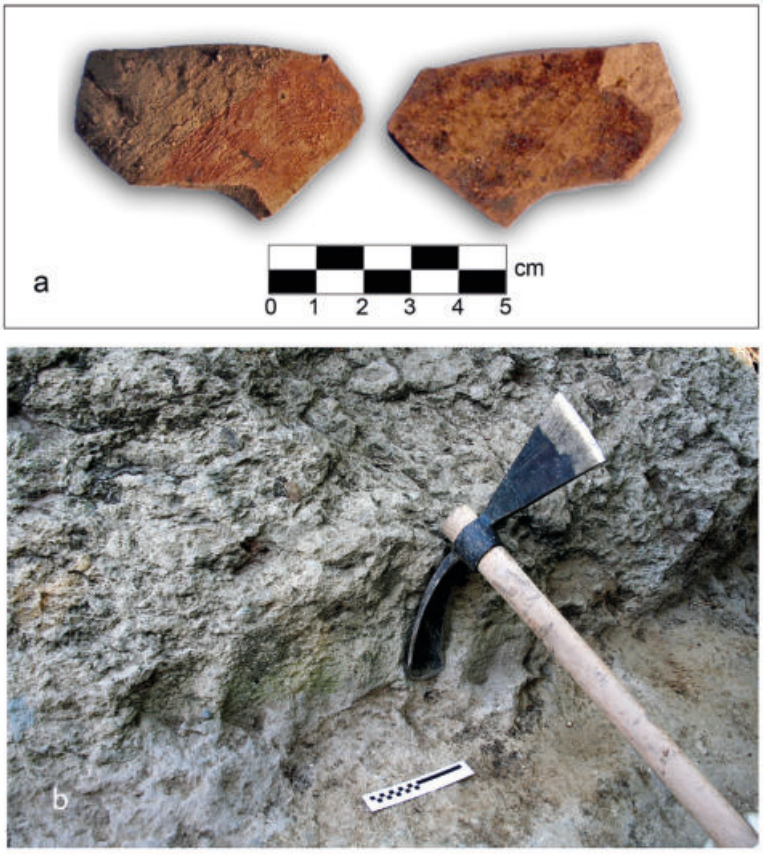

Fig. 7 - Some evidence of the historical age frequentation of the site that researchers identified during the 2009 field work: a) a ceramic fragment of a closed form painted with a red band (2 cm wide), which probably described an arch (12th century?); b) marks of alteration of the original tuff slope made with an ice axe with a curved blade (in the photo is shown the type of used metal-tool) (Scale-bar: 10 cm).

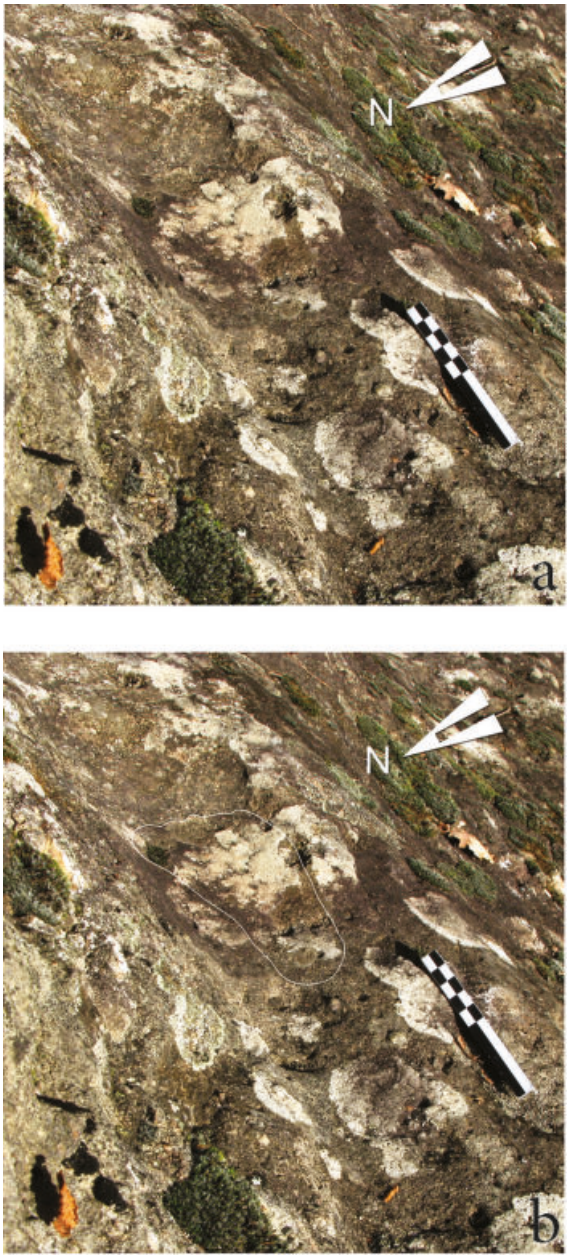

Fig. 8 - Western photo-view of F2 right-foot human footprint as it appears (a) and with highlighted print-contour (b) (Scale-bar: 10 cm).

the team in March 2016 to carry out the study of the mammal footprints noticed and/or exhumed during on-field work, as well as to examine the surfaces for other mammal footprints and study the geopaleontological context to infer the Middle Pleistocene (MIS 11-MIS 10) paleoenvironment. During the first inspection, M.R. Palombo confirmed and better clarified the nature of the already detected mammal footprints. Moreover, the peculiar nature of the coarse substrate and the surface alteration caused, for instance, by weathering and moss, recommended a more accurate inspection to search for the presence of poorly definite or altered footprints.

The paleontologist, accompanied by A. Panarello, successively made various accurate surveys that led to quite interesting observations and discoveries. First, the analysis was focalized on the well-preserved coupe of a middle-sized artiodactyl (ichno-order Artiodactipedida *sensu* Vialov, 1966), placed side by side, nearly parallel to each other, found on the sub-horizontal surface, bordering the pyroclastic flow slope, used by hominins as a double route-way (Fig. 9). The presence of only two footprints increases the issue of properly identifying artiodactyl tracks, especially those of ruminants, due to the similar basic morphology and the large variation in shape of footprints impressed by the same trackmaker in relation to its gait, age, and gender. The morphology and size of the F/DT footprints can be considered as consistent with those of a roe deer, assuming that the dewclaw impressions behind those of roofs have been left by a roe deer slowly walking on a soft substrate or jumping (Fig. 9). Given that the footprints are placed at the slope edge, towards which they face, M.R. Palombo carefully examined the slope surface with the aim of verifying the last hypothesis, which was corroborated by the discovery of four badly preserved plausible footprints at a distance consistent with the roe deer's jump (Palombo, unpublished data). M.R. Palombo also identified a definitely larger and poorly preserved Cervipeda footprint, with a morphology somehow similar to that of a red deer representative. Furthermore, she carefully examined a badly preserved footprint present in the thin mud layer interbedded between the surface of the pyroclastic flow of unit LS7 and the overlain volcanic deposit LS8. The debris covering the muddy layer was removed and a problematic second print was detected. The researcher noticed some mud cracks on the footprint surface, indicating that they were impressed on the surface of a wet muddy soil, then dried out (Fig. 10). Preliminary examination of the morphology revealed some similarities to bear footprints (Kowalski, 1961), especially with those of a cave bear, ascribed by Diedrich (2011) to the new ichnogenus and species *Ursichnus europeus*, to which the prints were tentatively ascribed (Panarello et al., 2017). However, studies are currently in progress to confirm whether they may have been left by a bear or not.

Finally, the inspection of the two short trackways, one crossing Trackway B, confirmed that they could be ascribed to medium-sized horses (*Hippipeda* ichnogenus), as suggested by the sub-circular shape of the deep footprints, with a convexly arched anterior part, nearly parallel outer margins, and a slightly enlarged posterior part. However, the typical caudal frog was hardly detectable, except for the EQ05 footprint where it is fairly outlined (Fig. 11) (Palombo and Panarello, unpublished data; Panarello et al., 2017b; Palombo, 2022).

M.R. Palombo and A. Panarello devoted successive surveys to tracking the sub-oval, roughly kidney-shaped, large depression, arranged in a short trackway, present at the top of the slope in a previously poorly investigated area because affected by recent human activity (Fig. 12) (some of which unearthed and surveyed during 2005 field work).

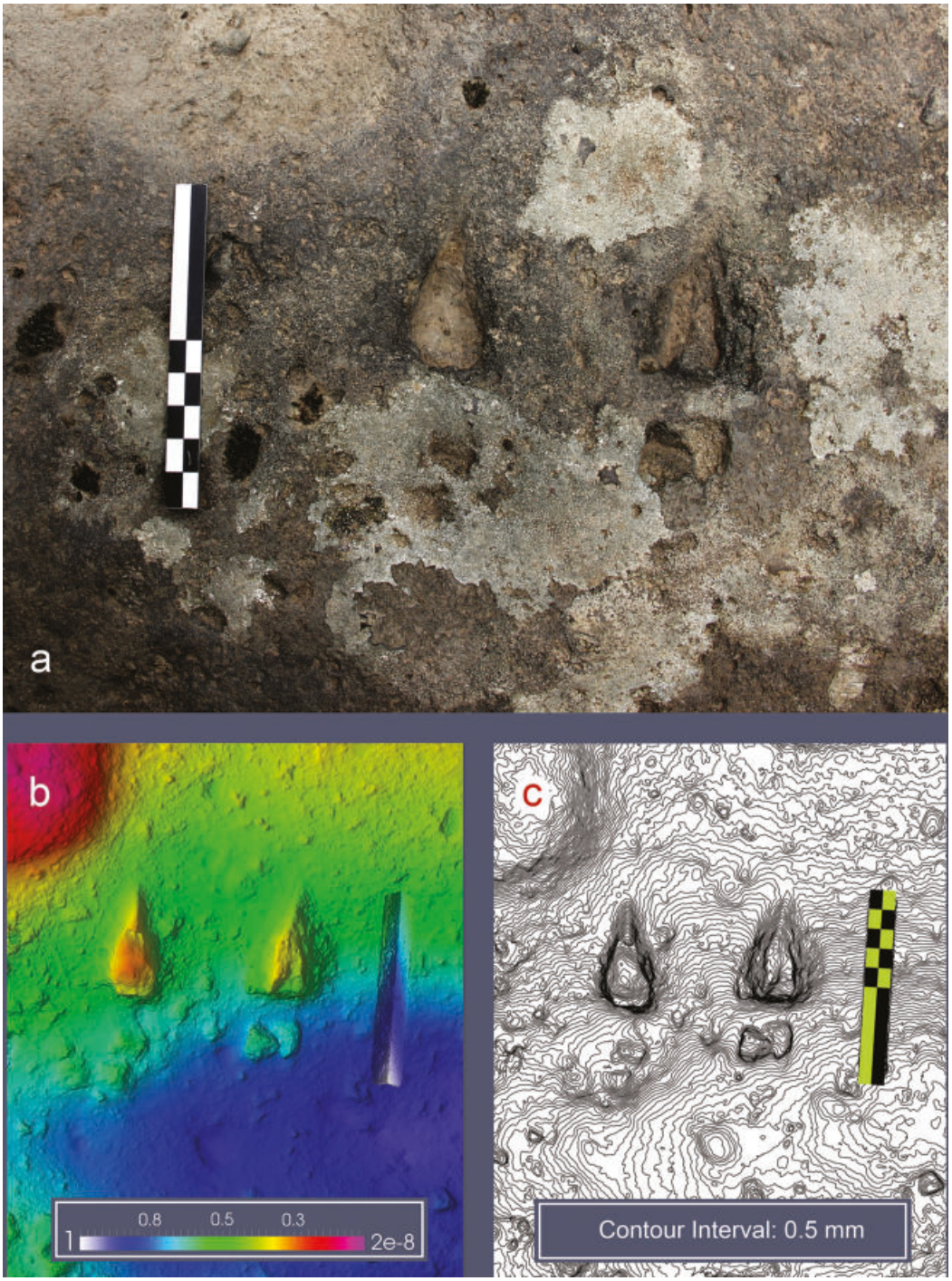

Fig. 9 - The artiodactyl footprints preserved at the edge of the slope on the sub-planar surface in the space of P1_Pathway: a) northern zenithal picture; b) depth map; c) contour map (Scale-bar: 10 cm).

The results of a preliminary analysis enabled to assign the footprint to the *Proboscipeda panfamilia* ichnospecies and to hypothesize that the trackmaker was a young individual (maybe a *Palalaeoloxodon antiquus* calf), as it is confirmed, for instance, by the presence of four toe imprints at the anterior end of the preserved footprints (M1-L) (cfr. Palombo et al., 2018 for details and discussion).

In the same period, A. Panarello completed a comprehensive and thorough study of the hand, calve-muscle, and buttock prints. Since the time when the handprint was first detected, in the middle of Trackway B, it has been believed to be the print of a left hand used by the trackmaker to regain lost balance. The new in-depth analysis confirmed that it is the oldest human fossil handprint in the world known so far (Panarello et al., 2018) (Fig. 13).

The results obtained from the new analysis and the detailed 3D photogrammetric modeling of the gluteus, ankle, and calve-muscle depicted a unique movie, a sort of "frames in sequence" printed in rock, describing a

Fig. 10 - A well preserved footprint on the thin mud layer interbedded between the surface of the pyroclastic flow of unit LS7 and the overlain volcanic deposit LS8, which was hypothetically believed to have been impressed by a bear (?*Ursichus europaeus*) (Scale-bar: 10 cm).

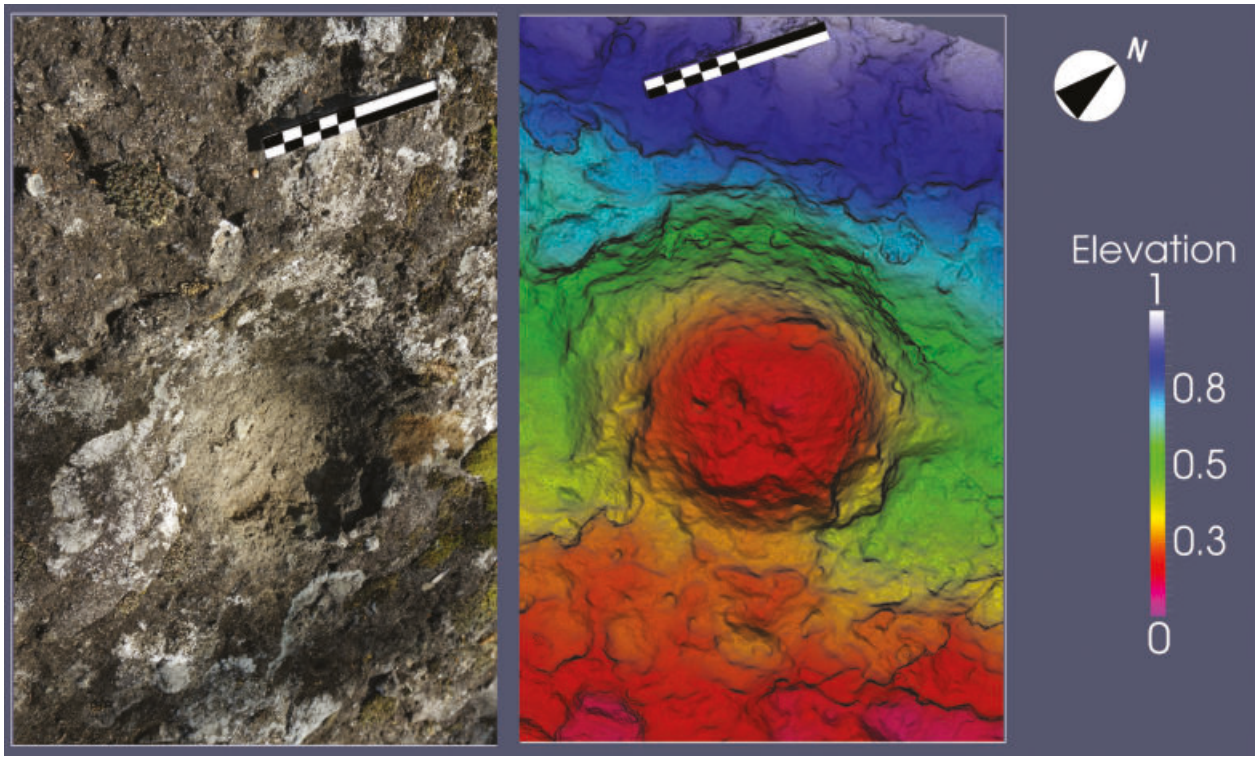

Fig. 11 - The quite well preserved *Hippipeda* footprint EQ05 of the equid trackway that flanks west the Trackwy B (Scale-bar: 10 cm): a) Zenithal southern photo view; b) Depth map from 3D model.

Fig. 12 - Photographic view from the North of the Proboscipeda trackway attributed to *Proboscipeda panfamilia* ichnospecies.

moment of movements of a hominin, living ~350 ka ago, during his instinctive attempt to regain and/or preserve balance after a sudden and prolonged slide along a very steep and slippery slope (Fig. 14) (Panarello 2020).

In 2018, Mauro Antonio Di Vito (INGV Vesuvian Observatory, Naples) joined the research team in order to carry out geo-volcanological studies, particularly focused on the depositional dynamics of LS7 and other exposed BLT units in the context of the geologic setting of the surrounding area. The study confirmed the depositional model proposed by Cole et al. (1993) according to which the distal part of the BLT units, emplaced by ignimbrites, likely moved by plug flow prior to the final emplacement that filled the valley, decelerating and becoming more and more viscous and coarse. Moreover, the researcher clarified that the distal part of the LS7 pyroclastic flow was not still compacted and as such affected by rapid erosional processes generating an inclined surface at the top of LS7. He also hypothesized that the time gap between the deposition of the LS7 and LS8 units was not long enough to allow the development of soil, which is not present in any part of the LS7 and LS8 contact (Panarello et al., 2020; Di Vito, 2022).

3. CONCLUSIVE REMARKS

The twenty years of research activities at the F/DT ichnosite (fieldwork, data collection, elaboration of digital data and models, which are especially appropriate for studying original morphology where tracks are susceptible to erosional processes, data analysis, and

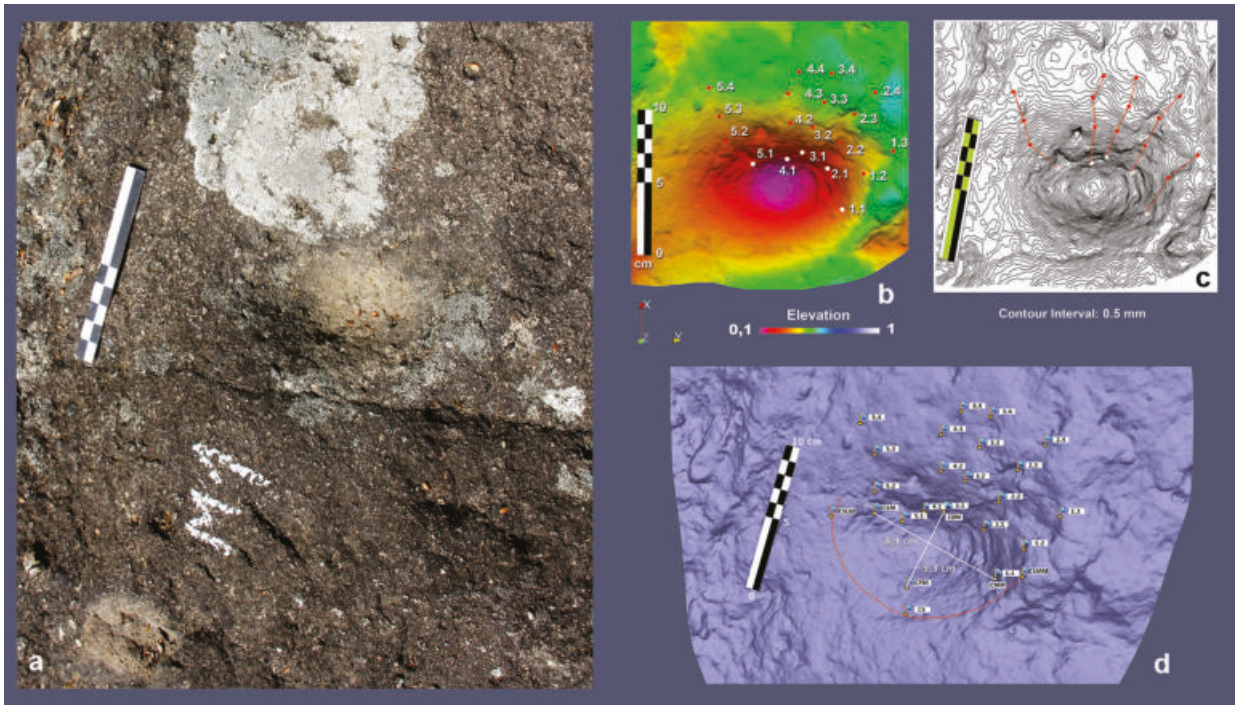

Fig. 13 - The human handprint TP_M1, north flanking the long slide in Trackway B (Scale-bar: 10 cm): a) zenithal western photographic view; b) depth map with landmark positions; c) contour map (interval: 1 mm) highlighting the possible directions of the fingers (red lines); d) detailed landmark map (from Panarello et al., 2018, 2022e).

Fig. 14 - A visual summary of an experimental re-enactment of the fossilised movements along the steep and slippery slope, causing the sudden and prolonged slide between the footprints B08-B10 (from Panarello, 2020).

so on) and some surveys in the surrounding area allow researchers to gradually increase knowledge on hominin and mammalian footprints, depositional dynamics and consolidation of the ignimbrite flow preserving the prints, and to lay the foundations for future developing of paleoenvironmental reconstruction and any other studies.

Currently, we know the basic geo-volcanological and ichnological aspects, and the study of some others is in

progress, but some relevant ones deserve attention and merit deep scrutiny in the near future.

3.1. WHAT WE KNOW

First and foremost, multidisciplinary research has demonstrated that hominins and mammals walked on a still soft pyroclastic flow and negotiated a high-angled and articulated surface up to 80% (an average incline of about 30°), in a distal outcrop exposed by an erosional process along a small valley (Panarello et al., 2020 and references therein). The Ar/Ar dating of the trampled layer precisely fixes, within a very narrow range, the chronology of the site frequentation as slightly younger than the Termination IV (337 ka), correlating it with late MIS 10.

The ichnological results obtained to date are the outcome of the field researcher observations made during repeated surveys and the analysis of data collected using increasingly sophisticated technologies such as laser-scanning and high-detail photogrammetry, and the examination of 3D models generated for both the entire site and each track. This has made it possible to re-examine each piece of ichnological evidence with the utmost objectivity and to draw an increasingly more precise scenario by correctly contextualizing even the planimetric arrangement of the individual pieces of evidence. Furthermore, the detailed examination of each human and other animal footprint made it possible to confirm most of the first impressions, considerably expanding the picture of knowledge and compiling a dataset of great completeness, precision, and reliability.

Except, probably, for Trackway E, the planimetric analysis of the general site revealed that almost all of the human footprints, arranged into different trackways, start from the ledge of the uppermost sub-planar zone of the exposed ignimbritic flow surface and descend the steep slope (Panarello et al., 2022a and references therein). This ledge is a quite unique ichnological structure that has been proven to be the oldest human pathway known to date in the world. Moreover, the presence of bi-directionally oriented footprints suggests that hominins used the pathway time by time, but it is unrealistic to speculate whether hominins went occasionally in the opposite directions or intentionally went and returned throughout the same way (Fig. 6). The F/DT prehistoric pathway (P1_Pathway) was also used in historical times and is still marked on current topographical maps, representing individual evidence of a substantial similarity in human settlement choices and dynamics conditioned by geomorphology from prehistory to the present day (Panarello, 2016; Panarello et al., 2017a; Panarello and Mietto, 2022 and references therein).

The realization of detailed depth maps, generated by means of zenithal 3D images (e.g., contour maps in millimeter and sub-millimeter increments with and without footprint outlines, oblique contoured depth maps,

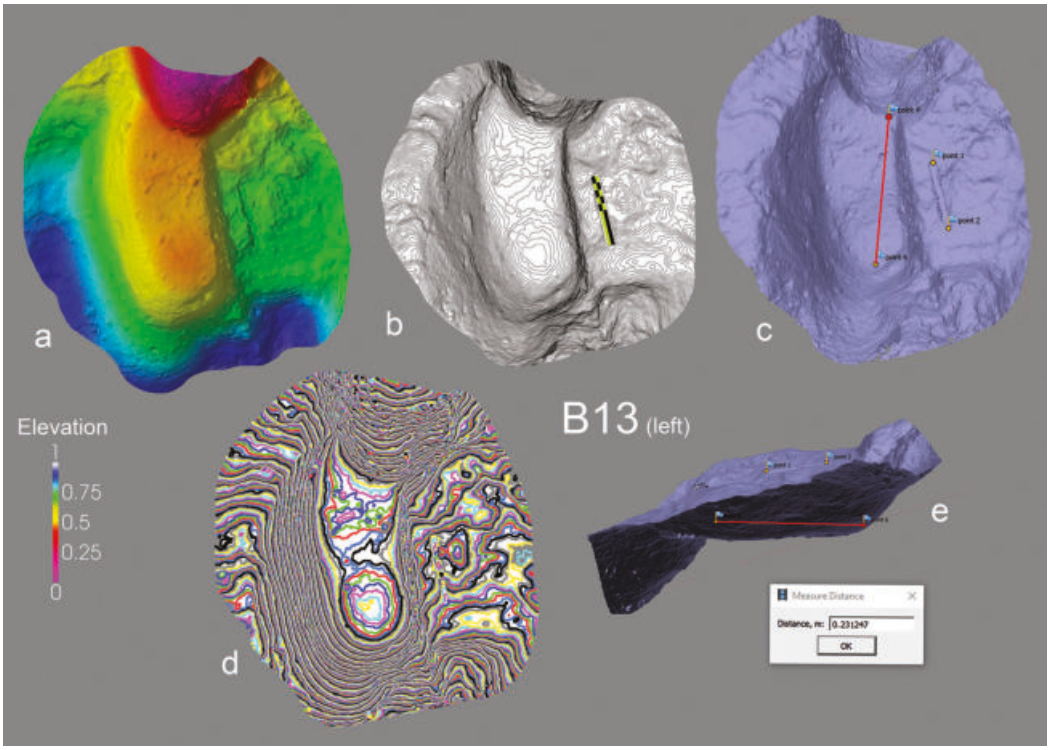

Fig. 15 - Example on footprint B13 (left foot) of some of standard measurements made on fossil human footprints on the F/DT slope (Scale-bar: 10cm): a) depth map; b) contour map (step: 1mm); c) flat surface; d) coloured/alternated 1mm contour map; e) sagittal view of 3D generated surface. The red-colored line indicate on the c) and e) images the most affordable measurement which can be taken on F/DT human footprints, i.e., the footprint length.

and et cetera) (Fig. 15), enabled researchers to analyze each piece of evidence both from an anatomical and structural point of view, in the light of the most modern morphometric analysis techniques (Panarello, 2022 and references therein), and propose methodological choices that are only applicable at the F/DT site due to its extreme inclination (Figs. 16, 17). The dynamic models developed led to a first evaluation of some hominin behavioral choices, such as the best path for maximum stability and minimum energy expenditure on an unsafe and slippery surface, and the estimation of some anthropometric parameters of trackmaker A (Saborit et al., 2019; Mondanaro et al., 2022). Furthermore, the discovery of the prints of hands, calve-muscle, and buttock represents an extraordinary and uncommon documentation of Middle Pleistocene human body anatomical parts that are not comparable to similar evidence found so far worldwide (Panarello et al., 2022e and references therein).

The total number of the hominin footprints identified to date is at least 81 (augmenting by 21 the number 56 of footprints noted at the beginning of the research), arranged into three quite long (Trackways A, B, and C),

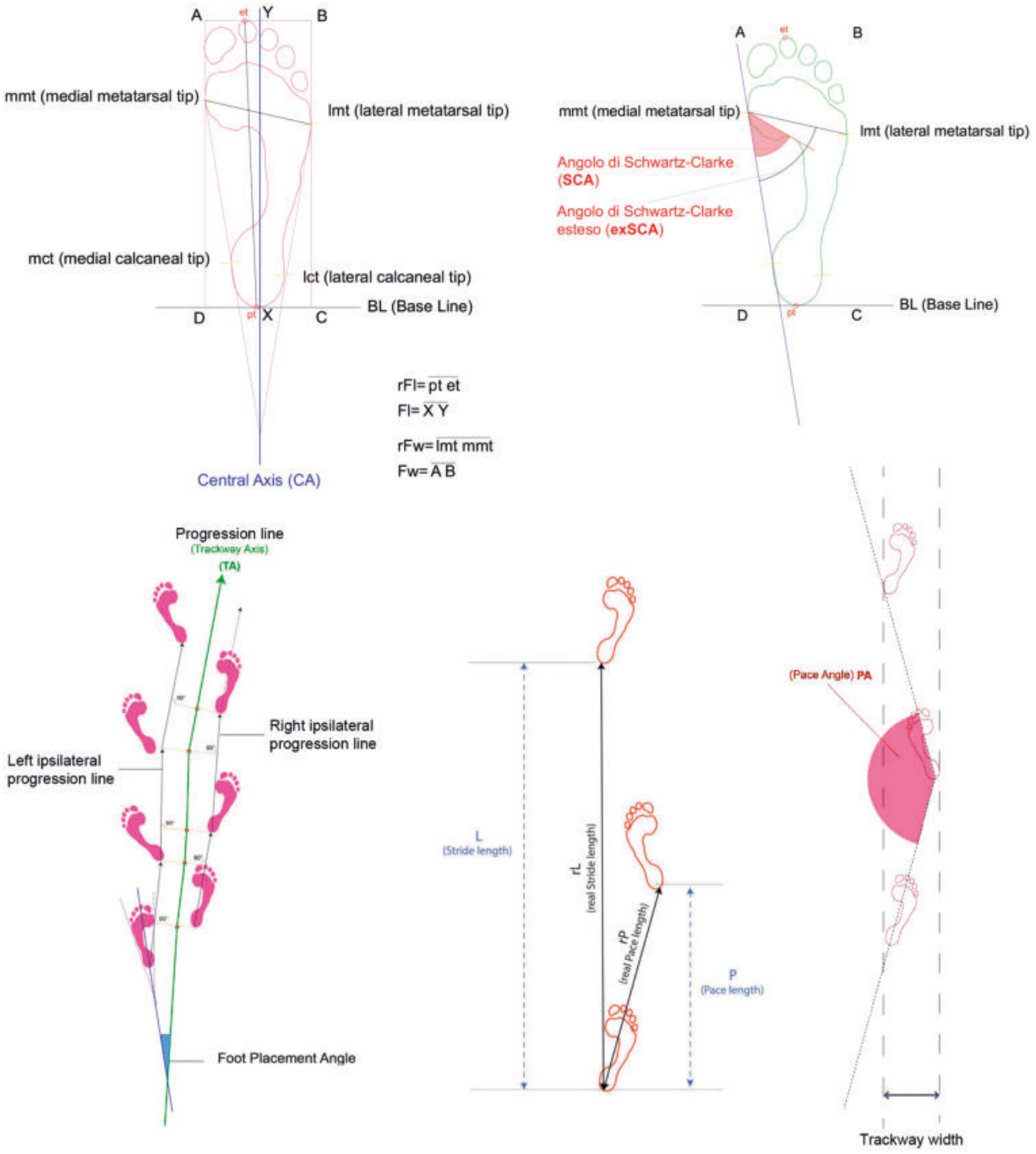

Fig. 16 - Dimensional conventions adopted for the Foresta/"Devils Trails" human footprints survey.

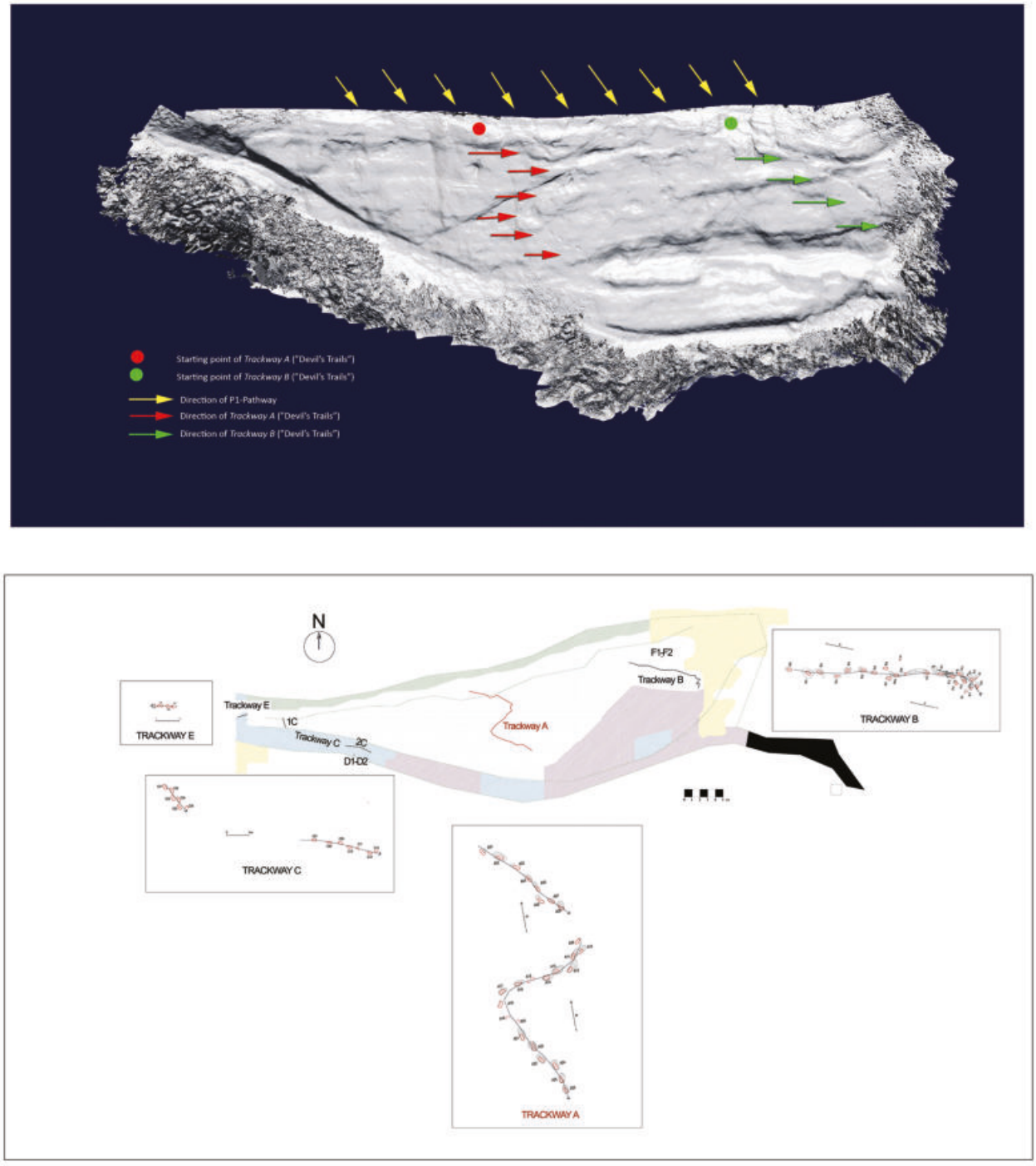

Fig. 17 - General Foresta/"Devils Trails" site diagram with trackway patterns A, B, C, E.

and 1 short Trackways E, plus two couple of footprints (D and F) indicating other directions of walking (Fig. 17; Tables 1, 2). Researchers demonstrated that the best-preserved footprints of trackways A, B, C, and E, which show a regular right to left succession of several or more than three footprints fully matching the scheme of human walking (Kim et al., 2008), always exceed the lengths calculated standard deviations (Table 3). As a result, they hypothesized that the number of human trackmakers was at least four including at least one male, and possibly two others due to the presence of very short tracks, where two footprints have been detectable (Panarello et al., 2022a, 2022b, 2022c, 2022d and references therein).

Overall, the findings from nearly two decades of research at F/DT and the nearby surveys highlight the site's uniqueness and great potential to offer new information and hints for a better understanding of some physical traits and the way that Paleolithic hominins may have reacted to specific situations and stimuli in a volcanic environment.

Tab. 1 - Average dimensions from best preserved human footprints (cm) (data from Panarello et al., 2022b).

Footprints	N	Footprint length (range)	Footprint width (range)
Trackway A	9	24.6 *(24.5-24.8)* SD=0.14	11.3 *(10.7-10.8)* SD=0.41
Trackway B	9	23.1 *(23.0-23.2)* SD=0.08	10.3 *(10.0-10.6)* SD=0.25
Trackway C	1	22.6	10.4
Direction D	1	19.3#	11.7#
Trackway E	1	27.0	10.5
Direction F	1	25.9	10.5

Inferred dimensions.

Tab. 2 - Average estimated of trackmaker physical parameters, based on the dimensions of the best-preserved footprints.

Footprints	N	Stature† cm (range)	Body mass[ε] kg (range)
Trackway A	9	161.3 (162.9-159.7)	~68
Trackway B	9	151.3 (149.8-152.9)	-
Trackway C	1	148.2 (146.8-149.7)	-
Direction D	1	126.6# (125.3-127.9)	-
Trackway E	1	177.1	-
Direction F	1	169.9	-

† Panarello et al., 2022b.

[ε] Saborit et al., 2019.

Tab. 3 - Average gait characteristics (data from Panarello et al., 2022b).

Footprints	Step or Pace cm (range)	Stride cm (range)	Relative Speed m/s (range)
Trackway A	52.1 *(34.1-69.0)* N = 21	99.0 *(56.8-128.8)* N = 20	0.68 *(0.26-1.04)* N = 21
Trackway B	57.3 *(37.8-83.0)* N = 19	92.3 *(40.9-130.0)* N = 16	0.63 *(0.22-1.0)* N = 16
Trackway C	44.0 *(28.0-66.5)* N = 11	86.5 *(50.7-138.0)* N = 7	0.57 *(0.22-1.16)* N = 7
Direction D	42.2# N = 1	-	-
Trackway E	34.2 *(27.5-40.5)* N = 3	69.5 *(64.5-74.5)* N = 2	0.37 *(0.33-0.42)* N = 2
Direction F	-	-	-

Inferred dimensions.

3.2. WHAT WE ARE DOING

The studies performed so far have allowed us to delineate the main features of the F/DT site, to gain a preliminary understanding of the number of hominin trackmakers and how they faced the step ignimbritic slope during the MIS 10 cold phase, and to roughly identify some of the mammals that were present in the Roccamonfina territory at the time. However, several matters and points deserve further attention, and important questions are still unanswered.

Two of us (A.P. and M.R.P.) are currently scrutinizing some of these issues, focusing on both hominin and mammalian footprints. The two researchers have nearly completed a study of the footprints of the three main trackways (A, B, and C), the few footprints of the short trackway E, and those of two very short successions of strides (D and F) with the purpose of defining the number of hominin trackmakers walking on the ignimbrite slope and investigating the potential impact of the substrate incline and the position of each footprint on their dimensions and proportions. To achieve these objectives, various statistical analyses have been applied to scrutiny the intra- and inter-trackway variation range of the body mass and stature estimates [box plots, univariate analysis, bivariate (reduced major axis, RMA), and multivariate analyses (similarity and principal component analysis)].

In a second ongoing research, the two researchers have been attempting to infer the physical parameters and hypothesize, if possible, the sex and age of the hominins that left their footprints on the F/DT slope. Researchers are conscious that this is a challenging task even when footprints have been clearly impressed by prehistoric humans in roughly regular succession on a soft, not strongly inclined substrate, and if footprints were impressed on an uneven ground and step slope, as in the case of F/DT footprints. The ongoing research focuses on the footprints of the quite long trackways A, B, and C, as well as the few footprints of the E trackway and the

few ones of D and F. The two objectives are to critically compare estimates obtained using various approaches and to determine which regression equations would best account for relationships between estimated body mass and footprint dimensions.

Moreover, they have initiated a thorough examination of mammalian footprints, which is presently focusing on studying horse tracks. The examination of detailed 3D models has allowed the identification of a fairly well-preserved footprint (Fig. 11) of the equid trackway located left and right of the last trait of Trackway B. The imprint preserves some anatomical details such as the typical caudal frog, which is one of three primary features useful in equid specific differentiation of *Hippipeda* hoofprints. Preliminary measurements seem to suggest that the trackmaker was a small-sized *Equus* representative. However, it will be difficult to specify if the small size depends on the trackmaker's young age or if it is a characteristic of the species.

Finally, research in progress attempts to estimate the range of relative velocity with which each trackmaker moved downwards on the trackways A, B, and C by comparing and critically analyzing the reliability of results obtained by means of different methodological approaches.

3.3. WHAT WE COULD FURTHER INVESTIGATE

Evidence provided thus far from the F/DT site and the Roccamonfina area highlights their high potential for reconstructing paleoenvironmental dynamics evolution, and human settlements and behavior in central Italy during the early Middle Pleistocene. Among the matters and points deserving further attention are volcanological, stratigraphic, paleoenvironmental, archaeological, and anthropological issues.

According to the evidence collected at the F/DT site, hominins and other mammals frequented the area during the final stages of MIS 10, but it is difficult to ascertain whether their presence was only casual, temporary, or a habit because F/DT was a part of their home range. A better understanding of human group behavior in response to the peculiar stimuli of living in a volcanic environment during a glacial cycle will require new data and in-depth study investigations at the site and in the surrounding areas. The availability of water, a variety of potential prey, and a rich flora (which are unquestionably a prerequisite for the presence of diversified fauna and hence of exploitable resources) are unquestionably attractive for Paleolithic hunter-gatherer groups. For instance, lithic industry and fauna at the nearby, modern site of Guado San Nicola evidence to a prolonged human presence between MIS11 and MIS10 (Pereira et al., 2016), thus even throughout a glacial period. As stated by Orain et al. (2013), the site was situated on the banks of a watercourse, and the local humidity may have promoted the persistence of wooded communities and the ensuing range of exploitable environments. New surveys and investigations, pending Sopraintendence's approval, may enable us to confirm the existence of watercourses in the hypothetical paleo-valley at the bottom of the exposed BTL sequence, overlaid by the F/DT ignimbrite slope.

All these data, as well as some palynologic investigations, could help to define the Foresta paleoenvironment more precisely and pinpoint some of the principal alluring attractive factors that could have promoted the presence of human groups in the Roccamonfina area.

Moreover, the characteristics of traces of humans and other animals on the surface of the LS7 unit have important implications that deserve further investigation from the volcanological point of view. For example, the thickness of the LS7 unit suggests that the footprints were left after an interval of time long enough to allow a process of alteration, and cooling of pyroclastic flow deposits, thus allowing walking at a often regular pace even if uncertain due to the high inclination of the substrate.

But the question arises as how long such a condition persisted and whether hominin and other mammalian footprints are strictly contemporaneous.

As regards to volcanology and geologic setting, it would be interesting to determine the age of each BLT unit and the temporal gap between the placement of various ignimbrite units that probably filled the paleo-valley, and to estimate the temperature of the ignimbritic LS7, both at the moment of its deposition, and at the time when hominins and other mammals impressed their tracks on the eroded, inclined slope. A rough estimate of the time gap between these two events will enable us to infer the time during which the erosive process that generated the slope occurred.

Furthermore, and always waiting for the Sopra-intendence's approval, it would be interesting to carry out some surveys to find additional evidence of the presence of a river in the paleovalley, probably present at the bottom of the BTL sequence exposed at Foresta. The presence of some fluvio-palustrine levels detected during a survey conducted in 2018 by A. Panarello, M. Di Vito, I. Biddittu, and M.R. Palombo, along a small valley in the south-eastern and south-western areas of the Foresta site, supports the presence of such a river.

The hominin frequentation in the Foresta area during the Middle Pleistocene could be verified by both looking for and analyzing exposed surfaces of other BLT units penecontemporaneous or younger than LS7 and by searching and investigating evidence of Paleolithic material culture at the site and in the surrounding area.

At the F/DT ichnosite, a lithic core was accidentally unearthed in historical times by quarrymen in the thin layer interbedded between LS7 and LS8 when they enlarged the sub-plane surface where the hominin pathway is located. The lithic implement was noted only in June 2016, when it was retrieved from sediment to be preserved and then analyzed (Panarello et al., 2017b) (Fig. 18).

A few other implements were discovered during a survey devoted to investigating the section exposed along a brook running in a narrow, small valley on the south-

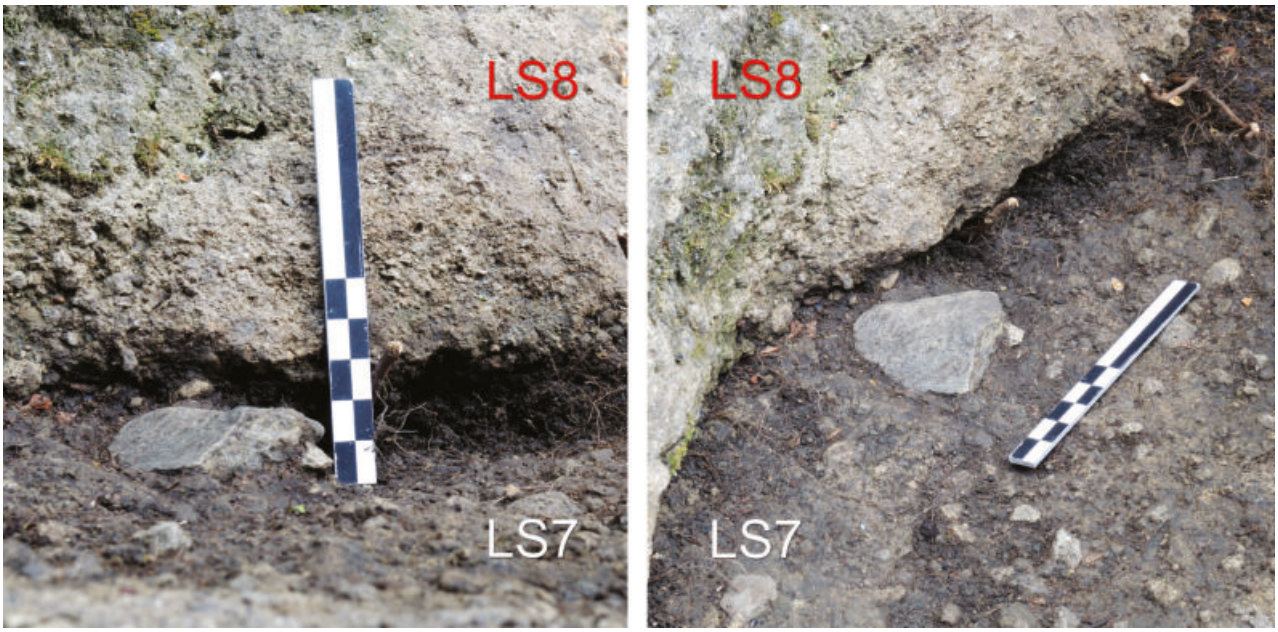

Fig. 18 - Photographs of the basalt core in primary deposition between LS7 and LS8 layers (2016) (Scale-bar: 10 cm).

western of the trampled slope and disappeared under the man-created plan currently located at the bottom of the BLT sequence exposed at the F/DT ichnosite (Biddittu and Panarello, 2022 and references therein). The basalt tools were clearly visible in some alluvial levels, whose chronostratigraphic settings would be analyzed in the future.

Given the little evidence found thus far, it would be interesting to enhance knowledge about the time and extent of the Paleolithic human presence in the area by looking for not reworked lithic artifacts and dating the levels where they are present or trying to radiometrically date any reworked implements found in the focal area. These new data would be critical in understanding the stone tool processing technique as it relates to the evolution of Paleolithic material culture in central Italy.

The most significant of the questions, which will likely remain unanswered for the moment, relates to the *Homo* species to which the hominin "Devil's Trails'" trackmakers belong. The Middle Pleistocene European hominid's systematics is, in fact, a matter of intense debate among specialists (e.g., Manzi, 2011, 2016; Stringer, 2012; Buck and Stringer, 2014; Roksandic et al., 2018, 2019; Martinón-Torres and Bermúdez de Castro, 2019; Delson and Stringer, 2022). Therefore, neither the dating of 349±3 ka, nor the lithic implement found at the site can be considered as decisive (Biddittu and Panarello, 2022).

Among the fossil bone remains found in the regions closest to the "Ciampate del diavolo" geosite, the most affordable element for an attribution seems to be the skull of Ceprano, dated around 400 ka and attributed to *Homo heidelbergensis* (Buzi et al., 2021 and references therein). However, Roksandic et al. (2022) claimed that many of the fossils from Western Europe currently assigned to *H. heidelbergensis* would be reassigned to *Homo neanderthalensis* due to the early appearance of Neanderthal-derived traits in the Middle Pleistocene in this region.

Regardless the accepted systematics of Middle Pleistocene European hominins, it would be interesting to compare the dimensions and maybe some anatomical features of F/DT footprints with those of the foot bones of European hominins, such as those from Tautavel (France), dated to 455 ka (de Lumley, 2015 and reference therein), and from Sima de los Huesos (Atapuerca, Spain), dated to about 450 ka (Demuro et al., 2018).

A preliminary comparison with the latter, which some scholars identified as *Homo heidelbergensis* and others as belonging to the Neanderthal lineage (e.g., Stringer, 2012; Buck and Stringer, 2014; Manzi, 2016; Roksandic et al., 2018, 2019), but with dental morphology distinct from both Heidelberg and Neanderthal hominins (Hanegraef et al., 2018), revealed that the dimensions of the E3 footprint, the largest at the F/DT ichnosite, fall within the range of hominin adult males from this site (Pablos, 2015; Pablos et al., 2017; McNutt et al., 2018 and references therein).

All things considered, the evidence demonstrates the great potential of the data that the Foresta Ichnosite can still provide and how it represents an unrepeatable source of information to enhance our knowledge of some aspects of the behavior of the Middle Pleistocene European hominins.

Therefore, it is of crucial importance that the parties in charge initiate interventions aimed at preserving this unique cultural heritage.

Currently, the "Devil's Trails" surface is progressively

eroding as a result of the adverse effects of natural agents and the unregulated use of the area by people and animals. Indeed, the F/DT ichnosite is close to the small village of Foresta, but it is surrounded by a forest and situated at the bottom of a gorge. It is in itself astonishing that the course and step surface of the "Devil's Trails" have preserved the basic footprint structure to this day despite being unearthed by a series of catastrophic floods in the first half of the 19th century (De Angelis, 2022; Panarello et al., 2022f). However, weathering and trampling, as well as the erosive action of mosses that are gradually covering the slope surface, are currently causing the gradual alteration and fading of such evidence.

A complete obliteration of the structures testifying to the actual nature of the F/DT footprints may sensibly reduce the scientific value and significance of this site, which is the only place where the footprints were impressed on a peculiar substrate among the rare Middle-early Late Pleistocene hominin ichnosites.

The F/DT team has frequently warned the authorities in charge of their protection of the impending danger to which the F/DT ichnosite is subject. Unfortunately, nothing has been done thus far. The issue was once more discussed in a recent publication (Panarello et al., 2022g), which highlighted the peculiar preservation requirements necessitated by an ichnonological site with respect to other archeological and paleontological sites. The study team came up with a potential answer after carefully examining every form of protection employed in other human ichnosites around the globe. It entails enclosing the site within a structure that can preserve the local ecosystem, controlling the action of natural agents and managing visitors' access. Modern technologies with 3D animations and augmented reality might likewise transform the site into a significant tourist and educational attraction with global significance with important economic repercussions also on local communities. Unfortunately, nothing has been done thus far, and there are increasingly clear signs on the ichnites, resulting in the inevitable loss of even the most minor information, regardless of its value. Many have already been lost, and only the photographs, casts, and 3D models collected in two decades of research still testify to their existence at the "Devil's Trails" site.

Our expectation is that the ongoing research and future analysis of the collected data conducted with a more and more advanced methodological approach, as well as the comparison with the already known human footprint and those discovered in the future, will enable us and any other scholars interested in the matter to enhance our knowledge of Paleolithic humans and their behavior.

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